CHEMICAL AND GEOMORPHIC CHARACTERIZATION OF THE CHURCH CREEK AND PAROLE PLAZA NPDES MONITORING STATIONS: 2020 - 2021

Prepared for

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1 INTRODUCTION

In 1998, Anne Arundel County began implementing a long-term monitoring program that satisfies requirements for its Countywide National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Discharge Permit (Permit). Monitoring has continued to be required as part of the terms of each renewed permit. Effective January 1, 2021, the County formally began participation in the Pooled Monitoring Program coordinated through the Chesapeake Bay Trust to meet the Best Management Practice (BMP) effectiveness monitoring and the Watershed Assessment monitoring requirements set forth in the Permit's Assessment of Controls section. Signed Memoranda of Understanding between the County and the Trust, documenting the County's participation in lieu of Assessment of Controls monitoring, was provided to MDE. The effective date by which all monitoring ceased at the Church Creek and Parole Plaza stations was March 18, 2021, providing overlap between the initiation of Pooled Monitoring Program participation and the cessation of Assessment of Controls monitoring.

Prior to March 18, 2021, the County conducted monitoring as required to satisfy conditions outlined in Section F: Assessment of Controls of the County's Permit issued in February 2014. The monitoring program includes chemical, biological, and physical monitoring in the Church Creek watershed located within the larger South River watershed. This document describes the monitoring effort undertaken during the abbreviated FY2021 reporting period (July 2020 through March 18, 2021). Versar, Inc. (Versar) was contracted by the County to perform the required monitoring for this reporting period.

Biological and physical monitoring take place at monumented locations along the study reach, as described in more detail below. In FY2021, no biological monitoring was conducted as the County opted into the Pooled Monitoring Program at the beginning of the spring biological monitoring index period. Annual physical monitoring was conducted during FY2021. The chemical monitoring activities continued through March 18, 2021, occurring at two stations in the Church Creek watershed:

- Downstream of two intensely developed commercial land use outfalls, called the Parole Plaza monitoring station
- An instream station downstream of the Route 2 culvert, called the Church Creek monitoring station

The basic permit requirements for storm event monitoring include sampling a target of 12 storms per year (three in each quarter) that are characterized by three representative (rising, peak, and falling limbs of the hydrograph) discrete samples per storm event, the collection of baseflow samples during extended dry periods, laboratory analysis of water quality parameters specified in the permit, biological and physical characterizations of the study reach, and continuous flow monitoring.

The County is interested in determining the extent to which stormwater management retrofit and stream restoration activities in the watershed have improved the quality of the stormwater effluent from the site. Retrofit and restoration efforts have included a) redevelopment of Parole Plaza (now known as the Annapolis Towne Centre at Parole); b) stream restoration in Church Creek; and c) stormwater pond retrofit at Annapolis Harbour Center.

Construction associated with the redevelopment of the Parole Plaza site (Annapolis Towne Centre at Parole), including installation of modified stormwater infrastructure and treatment, began in 2004 and the bulk of the site work was completed by late 2008. During late 2015 into early 2016, the South River Federation (now Arundel Rivers Federation), in cooperation with Anne Arundel County, undertook restoration of a portion of Church Creek behind the Annapolis Harbour Center and nearby the County's existing biological and physical monitoring sites. This work consisted of 1,500 linear feet of stream restoration and implementation of step-pool storm conveyance, riffle weirs, and grade control structures to improve habitat and increase floodplain connectivity. The retrofit of the stormwater pond at Annapolis Harbour Center took place during July to September 2017. The retrofit pond includes increased storage, additional forebays, a wetland berm, and wetland benches. The County's existing biological and physical monitoring locations downstream of these restorations and retrofit projects will be useful in assessing the cumulative effects of this work.

2 METHODS

2.1 CHEMICAL MONITORING

This section describes the equipment and techniques used in this sampling program. It includes discussions of sample collection, sample analysis, flow data collection, and basin rainfall characterization. A summary of maintenance activities is also included. Data and quarterly data reports (Versar 2020b, 2021a, and 2021b) were used to prepare this annual summary report.

2.1.1 Monitoring Sites

The long-term chemical monitoring program is performed at one outfall station, Parole Plaza, and one instream station, Church Creek (Figure 2-1). The two stations are described below:

Parole Monitoring Station. This station is a restoration station located at the head of the Parole Tributary to Church Creek. There are two outfalls draining to the sampling station. The first is a 60” corrugated metal pipe (CMP) that has been the historical sampling location for the monitoring of this station. The second is a 54” reinforced concrete pipe (RCP) that was connected to the drainage network during the summer of 2007 and is associated with the redevelopment of the Parole Plaza (aka Annapolis Towne Center).

Church Creek Monitoring Station. This station is an instream station on the mainstem of Church Creek. It is located approximately 500 feet downstream of the confluence of the Parole Tributary that carries the runoff from the Parole Plaza monitoring station. The samples are collected in the 96” CMP culvert that carries Church Creek underneath Maryland State Highway 2 (Solomons Island Road). The bottom of this culvert is lined with concrete that extends 1.8 feet in height up the sides of the corrugated metal culvert.

Location information and land use data were taken from the *Annapolis Towne Centre @ Parole Stormwater Management Report* (Greenhorne & O’Mara 2005), and summarized for each site in Tables 2-1 and 2-2. In FY2019, impervious surface and catchment areas were updated using (2017) Anne Arundel County LIDAR data. These updates reflect current and more accurate drainage area information that is also utilized in calculation of certain habitat metrics.

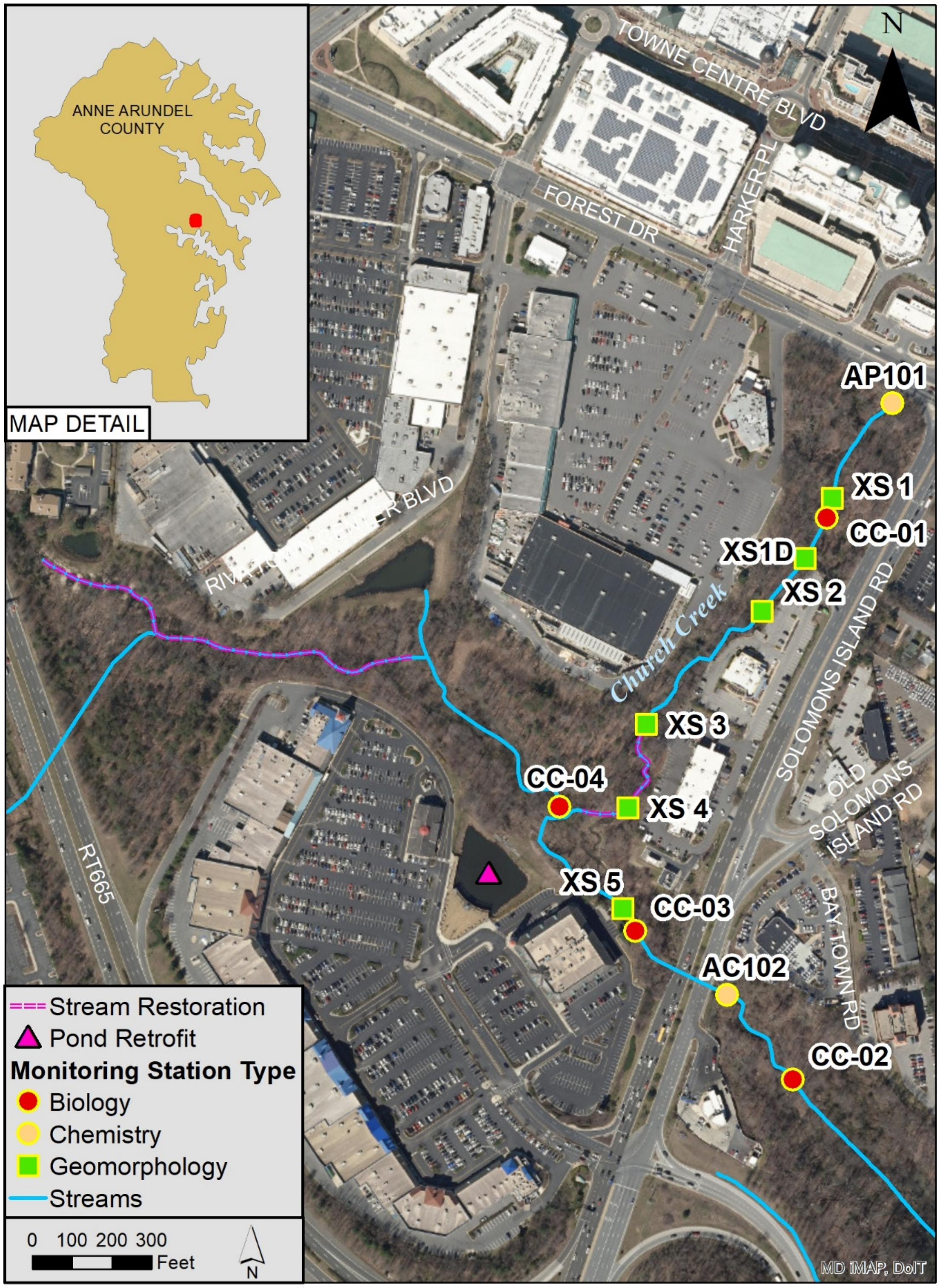

Figure 2-1. Church Creek and Parole Plaza study area, stream monitoring stations, and approximate stream restoration locations.

Table 2-1. Drainage areas and site locations of monitoring stations in Church Creek watershed			
Monitoring Station	**Station Type**	**Location**	**Area (acres)**
Parole Plaza	Restoration/Outfall	Southwest corner of Forest Drive and MD State Highway 2	106.04
Church Creek	Instream	Downstream (east) of MD State Highway 2	281.49

Table 2-2. Land use summary for the monitoring stations in the Church Creek watershed				
Land Use	**Land Use Area (acres)**		**Percent of Total Acreage**	
	Parole Plaza	**Church Creek**	**Parole Plaza**	**Church Creek**
Impervious	83.19	194.67	78.5	69.2
Open Space	22.84	86.82	21.5	30.8
TOTAL	**106.04**	**281.49**	**100**	**100**

2.1.2 Water Sample Collection and Data Analysis

The sample period for this reporting cycle extended from July 1, 2020 through March 18, 2021. Samples are analyzed for the presence of the pollutants listed in Table 2-3.

Table 2-3. Analytes, detection limits, and analytical methods for the Church Creek and Parole Plaza Monitoring stations		
Parameter	**Detection Limit (mg/L)**	**Analytical Method**
Biochemical Oxygen Demand (5 Day)	2/4	SM 5210 B-01
Total Kjeldahl Nitrogen	0.5	SM 4500-NH3 C97
Nitrate + Nitrite	0.05	SM 4500-NO3 H00
Total Phosphorus	0.01	SM 4500-P E99
Total Suspended Solids	1	SM 2540 D-97
Total Copper (µg/L)	2	EPA 200.8
Total Lead (µg/L)	2	EPA 200.8
Total Zinc (µg/L)	20	EPA 200.8
Total Petroleum Hydrocarbons	5	EPA 1664
E. coli (MPN/100 mL)	1, 10, 100	SM 9223 B
Hardness	1	SM 2340 C

During the sampling period, four storm samples were collected; four baseflow samples were taken in lieu of storm samples. Table 2-4 summarizes the sample dates and sample type. On average, approximately 1.4 of the sampled events during each calendar quarter were storm events. Information pertinent to both baseflow and storm event samples is provided in the text below.

Table 2-4. Fiscal Year 2021 Sample Dates and Sample Type

Sample Date	Sample Type
July 30, 2020	S
September 3, 2020	S
September 28, 2020	B
October 28, 2020	B
December 4, 2020	S
December 30, 2020	B
February 25, 2021	B
March 18, 2021	S

B: Baseflow Event
S: Storm Event

Baseflow Monitoring

- **September 28, 2020**

Due to the impending end of the quarter and a lack of forecast storm events, Versar staff conducted baseflow sampling at the Parole Plaza and Church Creek stations. At Church Creek, the only parameter to exceed its long-term average baseflow concentration was BOD by 355% with a value of 2 mg/L. At Parole Plaza, BOD also exceeded its long-term average, but only by 21% with a concentration of 5 mg/L. *E. coli* exceeded its long-term average concentration by just 1% at Parole Plaza.

- **October 28, 2020**

Since a storm event was not captured earlier in the month, Versar staff collected samples during baseflow at the Parole Plaza and Church Creek stations on October 28 in anticipation of potential cessation of Assessment of Controls monitoring.

At Church Creek, three parameters exceeded the respective long-term average baseflow concentration. Total Phosphorus (TP) exceeded the long-term average by 15% with a concentration of 0.07 mg/L. Total suspended solids (TSS) exceeded the long-term average by 23% with a concentration of 10 mg/L. Copper exceeded the long-term average by 62% with a concentration of 2.65 µg/L. Higher than usual concentrations of copper and TP, which are associated with TSS, may be a result of the residual effect of a storm occurring on October 25.

At Parole Plaza, just two of the parameter long-term average concentrations were exceeded. Nitrate-nitrite was 13% higher than the long-term average with a concentration of 5.2 mg/L. Hardness exceeded the long-term average by 31% with a concentration of 320 mg/L. High concentrations of nitrate-nitrite and hardness are typical of baseflow conditions, suggesting higher than usual leaching of material by groundwater in the catchment.

- **December 30, 2020**

Due to the impending end of the quarter and a lack of forecast storm events that met upper bound duration requirements, Versar staff conducted baseflow sampling at the Parole Plaza and Church Creek stations. At Church Creek, none of the parameters exceeded their respective long-term average concentrations, probably due to the five-day period between the sampling event and the previous rainfall event. At Parole Plaza, and similar to the October 28 baseflow results, nitrate-nitrite was 13% higher than the long-term average with a concentration of 5.2 mg/L. Hardness exceeded the long-term average concentration by 23% with a value of 300 mg/L.

- **February 25, 2021**

Due to unsuccessful storm attempts and no storm having been captured during the quarter, Versar staff conducted baseflow sampling at both the Parole Plaza and Church Creek stations. At Church Creek, hardness was the only parameter that exceeded its long-term average by just 1% with a concentration of 140 mg/L. At Parole Plaza, hardness was also the only parameter to exceed its long-term average concentration. The concentration was 320 mg/L which exceeded the long-term average by 29%.

Storm Event Monitoring

Below is a discussion of the storm events that were sampled during the monitoring period. Additional discussion of these events can be found in Appendix A.

- **July 30, 2020**

The total rainfall for this event was 0.60 inches and lasted approximately two and one half hours. These measurements were based on data from the Church Creek rain gauge.

- **September 3, 2020**

The total rainfall for this event was 0.62 inches. The storm lasted approximately five hours. These measurements were based on data from the Church Creek rain gauge.

- **December 4, 2020**

The total rainfall for this event was 1.62 inches. The storm lasted approximately 13 hours. These measurements were based on data from the Church Creek rain gauge.

- **March 18, 2021**

The total rainfall for this event was 0.19 inches and lasted approximately five and one half hours. These measurements were based on data from the Church Creek rain gauge.

Approximately 40.02 inches of precipitation was recorded at the Church Creek station during the abbreviated FY2021 reporting period. Rainfall was measured using a tipping bucket rain gauge located at the Church Creek station.

During the FY2021 Fall Quarter (October to December 2020) only one storm event was captured despite Versar staff constantly monitoring forecasts and attempting to capture storms during this period. In October there were several rain events forecasted, two of which exceeded the duration guidelines and one which the forecast rain amounts were below the required minimum of 0.1 inches. The two storm events that exceeded the duration limits took place during October 11-13 and October 28-31. Versar staff closely monitored the forecasts for those events, ultimately determining that they would each be too long to sample. The event forecast for October 15-16 was not pursued because there had been a preceding storm event less than 72 hours before, coupled with the predicted amount of rainfall being so close to the minimum amount required for a valid storm. In November there was one storm event during November 11-12 that was forecast to be approximately 27 hours, much longer that the duration limit of 16.5 hours. In the morning of November 23, Versar staff assembled and deployed a sampling team, but that storm dissipated and did not produce sufficient rain at the monitoring stations. In December one storm event was captured but a second event took place from December 14-18 and could not be sampled because it exceeded the duration limit of 16.5 hours. Another storm occurred on December 24-25 and could not be sampled due to staff unavailability during the holiday.

Effective January 1, 2021, the County opted into the Pooled Monitoring Program coordinated through the Chesapeake Bay Trust; however, during the FY2021 Winter Quarter (January to March 2021), Versar provided redundant monitoring services. During the quarter, field teams conducted one baseflow sampling event and one storm event as described above. Versar did not complete the Permit-required three monitoring events during the quarter because monitoring activities ceased prior to the end of the calendar quarter.

Table 2-5 lists the total rainfall for each sampled event. Hydrographs are provided in Appendix A. These data, along with stream level readings collected at five-minute intervals from a permanently mounted pressure transducer, were logged into an ISCO 6712FR automated sampler.

Table 2-5. Rainfall data for sampled storm events	
Date	**Rainfall (inches)**
July 30, 2020	0.60
September 3, 2020	0.62
December 4, 2020	1.62
March 18, 2021	0.19

The ISCO sampler located at the Church Creek station is configured to hold 24 one-liter polyethylene bottles, and can be used to collect samples directly from the 96" CMP. However, this station is generally manned for the entire duration of each event. Therefore, all samples are typically taken as grabs from the culvert outfall. Total petroleum hydrocarbon and *E. coli* samples are always collected as manual grab samples per appropriate sampling protocol for these analytes. The grab sample location is approximately six feet downstream of the intake for the automated sampler and therefore is considered effectively the same sampling location as for the other parameters using the automated sampler.

During the FY2021 monitoring period, the rating curve for the 96" culvert at the Church Creek station was revised. The revised rating curve was developed from directly measured discharges within the pipe at various times and stages during the period 2006-2020. The revised rating curve was applied to continuous stage data collected from FY2013 until the conclusion of monitoring in March 2021. Loading and EMC data previously reported in FY2013 to FY2020 have been recalculated using the revised continuous flow rate data and are presented in this report. The revised rating curve for Church Creek is presented in Appendix A.

When the 54" RCP was installed at the Parole Plaza monitoring station in the summer of 2007, portions of the drainage that had historically been passing through the 60" CMP began flowing through the new pipe. To maintain consistency in the characterization of the watershed, it was determined that samples were required from both pipes. Pressure transducers were permanently mounted in the 60" CMP and 54" RCP. These measured water depth at 5-minute intervals, and stored data for up to three months. Data were downloaded bi-weekly. Stage/discharge relationships were developed for each outfall pipe, to determine the discharge based on depth measurements from the pressure transducer. The relationships are based on a combination of field measurements and extrapolated values. The extrapolation is necessary to characterize major storm events where directly measured values are not currently available. The rating tables are included in Appendix A.

A spreadsheet was developed to allow the field sampling crews to input field-measured level data. The spreadsheet interpolated the corresponding flow from the rating curves developed as described above. The flows from the 60" CMP and the 54" RCP were totaled and the resulting combined hydrograph for each event was plotted in real-time. This method allowed the field crews to determine when the rising, peak, and falling limbs for the combined hydrograph occurred. The spreadsheet also calculated the percentage of the combined flow that each outfall pipe was contributing. Using volumetric containers, the sampling team prepared composite samples using these percentages, and distributed them to the sample containers. A Technical Memorandum describing the composite sampling procedures in detail was submitted to the Maryland Department of the Environment in May 2008, and is included in Appendix A. To identify which pipe (CMP or RCP) discharged elevated concentrations of *E. coli*, the County requested that *E. coli* samples be collected and analyzed separately, beginning in summer 2017. Previously the samples collected during each limb were composited during the storm event as described above and the results were provided as single values. Using the new method, the discharge volume weighted average of the two results per limb was calculated in the EMC spreadsheet to arrive at a single, composite result.

Water quality instruments for measuring pH, temperature, and conductivity were used at both stations. At Parole, an In-Situ Troll 9500 unit mounted within each pipe was used to obtain measurements during storm events, providing measurements every five minutes. Measurements for these parameters were not available when personnel were not present due to the low flow conditions at this station. Permanently installed probes would likely dry out and need to be replaced often, thus these units are engaged only during storm events. At the Church Creek station, a YSI 600 XL multiparameter sonde was permanently mounted within the culvert and was connected directly to the ISCO automated sampler; providing measurements every five minutes. This unit operated continuously until September 3, 2020, when high flow rates severed the data cable. For subsequent storm events, pH and temperature data for each limb were collected using a calibrated handheld YSI meter unit.

Samples were distributed into appropriate bottles provided by Martel Laboratories and delivered within 48 hours, except for *E. coli* samples which were delivered to Water Testing Labs of Maryland due to a shorter, six hour, holding time.

Event Mean Concentrations (EMCs) for each parameter were calculated for each storm and applied to total stormflow discharges to calculate stormflow pollutant loads for each site. An EMC is a statistical parameter used to represent the flow-weighted average concentration of a given parameter during a storm event (USEPA 2002). The EMC for a storm event where discrete samples have been collected (i.e., samples collected during the rise, peak, and falling limb of a storm event), was calculated using the following formula:

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

where,

V: volume of flow during period *i*, which is determined from the interval associated with the samples collected during each limb

C: analytical result associated with period *i*

n: total number of limbs taken during event

The stormflow pollutant load for each parameter was calculated using:

$$Load = EMC_j V_j$$

where,

V: total volume of flow during period *j* (entire storm event).

Average annual EMCs were calculated by taking the arithmetic average of EMCs calculated when non-detects were set to zero and when non-detects were set to the detection limit. Since the true concentration of non-detect samples falls somewhere between the detection limit and the null value, this calculation represents a more accurate estimate than using EMCs with non-detects set to either zero or the detection limit. Seasonal loads (also referred to as quarterly loads) for monitored events were calculated by summing all monitored event loads for a specific season. Total seasonal loads were calculated by multiplying the average seasonal EMC by the total volume for the season. Annual loads were calculated by summing all seasonal loads.

2.1.3 Monitoring Station Maintenance and Concerns

Maintenance was conducted at each sampling station on a biweekly basis. Maintenance included calibration of all probes, inspection of the sampling equipment, intake lines, and programming; and an overall cleaning and organization of the stations. A few issues concerning the replacement of monitoring equipment and the loss of data occurred during the monitoring period; below is a summary of these issues:

- Staff conducted routine maintenance at both stations on July 7; July 23 and 24; August 6 and 18; and September 3 (captured storm), 18, 22, and 28, 2020. Maintenance logs encompassing these nine visits are enclosed with this letter. During most maintenance visits and storm events for Church Creek prior to September 18, Versar staff cleaned, calibrated, and performed quality control checks on the YSI sonde.

  During the July 23 visit at Church Creek, staff noted missing rainfall data, however the team found no obstructions of the rain gauge bucket and surmised that the gauge wasn't properly recording data because of another reason. Staff returned the next day with a replacement rain gauge. The field team noted the existing rain gauge had satisfactorily logged overnight rainfall, deduced that it was again functioning normally, and left it in place.

  During the August 18 visit at Church Creek, field staff found the stage logger dislodged from the cradle and reattached it. The rainfall data were checked to confirm the functioning of the rain gauge.

  During the September 3 visit at Church Creek, ahead of the storm, field staff noted the rain gauge was again not functioning properly. Staff performed troubleshooting on the gauge and remedied the issue.

During the September 18 visit at Church Creek, staff again noted that the rain gauge was not functioning properly but could not resolve the issue by troubleshooting. Field staff returned on September 22 and replaced the rain gauge. At Parole Plaza, the batteries for the level logger in the RCP were found to have died. Data for the RCP are missing from 20:05 EST on 09/11/2020 to 09:25 EST on 09/18/2020. Data from Baltimore-Washington International Airport showed 0.17 inches of rainfall in this period. The field team removed the YSI sonde from the field because the logging cable was severed during the storm on September 3, most likely by high flows at the height of the storm. The status of the YSI sonde and the protocol for recording pH during future storms was discussed with the County during a teleconference on September 9.

- Staff conducted routine maintenance at both stations on October 13 and 28 (baseflow); November 4 and 23 (storm attempt); and December 17 and 30 (baseflow).

  During the December 17 visit at Parole Plaza, Versar staff discovered the batteries for the level logger in the corrugated metal pipe had died on December 10, 2020 at 00:55 EST. According to the rain data from the Church Creek station, 2.42 inches of rain fell during the outage. Staff replaced the batteries in the logger on December 17 to restore flow logging functionality.

- Staff conducted routine maintenance at both stations on January 12 and 27; February 9 and 25 (baseflow); and March 11. All equipment was found functioning and in good working order during each maintenance visit.

2.2 PHYSICAL MONITORING

Geomorphic assessment data were collected in accordance with the standard operating procedures (SOPs) approved for the County's NPDES Program. All methods are consistent with previous years' methods (with applicable updates) to ensure data comparability between years. Collection methods are summarized below. Field data were collected in 2020 by Versar, Inc.

2.2.1 Monitoring Sites

Five cross-sections (XS), four of which were established in 2003, one which was established in 2007, have been measured annually through 2020. A sixth cross-section was established in 2020 per the request of the County. Five of these cross-sections are located along the Parole Plaza Tributary, and one cross-section is located on the Church Creek mainstem, just upstream of Solomon's Island Road (Maryland State Highway 2; Figure 2-1). Cross-section monuments, placed on each bank, consist of capped steel reinforcement bars set within six inches of the ground surface. Field data collected by Versar, Inc. during 2020 were used to prepare this annual summary report.

2.2.2 Physical Data Collection and Analysis

Geomorphic assessments include a longitudinal profile survey, cross-section surveys, and representative pebble counts. A spreadsheet tool, *The Reference Reach Spreadsheet* version 4.3L (Mecklenburg 2006), was used to facilitate data entry and analyses. This spreadsheet was used to compile, manipulate, and plot field data and to analyze dimension, profile, and channel material characteristics of the Church Creek study area.

Data from geomorphic assessments were used to determine the stream type of each reach as categorized by the Rosgen Stream Classification methodology (Rosgen 1996). In this classification methodology, streams are categorized based on their measured field values of entrenchment ratio, width/depth ratio, sinuosity, water surface slope, and channel materials according to the table in Appendix C. As illustrated in Appendix C, the Rosgen Stream Classification categorizes streams into broad stream types, which are identified by the letters Aa, A, B, C, D, DA, E, F, and G. Table 2-6 includes general descriptions of each Rosgen stream type. A summary of the stream types identified within this study is included in Appendix D.

The cross-section surveys were performed at the six permanent cross-section locations, and photos were taken of upstream, downstream, left bank, and right bank views at each cross-section location. Cross-section surveys consisted of measuring the topographic variability of the associated stream bed, floodplains, and terraces, including:

- Monument elevations
- Changes in topography
- Top of each channel bank
- Elevations of bankfull indicators
- Edge of water during the time of survey
- Thalweg or deepest elevation along active channel
- Depositional and erosional features within the channel

During the cross-sectional survey, the following measurements and calculations of the bankfull channel, which are critical for determining the Rosgen stream type of each reach, also were collected:

- Bankfull Width (Wbkf): the width of the channel at the elevation of bankfull discharge or at the stage that defines the bankfull channel.
- Mean Depth (dbkf): the mean depth of the bankfull channel.
- Bankfull Cross-sectional Area (Abkf): the area of the bankfull channel, estimated as the product of bankfull width and mean depth.
- Width Depth Ratio (Wbkf/dbkf): the ratio of the bankfull width versus mean depth.
- Maximum Depth (dmbkf): the maximum depth of the bankfull channel, or the difference between the thalweg elevation and the bankfull discharge elevation.

- Width of Floodprone Area (Wfpa): the width of the channel at a stage of twice the maximum depth. If the width of the floodprone area was far outside of the channel, its value was visually estimated or paced off.
- Entrenchment Ratio (ER): the ratio of the width of the floodprone area versus bankfull width.
- Sinuosity (K): ratio of the stream length versus the valley length or the valley slope divided by the channel slope. Sinuosity was visually estimated, or the valley length was paced off so that an estimate could be calculated.

Table 2-6. Rosgen stream classification types

Channel Type	General Description
Aa+	Very steep, deeply entrenched, debris transport, torrent streams.
A	Steep, entrenched, confined, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.
B	Moderately entrenched, moderate gradient, riffle dominated channel with infrequently spaced pools. Moderate width/depth ratio. Narrow, gently sloping valleys. Very stable plan and profile. Stable banks.
C	Low gradient, meandering, slightly entrenched, point-bar, riffle/pool, alluvial channels with broad, well-defined floodplains.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks. Active lateral adjustment, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well-vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuosities and width/depth ratios. Very stable streambanks.
E	Low gradient, Highly sinuous, riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander/width ratio.
F	Entrenched, meandering riffle/pool channel on low gradients with high width/depth ratio and high bank erosion rates.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients. Narrow valleys. Unstable, with grade control problems and high bank erosion rates.
Source:	Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado

To quantify the distribution of channel substrate particles sizes within the study area, a modified Wolman pebble count (Rosgen 1996) was performed at each cross-section location. A pebble count was not performed at the newly established cross-section in Spring 2020 as it was only requested to compare channel shape to XS-1; a pebble count was performed in the Fall 2020 survey. Reach-wide proportional counts were used. Each pebble count consisted of stratifying the reach based on the frequency of channel features in that reach (e.g., riffle, run, pool, glide) and measuring 100 particles across ten transects (i.e., 10 particles in each of 10 transects). The transects were allocated across all feature types in the proportion at which they occurred within the reach. The intermediate axis of each measured pebble was recorded. The goal of the pebble count was to measure 100 particles across the bankfull width of the channel and calculate the median substrate particle size (i.e., D_{50}) of the reach. This value was used for categorizing the sites into the Rosgen Stream Classification (Rosgen 1996). If a channel was clearly a sand or silt bed channel with no distinct variation in material size, the pebble count was not performed, and the D_{50} was visually estimated. However, if the channel had variation in bed material size from feature to feature, a full pebble count was performed.

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3 RESULTS

3.1 POLLUTANT CONCENTRATIONS

During this sampling period, 32 water chemistry samples were analyzed. In some instances, analyte concentrations fell below the specified detection limits. Table 3-1 shows the percentage of samples that were below the detection limit.

Table 3-1. The percentage of non-detects by parameter

Parameter	Detection Limit	Wet Weather	Dry Weather
BOD_5 (mg/L)	2/4	17	75
TKN (mg/L)	0.5	79	100
Nitrate + Nitrite (mg/L)	0.05	0	0
Total Phosphorus (mg/L)	0.01	0	38
TSS (mg/L)	1	0	25
Total Copper (µg/L)	2	0	50
Total Lead (µg/L)	2	38	100
Total Zinc (µg/L)	20	0	0
TPH (mg/L)	5	96	100
E. coli (MPN/100 mL)	1, 10, 100	0	25
Hardness (mg/L)	1	0	0

Table 3-2 and Table 3-3 show the maximum values observed for dry and wet weather samples for both stations. The maximum value for each parameter during wet weather monitoring, station of occurrence, and storm date of observation are listed in Table 3-4. Of the two stations, Parole Plaza had the highest values for seven of the thirteen parameters measured during wet weather sampling in 2021. Three of the maximum wet weather values for the parameters were measured during the July 30 storm event. The maximum *E. coli* concentration at Parole Plaza was 22,095 MPN/100 mL and was observed during the September 3 storm. Chemical monitoring summaries can be found in Appendix E.

Table 3-2. Maximum dry weather values observed during sampling period		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)	70.34	70.94
pH	7.3	7.2
BOD_5 (mg/L)	2	5
TKN (mg/L)	BDL	BDL
Nitrate + Nitrite (mg/L)	0.92	5.20
Total Phosphorus (mg/L)	0.07	0.02
TSS (mg/L)	10	5
Total Copper (µg/L)	3	8
Total Lead (µg/L)	BDL	BDL
Total Zinc (µg/L)	55	122
TPH (mg/L)	BDL	BDL
E. coli (MPN/100 mL)	331	930
Hardness (mg/L)	140	320
BDL: Below Detection Limit		

Table 3-3. Maximum wet weather values observed during sampling period		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)	80.24	79.43
pH	8.8	8.0
BOD_5 (mg/L)	13	47
TKN (mg/L)	1.3	4.3
Nitrate + Nitrite (mg/L)	1.20	1.60
Total Phosphorus (mg/L)	0.42	0.32
TSS (mg/L)	130	52
Total Copper (µg/L)	30	81
Total Lead (µg/L)	23	4
Total Zinc (µg/L)	184	362
TPH (mg/L)	6	BDL
E. coli (MPN/100 mL)	12,033	22,095
Hardness (mg/L)	140	86
BDL: Below Detection Limit		

Table 3-4. Storm dates for wet weather maximum values			
Parameter	**Date of Storm**	**Site**	**Maximum Value**
Water Temperature (°F)	7/30/20	Church Creek	80.24
pH	7/30/20	Church Creek	8.9
BOD_5 (mg/L)	7/30/20	Parole Plaza	47
TKN (mg/L)	7/30/21	Parole Plaza	4.3
Nitrate + Nitrite (mg/L)	3/18/21	Parole Plaza	1.60
Total Phosphorus (mg/L)	7/30/20	Church Creek	0.42
TSS (mg/L)	7/30/20	Church Creek	130
Total Copper (µg/L)	3/18/21	Parole Plaza	81
Total Lead (µg/L)	7/30/20	Church Creek	23
Total Zinc (µg/L)	7/30/20	Parole Plaza	362
TPH (mg/L)	9/3/20	Church Creek	6
E. coli (MPN/100 ml)	9/3/20	Parole Plaza	22,095
Hardness (mg/L)	3/18/20	Church Creek	140

3.2 EVENT MEAN CONCENTRATIONS AND POLLUTANT LOADINGS

Flow-weighted EMC values are presented in Table 3-5. EMCs for BOD_5, TKN, total phosphorus, TSS, copper, lead, TPH, and hardness were higher at Church Creek than at Parole Plaza.

Table 3-5. Average EMCs observed during July 2020 to March 2021		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)*	66.03	64.92
pH*	8.2	7.6
BOD_5 (mg/L)	4	3
TKN (mg/L)	0.4	0.3
Nitrate + Nitrite (mg/L)	0.21	0.22
Total Phosphorus (mg/L)	0.20	0.10
TSS (mg/L)	50	15
Total Copper (µg/L)	10	8
Total Lead (µg/L)	8	2
Total Zinc (µg/L)	68	70
TPH (mg/L)	3	3
E. coli (MPN/100 mL)	6,259	6,944
Hardness (mg/L)	28	26
* Values presented are discharge-weighted means		

Summed loads for the sampled events monitored during the July 2020 to March 2021 sampling period are shown in Table 3-6. Per-acre loading rates for monitored events were higher at Church Creek than at Parole Plaza for all parameters.

Table 3-6. Estimated pollutant loadings for all observed events, in pounds, for the July 2020 to March 2021 sampling period

Parameter	Church Creek		Parole Plaza	
	Total	**Per Acre**	**Total**	**Per Acre**
BOD_5	566	2.01	48	0.45
TKN	49	0.18	4	0.04
Nitrate + Nitrite	28	0.10	4	0.03
Total Phosphorus	26	0.09	2	0.01
TSS	6,544	23.25	255	2.40
Total Copper	1	0.005	0.1	0.001
Total Lead	1	0.004	0.03	0.0002
Total Zinc	9	0.03	1	0.01
TPH	357	1.27	41	0.39
Hardness	3,726	13.24	436	4.11

3.3 GEOMORPHIC ASSESSMENT

Due to the highly altered conditions of the drainage area (i.e., high imperviousness, altered flow regime, numerous stormwater outfalls) and stream channel (i.e., channelization, stabilization) in the study area, reliable bankfull indicators were often difficult to locate in the field. In the absence of reliable bankfull indicators, bankfull elevations were adjusted to match the predicted values for bankfull area provided by the bankfull channel geometry relationship for urban streams developed specifically for Anne Arundel County (AADPW 2002). Furthermore, categorization of segments into the Rosgen Classification scheme for natural rivers required professional judgment, in some cases, to interpret the data. When assigning the stream classification types, values for some parameters fit into the prescribed ranges according to the Rosgen Classification while others would not. Many of the features at the existing cross-section locations have shifted from riffle features to pool features, which can skew the channel dimensions since classifications are based on riffle dimensions. Consequently, it was sometimes necessary to apply best professional judgment and incorporate supplemental information (e.g., presence of depositional features) to assign the most appropriate stream classifications. The Rosgen classification system is summarized in Appendix C and 2020 data for Church Creek sites are in Appendix D. Also noteworthy, prior to the 2016 geomorphic survey, stream restoration occurred downstream of XS-4, on an unnamed tributary, and upstream of XS-5 on the mainstem Church Creek in the vicinity of the Annapolis Harbor Center. As a result of this stream restoration construction and channel reengineering, the longitudinal profile length shortened between the 2015 and 2016 surveying. The 2020 geomorphic surveys provide a look at changes four years after the restoration was completed between XS-4 and XS-5.

The most upstream reach on the Parole Plaza Tributary, XS-1, has been undergoing a transition from a Rosgen C4/5 channel to a F4 channel, as evidenced by changes in the width/ depth and entrenchment ratios. Previous monitoring in 2010 suggested that this reach was shifting from an E to a C channel because of channel degradation, a notable increase in sediment deposition, and point bar formation along the right bank just downstream. Additional degradation between 2010 and 2012 suggest that the channel had lost connectivity to the floodplain and had likely shifted to an F stream type. Mid-channel degradation continued between 2014 and 2020 showing approximately a 0.9-foot difference. In 2020, geomorphic assessment parameters continued to support the classification of this reach as an F channel, but due to continued small median particle size this site remained classified as a F5 in 2020. The channel evolution is supported by an 97.0% increase in channel cross-sectional area since 2003 and considerable widening and mid-channel bar formation immediately downstream, which is indicative of a channel that is not stable and is undergoing a widening and degradation phase. Cross-sectional area at this location has been increasing every year since 2009. Left bank widening was also apparent between 2013 and 2014 monitoring years, remained consistent during 2015 through 2018, and continued to widen in 2019 and 2020. However, it is important to acknowledge that this cross-section is no longer located in a riffle feature and is now in a pool feature, which affects the channel dimensions and complicates classification using the Rosgen system.

As a result of the change in feature, at the County's request, Versar surveyed an additional cross-section during the Spring 2020 assessment at a riffle downstream of XS-1 for comparison to previous classifications at this site before it transitioned to a pool feature; this cross-section was named XS-1D. This site was permanently monumented using yellow-capped rebar should the County decide to continue monitoring this cross-section in future assessments so that annual comparisons could be made with this initial survey. A pebble count was not performed during the initial survey as the initial request was made to confirm only channel shape and dimension. Bed roughness was assigned in the Rosgen classification based on observed field conditions by the survey crew and photographic verification. Based upon the Spring 2020 survey, XS-1D was classified as a C4 channel using the Rosgen system, comparable to the classification XS-1 had received prior to transitioning to a pool feature in 2011. The subsequent assessment in Fall 2020 included a pebble count at this cross-section, and XS-1D was reclassified as a F5 channel due to a reduction in entrenchment ratio at this site, reflecting the similar classification seen at XS-1 after to 2011.

The next site downstream on the Parole Plaza Tributary, XS-2, was classified as a Rosgen G4c channel based on its continued low width/depth ratio, low slope, and gravel substrate. Since 2012 its entrenchment ratio has been slightly higher than those typical of G streams, but in 2017-2020 the ratio of entrenchment decreased. This reach was previously classified as an E type channel; however, it was noted that the reach was actively degrading and widening. While E streams are typically more sinuous, this segment has been noticeably straightened and stabilized by a retaining wall and rubble/fill along the left bank (facing downstream), likely resulting in instability, and consequently resulted in a shift to a less-stable form.

Site XS-3, located along the restored segment of Parole Plaza Tributary, was not classified until 2013, allowing 3 years after restoration for the area to settle and stabilize. In 2013 and 2014 it was classified as a Rosgen G4c channel based on its low entrenchment ratio, low width/depth ratio, and low slope. In 2015, XS-3 remained a G type channel; however, the substrate had become coarser resulting in a G4/3c classification. Variable coarseness caused XS-3 to return to a G4c during the 2016 survey and it has maintained that classification since. Before restoration, this cross-section was classified as a Rosgen G5c channel; however, since the Rosgen scheme was developed to classify natural channels, or those that are shaped naturally by fluvial processes, it was deemed inappropriate to classify immediately after construction. This section is still heavily armored and reliable bankfull indicators are not easily identified. Little overall change has been documented at XS-3 but the cycle of erosion and aggradation that has been observed on the right bank continued in 2020, with the most recent survey showing a retreat of approximately 2.2 feet in the seven months between the 2020 surveys. The reach at XS-3 was classified as a G5c channel in the Fall 2020 survey.

The most downstream site on the Parole Plaza Tributary, XS-4, has transitioned from a Rosgen E5 channel to a C4/5, back to an E4/5 channel, and to an E5 channel in 2020 due to fluctuations in substrate size and in width/depth ratio. A large woody debris jam located just downstream of the cross-section location resulted in a considerable accumulation of fine sediment and debris across the channel and, consequently, led to aggradation and a reduction in the cross-sectional area up until 2016. In 2016, before the cross-section survey was performed, restoration on the reach had begun and was completed just downstream of XS-4. Construction activities included the removal of the woody debris jam. Following construction, it is likely that fine sediment behind the debris jam cleared and resulted in increased substrate size. Between 2011 and 2015 cross-sectional area had consistently been lower than baseline monitoring in 2003. Restoration in 2016 caused cross-sectional area to increase by 9.8% from 2003 monitoring. Subsequently, in 2020 the cross-sectional area decreased from 2016 by 5.1% and has increased by 4.2 % since the 2003 monitoring.

Located on the mainstem of Church Creek, upstream of the MD Rt. 2 culvert, XS-5 has transformed from a Rosgen C3/5 channel into a F4 channel due to a significantly decreased entrenchment ratio from 4.0 to 1.4 between 2012 and 2020. Between 2015 and 2016, sediment in this portion of the reach had become slightly less coarse from a D_{50} of 61 mm to 24 mm. In 2018, sediment coarsened substantially with a D_{50} particle size of 85 mm, but decreased in 2019 to a D_{50} particle size of 32 mm. In Spring 2020, sediment classification remained similar compared to measurements in 2019, with a D_{50} particle size of 25 mm. This segment shows evidence of previous alteration in the form of cobble-sized riprap armoring along the bed and lower banks to protect a sewer line crossing and obvious channel straightening, which explains the lack of sinuosity typical of F type streams. The substantial amount of cobble-sized rip-rap in the stream channel has resulted in a multi-modal distribution of substrate particles within this reach, with a predominance of sand

and silt in the pools and glides and artificial cobbles in the riffles. Between 2018 and 2020, the cross-sectional area and the width/depth ratio remained similar.

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4 DISCUSSION

Results from the July 2020-March 2021 study period are discussed in the following section. Water quality and geomorphological data are interpreted, presented and compared to previous data. A discussion of the characteristics of the watershed is also included.

4.1 WATER CHEMISTRY

Water quality criteria are presented in Table 4-1. The measured data are compared, where possible, to these criteria to assess the extent of the pollution in this tributary.

Table 4-1. State and Federal water quality criteria available for parameters sampled at Church Creek

Parameter (mg/L, except as noted)	Chronic	Acute	Reference
Lead (µg/L)	2.5	65	COMAR 26.08.02.03-2
Copper (µg/L)	9	13	COMAR 26.08.02.03-2
Zinc (µg/L)	120	120	COMAR 26.08.02.03-2
Total P	0.0225		USEPA 2000
BOD_5	7		USEPA 1986
Nitrate + Nitrite	0.095		USEPA 2000
TSS	500		USEPA 1974
TKN	None		
TPH	None		
*E. coli** (MPN/100 mL)	126		COMAR 26.08.02.03-3
Hardness	None		

* Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion

Criteria are used to protect against both short-term and long-term effects. Numeric criteria are important where the cause of toxicity is known or for protection against pollutants with potential human health impacts or bioaccumulation potential. Narrative criteria can be the basis for limiting toxicity in discharges where a specific pollutant can be identified as contributing to the toxicity. Biological criteria can be used to complement traditional, chemical-specific criteria as indicators of aquatic health and impacts to the aquatic ecosystem.

Tables 4-2 and 4-3 compare baseflow and storm event results to the Federal and State acute and chronic criteria. Comparison and interpretation of Church Creek pollutant concentrations to Federal and State water quality criteria, and relating these conditions to ultimate ecological outcomes in the system, however, are difficult. Criteria do not exist for all parameters measured at the monitoring stations. In addition, a clear cause and effect relationship between water quality and ecological condition is difficult to determine. However, these comparisons can be used as general indicators of water quality impairment. Both State and Federal criteria are based on ambient stream conditions. Chronic criteria consider the maximum levels at which aquatic life can survive if continuously subjected to a pollutant concentration. Acute criteria reflect the maximum level at which an aquatic organism can survive if periodically subjected to a pollutant concentration. Since storm events represent a periodic condition, wet-weather samples are compared only to acute criteria.

Table 4-2. Maximum concentrations observed for baseflow samples compared to appropriate criteria

Parameter (mg/L, except as noted)	Chronic	Acute	Church Creek	Parole Plaza
Lead (µg/L)	2.5	65	BDL	BDL
Copper (µg/L)	9	13	3	8
Zinc (µg/L)	120	120	55	122*
Total P	0.0225		0.07*	0.02
BOD_5	7		2	5
Nitrate + Nitrite	0.095		0.92*	5.20*
TSS	500		10	5
TKN	None		BDL	BDL
TPH	None		BDL	BDL
*E. coli*** (MPN/100 mL)	126		331*	930*
Hardness	None		140	320

* Criterion exceeded
** Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion
BDL: Below Detection Limit

As in previous years, comparisons to water quality criteria indicate elevated pollutant concentrations in the Church Creek watershed. As shown in Table 4-2, established water quality criteria were exceeded for zinc, combined nitrate and nitrite, and *E. coli* at Parole Plaza and for total phosphorus, combined nitrate and nitrite, and *E. coli* at Church Creek during baseflow sampling. The number of exceedances of the water quality criteria at both Parole Plaza and Church Creek during baseflow sampling in 2021 were comparable to 2020.

Table 4-3 shows the maximum wet weather concentrations for each sampling site, and compares these to the corresponding criteria. In particular, copper, zinc, total phosphorous, BOD_5, nitrate-nitrite, and *E. coli* exceeded criteria at both sampling stations, as was the case in 2020. Table 4-4 shows the percentage of wet weather samples for which criteria were exceeded. *E. coli* concentrations exceeded the water quality criterion in 81 percent of samples at Church Creek and in 75 percent of samples at Parole Plaza, continuing a downward trend observed since 2019. Total phosphorus and combined nitrate and nitrite results exceeded the corresponding criteria 100% of the time at Church Creek, but only in 75 percent and 94 percent of samples, respectively, at Parole Plaza. Percentage exceedances for copper and zinc were higher at Parole Plaza than at Church

Creek, similar to 2020. In contrast to 2020, the percentage exceedance for BOD_5 was lower at Parole Plaza than at Church Creek.

Table 4-3. Maximum concentrations observed for wet weather samples compared to appropriate criteria

Parameter (mg/L, except as noted)	Criteria***	Church Creek	Parole Plaza
Lead (µg/L)	65	23	4
Copper (µg/L)	13	30*	81*
Zinc (µg/L)	120	184*	362*
Total P	0.0225	0.42*	0.32*
BOD_5	7	13*	47*
Nitrate + Nitrite	0.095	1.20*	1.60*
TSS	500	130	52
TKN	None	1.3	4.3
TPH	None	6	BDL
*E. coli*** (MPN/100 mL)	126	12,033*	22,095*
Hardness	None	140	86

* Criterion exceeded
** Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion
*** Used acute criteria for metals
BDL: Below Detection Limit

Table 4-4. Percentage of all wet weather samples that exceed appropriate criteria

Parameter (mg/L, except as noted)	Criteria**	Church Creek (%)	Parole Plaza (%)
Lead (µg/L)	65	0	0
Copper (µg/L)	13	38	44
Zinc (µg/L)	120	25	44
Total P	0.0225	100	75
BOD_5	7	31	19
Nitrate + Nitrite	0.095	100	94
TSS	500	0	0
TKN	None	NA	NA
TPH	None	NA	NA
*E. coli** (MPN/100 mL)	126	81	75
Hardness	None	NA	NA

* Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion
** Used acute criteria for metals
NA: Not applicable

High levels of pollutants observed in the watershed are typical for commercial and retail land uses that are coupled with high levels of automobile traffic and impervious surface area (U.S. EPA 1983). As shown in Table 2-2, impervious surface covers 78% of the Parole monitoring station drainage area and 69% of the Church Creek monitoring station drainage area.

High levels of zinc and copper recorded during storm events in 2021 may have been associated with leachate from building materials and automobile parts in the runoff during the initial stages of the event. Additionally, zinc coating is often used in the manufacture of corrugated metal pipe, such as one of the outfall pipes at the Parole Plaza location. During 2021, percent exceedances for zinc and copper at Parole Plaza were slightly lower in contrast to 2020 whereas the exceedances slightly increased at Church Creek for most parameters. The average size of monitored storm events in 2021 was 0.76 inches, down from 0.79 inches in 2020, which may explain generally lower exceedances at Parole Plaza. Given that larger storms tend to cause the discharge of higher concentrations of pollutants, the increased percentage of exceedances of metals during stormflow at Parole Plaza in 2020 may indicate higher pollution conditions in the catchment or deteriorating portions of the stormwater infrastructure that are constructed of metal.

Table 4-5 shows the annual average storm EMCs that exceeded water quality criteria. As can be seen from the table, total phosphorous, nitrate-nitrite, and *E. coli* consistently exceeded their corresponding criteria at both stations, as was the case in 2020. During 2021, the EMCs for copper and zinc did not exceed their criteria at Parole Plaza, in contrast to 2020.

Table 4-5. Annual average storm EMCs and criteria (parameters that exceeded appropriate criteria are indicated)

Parameter (mg/L, except as noted)	**Criteria*** **	**Church Creek**	**Parole Plaza**
Lead (µg/L)	65	8	2
Copper (µg/L)	13	10	8
Zinc (µg/L)	120	68	70
Total P	0.0225	0.20*	0.10*
BOD_5	7	4	3
Nitrate + Nitrite	0.095	0.21*	0.22*
TSS	500	50	15
TKN	None	0.4	0.3
TPH	None	3	3
*E. coli*** (MPN/100 mL)	126	6,260*	6,944*
Hardness	None	28	26

* Criterion exceeded
** Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion
*** Used acute criteria for metals

Historical annual loading data (Tables 4-6 and 4-7) indicate that in 2007 loading rates increased sharply at both stations. Loading rates in 2008 were still high, when compared to historical values, but dropped dramatically from the 2007 levels. During the 2009 reporting year, loading rates dropped further and aligned more closely with historical values. High loading rates in 2007 likely resulted from redevelopment construction activity that was underway immediately upstream of the Parole Plaza station. Since the majority of the site was stabilized by the end of 2008, the cessation of construction likely caused pollutant loads to decrease.

Table 4-6. Total annual loading rates, in pounds, observed at the Parole Plaza Sampling Station from 2002 to 2021

Year	BOD_5	TSS	TP	TKN	NO_3+ NO_2	Zinc	Lead	Copper	Hardness	Fecal Coliform[a]
2002	2,912	26,585	1,178	388	323	58	14	1	NA	1,152,001
2003	21,665	86,385	372	1,477	714	176	69	15	NA	5,350,164
2004	8.025	57,447	293	655	391	57	7	8	NA	402,127
2005	4,573	33,015	184	483	350	50	12	8	NA	665,232
2006	13,562	94,306	650	1,867	410	177	13	25	NA	3,360,952
										***E. coli*[a]**
2007	40,009	848,116	1,649	2,328	1,401	349	26	162	NA	11,017
2008[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2009	2,175	11,787	59	490	117	56	0.8	6.5	NA	2,115
2010	2,209	17,609	89	309	120	40	1.2	4.1	NA	1,740
2011	2,114	13,894	42	371	131	58	1.1	6.3	6,987	2,682
2012	3,660	15,335	62	284	214	57	1.0	6.6	14,578	10,209
2013	1,481	6,079	34	155	108	34	0.5	4.9	8,586	16,041
2014	2,040	18,953	54	536	497	50	1.0	8.1	36,945	12,716
2015	940	14,606	45	232	162	38	1.1	5.3	29,023	3,333
2016	1,308	10,887	29	218	103	36	1.0	9.3	14,779	18,268
2017	1,120	19,913	50	318	161	57	1.2	8.3	18,876	7,366
2018	1,467	16,532	52	187	173	60	1.0	8.0	15,554	16,965
2019	1,405	8,784	40	147	162	53	0.8	6.3	11,616	5,720
2020	287	6,791	21	109	90	33	0.7	4.7	9,111	5,466
2021	1,176	5,744	38	108	123	36	0.6	5.9	9,823	6,944
2002-2006 Mean	8,544	59,548	535	974	438	104	23	11	NA	2,186,095
2009-2021 Mean	1,579	12,808	46	263	178	46	1	6	15,776	8,428
2002-2021 Mean	5,434	69,071	259	559	310	77	8	16	15,776	8,613[c]

[a] Units of Fecal Coliform and *E. coli* are MPN/100 mL.
[b] In 2008, monitoring was conducted for both outfalls at Parole Plaza, but continuous level monitoring was not available for the 54" RCP; therefore, loads could not be calculated.
[c] Mean *E. coli* value, does not include pre-2007 Fecal Coliform data.

Table 4-7. Total annual loading rates, in pounds, observed at the Church Creek Sampling Station from 2002 to 2021; revised values determined using the updated rating curve are shown in shaded cells

Year	BOD_5	TSS	TP	TKN	NO_3+ NO_2	Zinc	Lead	Copper	Hardness	Fecal Coliform[(a)]
2002	6,408	58,501	2,593	854	711	127	32	3	NA	2,534,970
2003	47,673	190,090	818	3,250	1,571	387	151	32	NA	11,773,001
2004	17,660	126,411	645	1,441	860	126	19	18	NA	884,887
2005	10,062	72,648	405	1,062	771	109	27	16	NA	1,463,839
2006	29,844	207,520	1,431	4,109	902	390	29	54	NA	7,395,753
										E. coli[(a)]
2007	265,499	3,312,794	8,381	20,330	436,206	3,663	277	652	NA	1,755
2008	60,843	458,185	3,037	12,468	4,444	693	37	36	NA	3,857
2009	35,521	206,184	1,296	9,377	2,505	531	30	57	NA	3,912
2010	49,256	341,877	2,066	9,561	2,912	739	39	77	NA	3,358
2011	42,883	214,820	1,340	7,410	3,606	704	30	41	259,076	3,995
2012	40,145	150,490	1,103	3,714	3,018	551	20	31	250,747	5,549
2013[(b)]	9,047	53,232	250	928	574	137	7	17	68,829	4,568
2014	12,640	117,533	395	4,158	2,019	202	11	31	218,516	10,623
2015	5,981	126,732	372	2,084	962	238	13	38	139,720	2,323
2016	18,558	124,057	374	2,287	1,142	287	15	33	114,819	9,299
2017	6,566	1,318	553	247	75,402	19	10	131	68,645	6,653
2018	4,969	94,452	301	854	555	136	10	20	60,721	7,864
2019	5,892	76,267	320	741	687	136	9	19	64,643	6,655
2020	3,333	88,504	299	601	481	112	11	18	56,599	5,492
2021	5,986	67,931	285	508	420	104	10	16	51,141	6,259

(a) Units of Fecal Coliform and *E. coli* are MPN/100 mL.
(b) Rating curve updated and applied to data from 11/2012 to present.
(c) Mean *E. coli* value, does not include pre-2007 Fecal Coliform data.

When compared to the 2020 reporting year, 2021 loading rates decreased for all parameters except for BOD_5 at the Church Creek Station. At the Parole Plaza Station, 2021 reporting year loading rates decreased for TSS, TKN, and lead when compared to 2020. Annual mean concentrations of *E. coli* were higher in 2021 at both stations.

A comparison of mean annual loading rates for the pre-redevelopment period (2002-2006) with those of the post-redevelopment period (2009 to 2021), indicates the mean loading rates for all parameters at the Parole Plaza station were lower during the post-redevelopment period. A comparison of the post-redevelopment to pre-redevelopment values at the Church Creek station is not discussed in this report because the update of the rating curve resulted in pollutant loadings that have been revised lower for reporting years 2013 to 2020 only.

Seasonal pollutant loads in 2021 are provided in Table 4-8. At Church Creek, the seasons in which the highest pollutant loads occurred were summer and winter. Combined nitrate-nitrite was higher in the winter and the remainder were higher in the summer. At Parole Plaza, most parameters were at their highest during the winter except for TSS and *E. coli*, which were highest in the summer.

Table 4-8. Seasonal loading rates, in pounds, observed at the Church Creek and Parole Plaza sampling stations in 2021

Season	BOD_5	TSS	TP	TKN	NO_3+NO_2	Zinc	Lead	Copper	Hardness	*E. coli*[*]
Church Creek										
Summer	4,437	47,186	178	304	152	61	8	9	20,691	10,281
Fall	566	10,973	58	137	87	17	1	2	12,007	1,444
Winter	983	9,772	50	66	180	26	1	5	18,443	1,939
Parole Plaza										
Summer	517	2,598	13	33	17	9	0.2	1	2,681	9,299
Fall	95	667	7	22	24	5	0.1	0.4	2,738	4,286
Winter	564	2,479	18	53	81	22	0.3	4	4,404	3,038

* Units of *E. coli* are MPN/100 mL

Annual average EMCs were plotted for each monitoring year. Plots were constructed to illustrate the impact that construction activity and redevelopment of the Annapolis Towne Centre site (2004-2008), subsequent stream restoration (2015-2016), and stormwater retrofit (2017) has had on water quality within the study reach. Figures 4-1 through 4-5 show the change in EMCs from 2004 to 2021 at the Parole Plaza Monitoring Station. Nearly every EMC rose substantially between 2006 and 2007, coinciding with the majority of the site work at the Towne Centre. These EMCs fell notably in 2008 as the site stabilized and this stability has been reflected in time series plots ever since. At Parole Plaza, annual pollutant EMCs of TKN, combined nitrate and nitrite, copper, lead, zinc, and TSS in 2021 resumed their recent, downward trending track that initiated approximately 2006. EMCs of BOD_5 and total phosphorus slightly increased in 2021, but overall maintained their downward trend. EMCs of *E. coli* increased slightly in 2021, continuing their overall upward, though variable, trend. EMCs of TPH have been nearly flat since an increase in the analytical detection limit in 2013 resulted in only higher concentration results to be incorporated into EMCs and plotted. Note that the 2013 data included in these plots do not include the summer season (Versar 2013), which is often the season that produces the highest EMCs for many of the parameters.

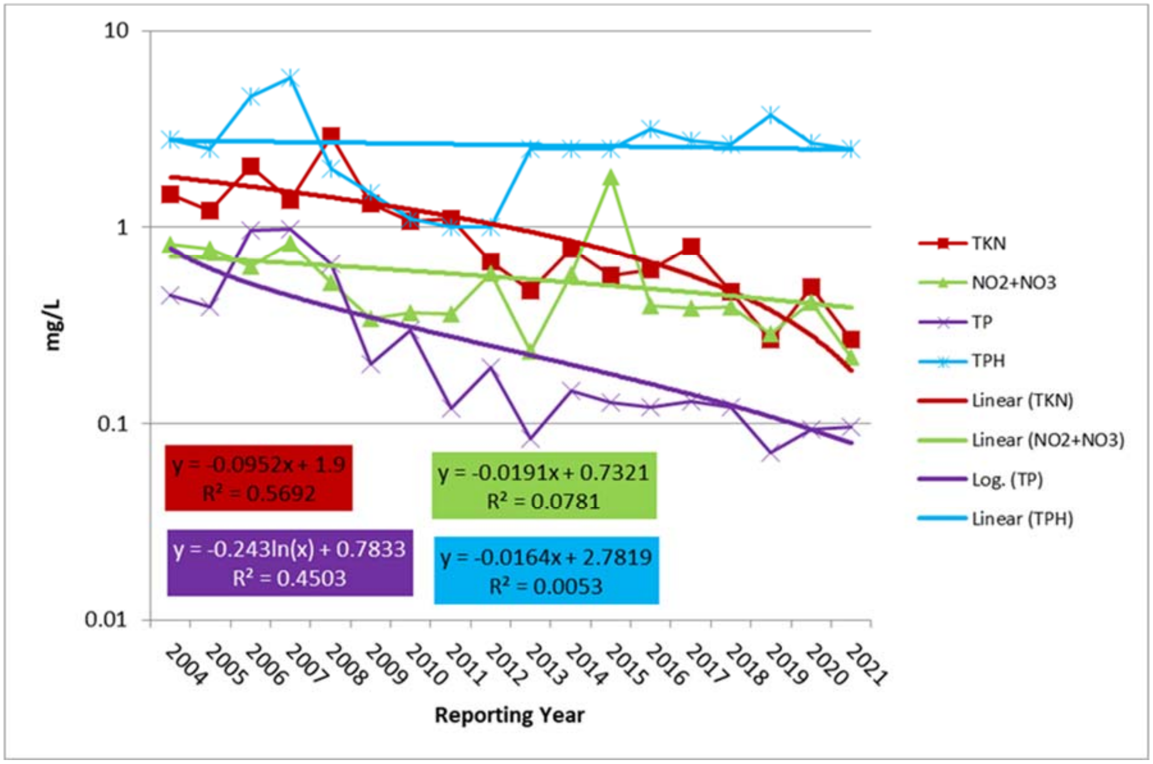

Figure 4-1. Parole Plaza station long-term monitoring: annual EMCs (TKN, NO_3+NO_2, TP, TPH; mg/L)

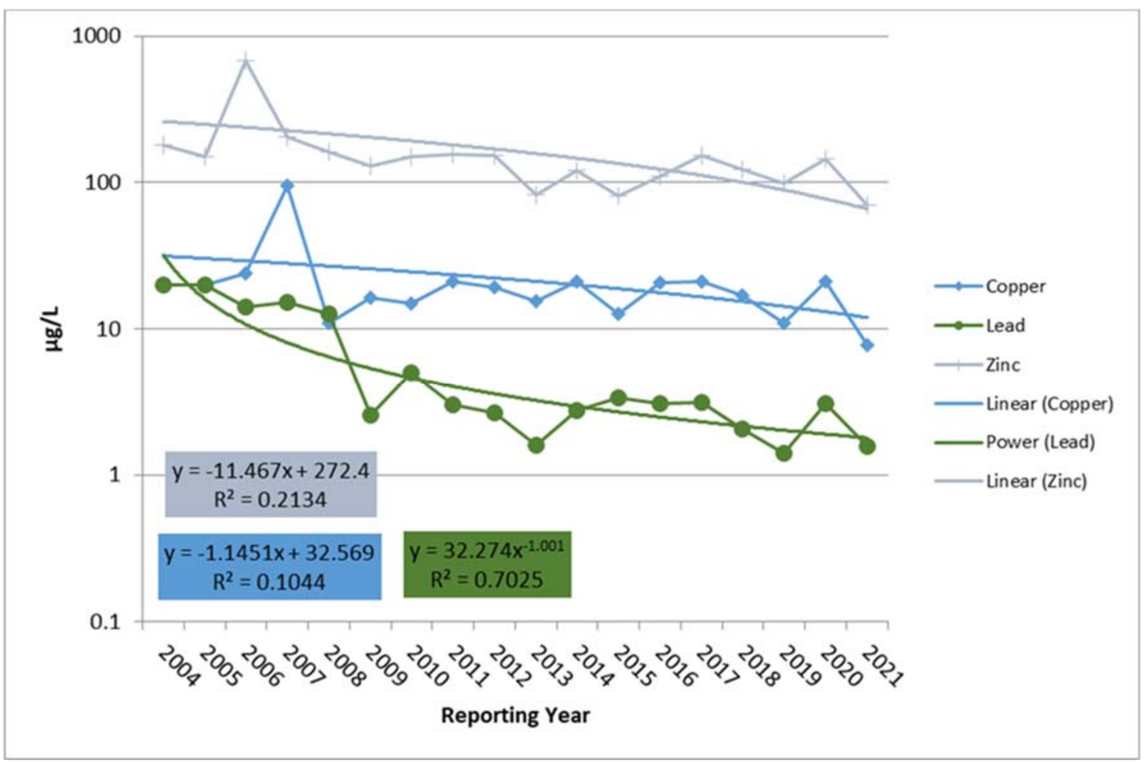

Figure 4-2. Parole Plaza station long-term monitoring: annual EMCs (Cu, Pb, Zn; µg/L)

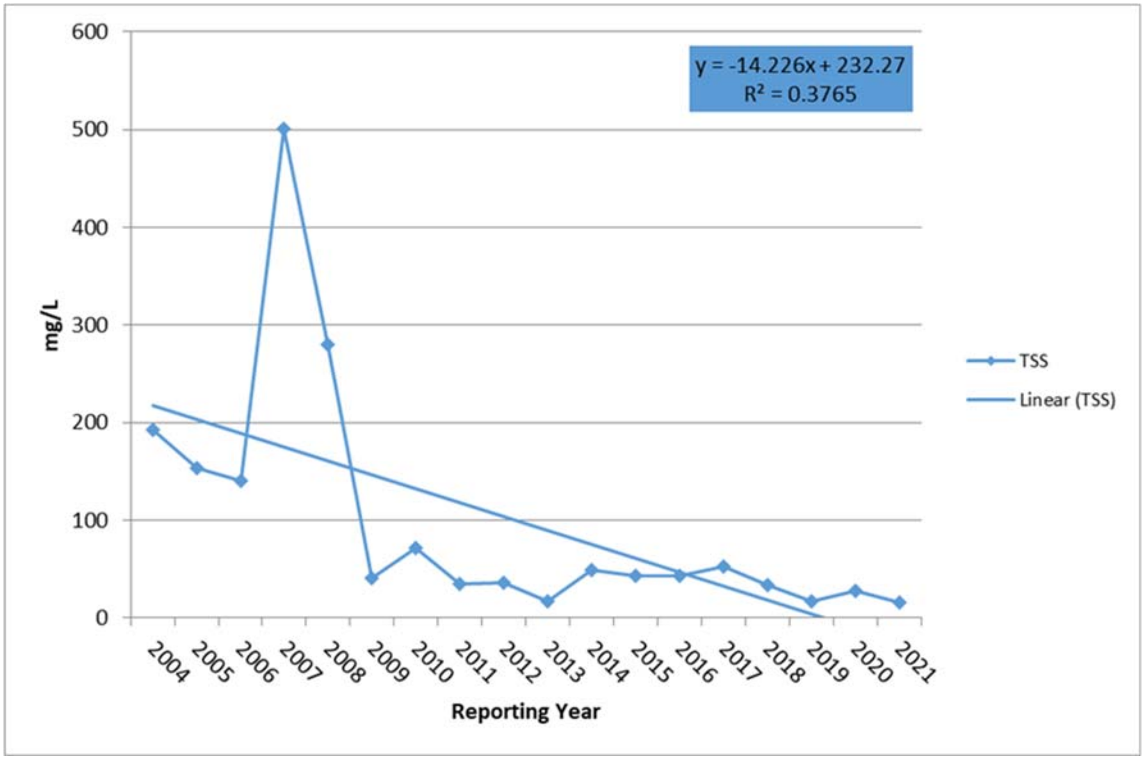

Figure 4-3. Parole Plaza station long-term monitoring: annual EMCs (TSS; mg/L)

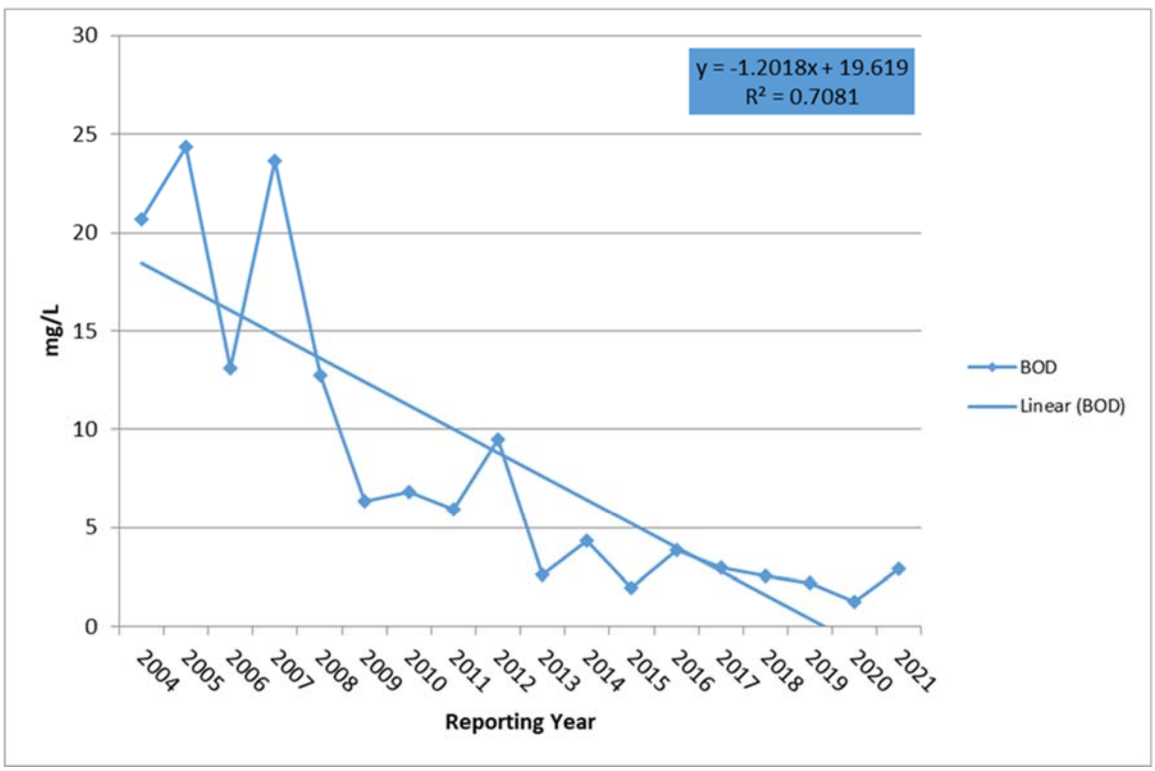

Figure 4-4. Parole Plaza station long-term monitoring: annual EMCs (BOD_5; mg/L)

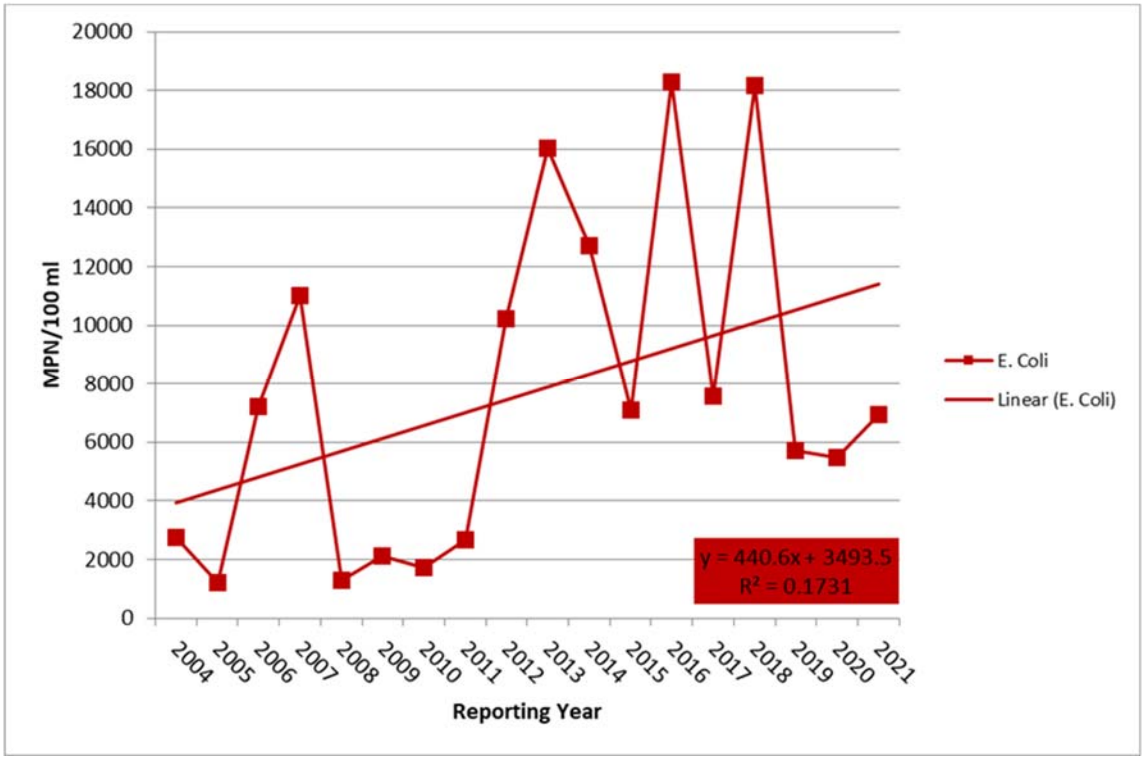

Figure 4-5. Parole Plaza station long-term monitoring: annual EMCs (fecal coliform 2004-2006 and *E. coli* 2007-2021; MPN/100 mL)

Figures 4-6 through 4-10 show trends in average annual EMCs for the Church Creek monitoring station. Note that the apparent rise in TPH at Church Creek in 2013 was due to an increase in the detection limit. Also, summer season concentrations were not included with the EMC data for 2013 (Versar 2013).

Pollutant EMCs for all parameters decreased at Church Creek in 2021 compared to 2020 EMCs except for lead, BOD_5, and *E. coli*. Time series of annual EMC values generally continued their downward trend, except for *E. coli*. The upward trend in *E. coli* at this station appears to be weaker than the trend observed at Parole Plaza. Similar to Parole Plaza, annual average EMCs of most parameters achieved local maxima during the 2006-2007 periods, probably due to redevelopment construction effects carrying downstream. Local maxima for most parameter EMCs reappeared during 2016-2017 time frame, possibly in response to disturbances as a result of construction of the additional stream restoration and retrofit projects. EMCs of lead, total phosphorus, TSS, and BOD_5, however, along with *E. coli*, have been increasing since approximately 2015.

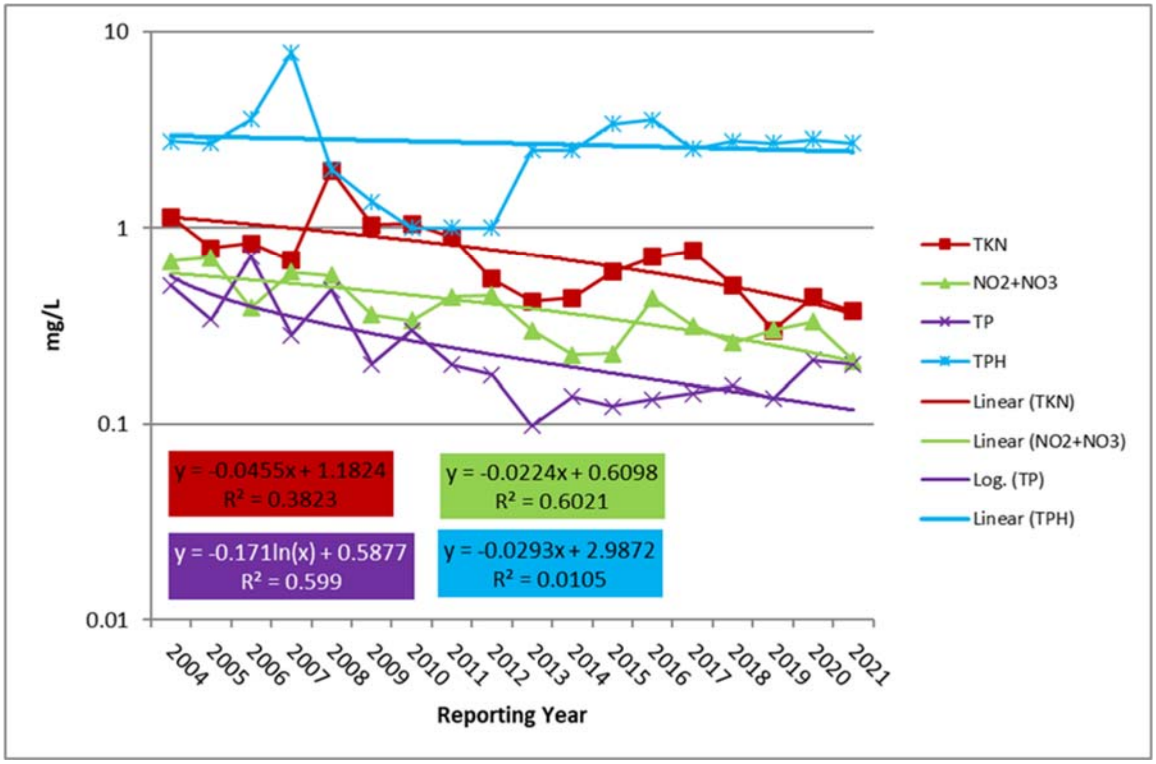

Figure 4-6. Church Creek station long-term monitoring: annual EMCs (TKN, NO_3+NO_2, TP, TPH; mg/L)

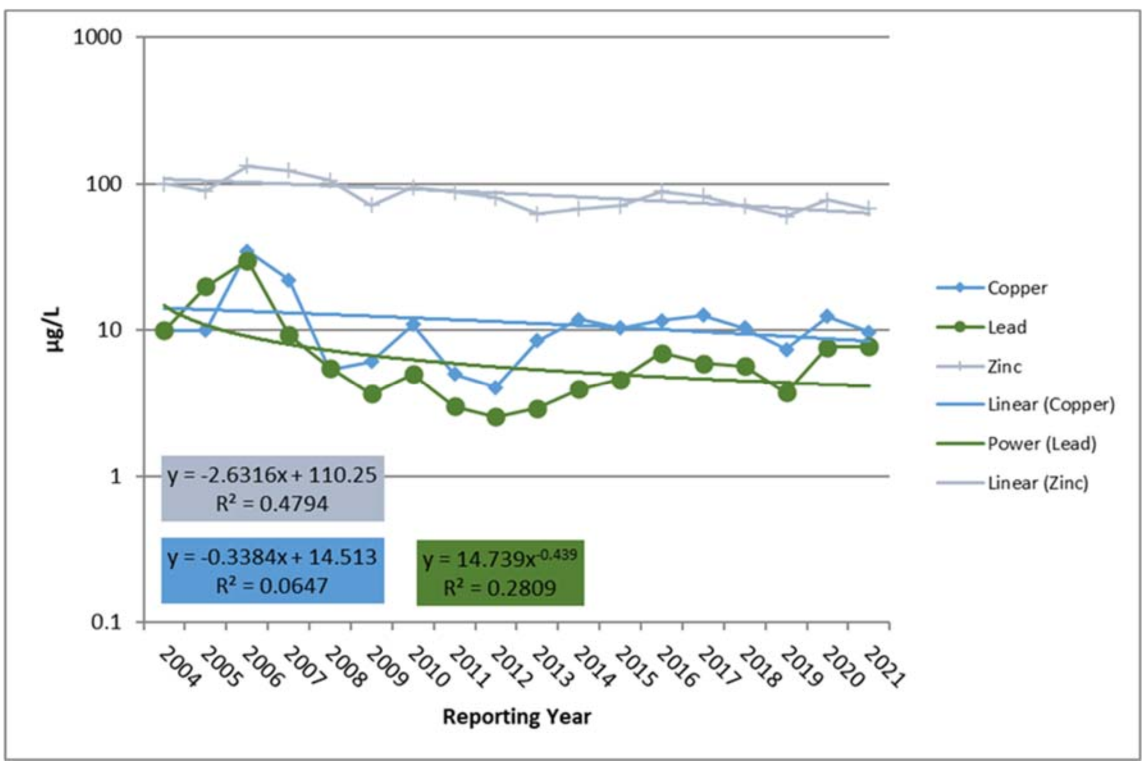

Figure 4-7. Church Creek station long-term monitoring: annual EMCs (Cu, Pb, Zn; µg/L)

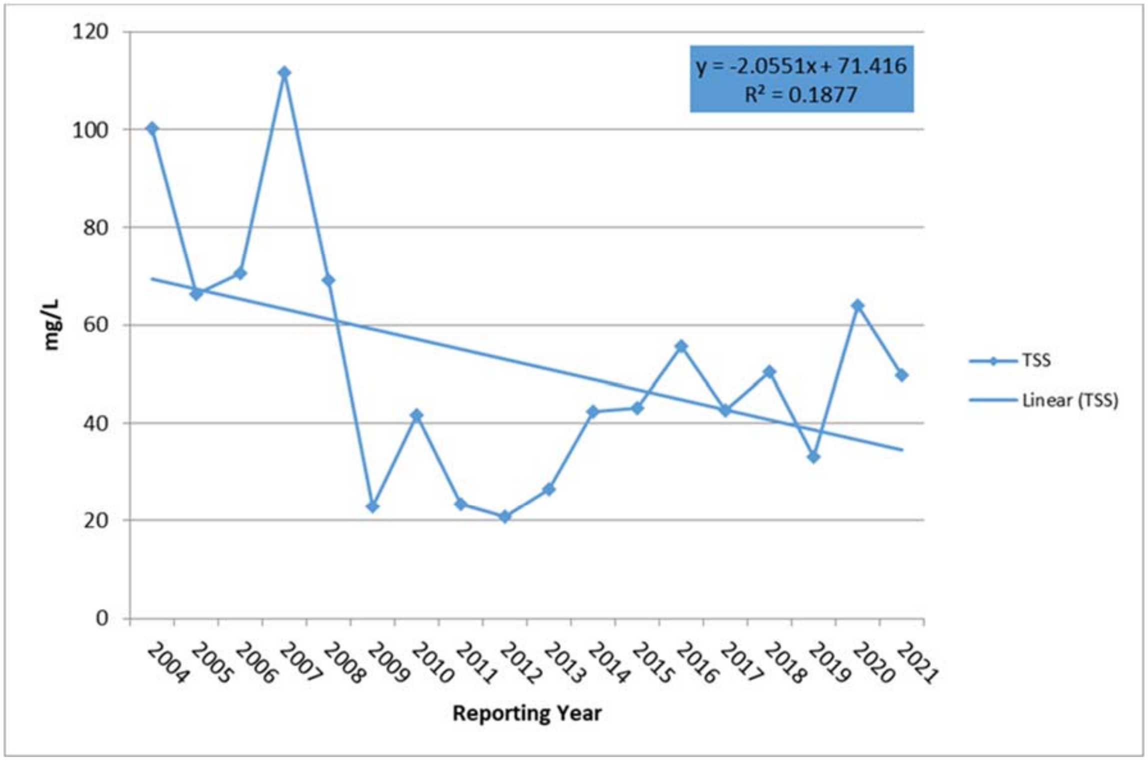

Figure 4-8. Church Creek station long-term monitoring: annual EMCs (TSS; mg/L)

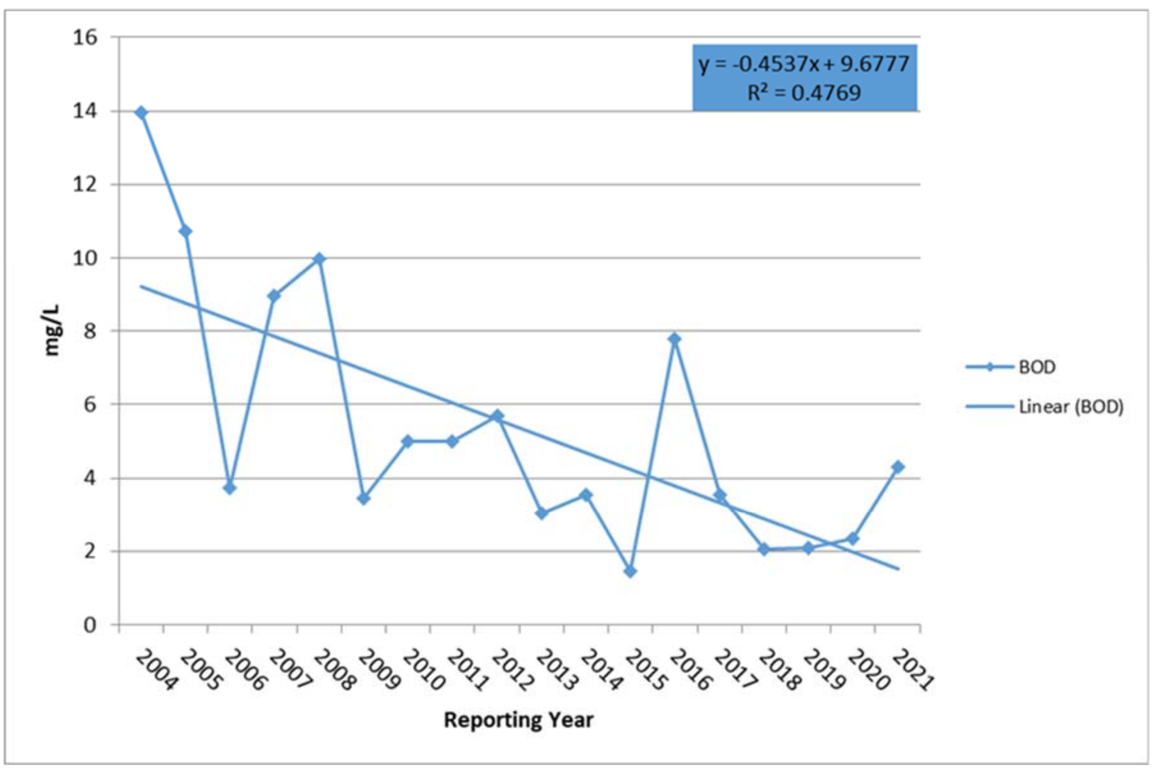

Figure 4-9. Church Creek station long-term monitoring: annual EMCs (BOD_5; mg/L)

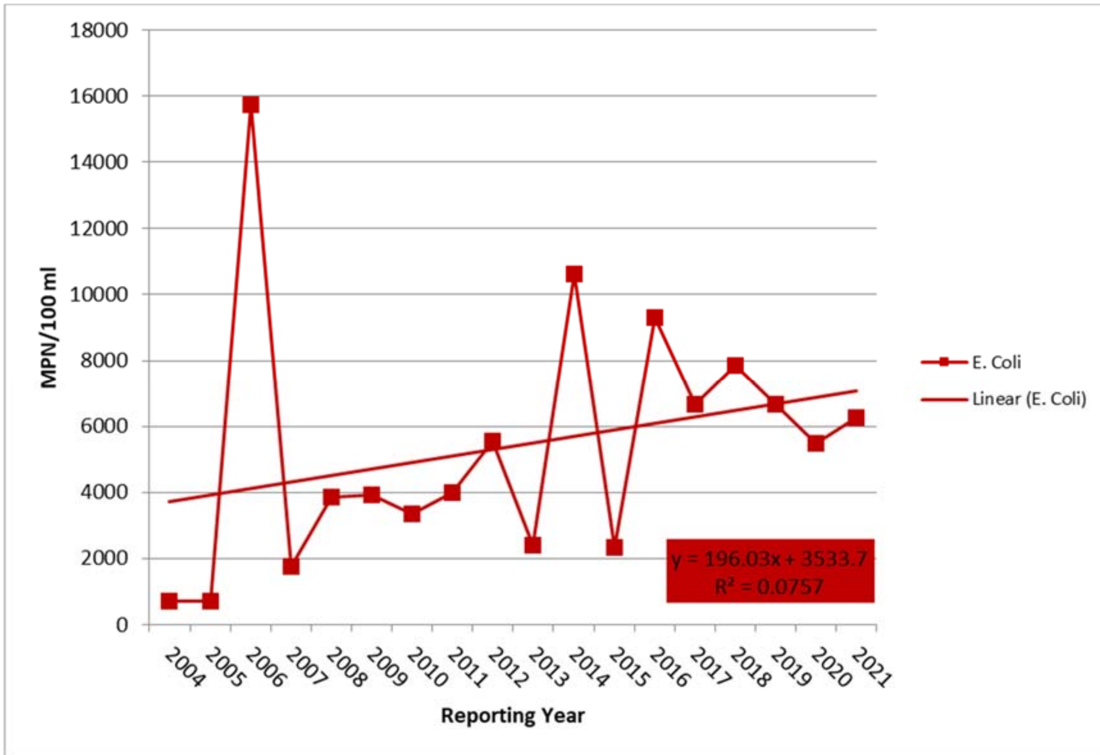

Figure 4-10. Church Creek station long-term monitoring: annual EMCs (fecal coliform 2004-2006 and *E. coli* 2007-2021; MPN/ 100 mL)

4.2 GEOMORPHIC CONDITIONS

The Church Creek study area has a very high percentage of impervious surface cover (approximately 64 percent). Five reaches were classified as either F or G channels, which are more entrenched and less stable. The most downstream reach of the Parole Plaza Tributary was classified as an E channel and maintains some limited connectivity to its floodplain even though there are significant stormwater inputs feeding into the stream, which typically result in accelerated channel erosion and degradation. There were no changes in the overall classifications of each stream reach from 2017 to 2018. Stream types remained the same in 2019, apart from XS-1 which changed from an F4 to an F5 stream type as its substrate became less coarse. In 2020, stream types remained stable as well, with minor changes seen at XS-3 from G4c to G5c and at XS-4 from an E4 to an E5, due to decreased substrate size. Only one site, the newly established XS-1D, required reclassification, shifting from a C4 to a F5 stream type due to a reduction in entrenchment ratio between surveys; though this segment does not exhibit the classic "U" channel shape associated with a F stream type, the low slope, meandering channel, and presence of depositional bars in the immediate area, in conjunction with the lower entrenchment ration, indicate that this site is transitioning between Rosgen classifications. Future assessments would be needed to determine if this site continues to downcut and exhibit traditional F stream type channel form. Evolution of channel type over the course of the study at each cross-section is presented in Table 4-9. It is likely that current stormwater management and wetland storage on the Church Creek mainstem, as well as the presence of an intact riparian vegetative buffer along much of the stream corridor, contributes to minimizing some of the adverse effects of the high imperviousness in the watershed. Additionally, grade controls such as the culvert at Solomon's Island Road and cobble rip-rap armoring at XS-5 likely prevent some degradation from occurring in the channel upstream. Nonetheless, there are clear indications of channel instability (i.e., degradation, aggradation, widening) in the upper reaches of the Parole Plaza Tributary, and thus, a need for additional stormwater management to prevent further channel erosion.

Table 4-9. Past Rosgen classifications

Cross-section	XS-1	XS-1D	XS-2	XS-3	XS-4	XS-5
2006	E5	No Data	E5	G5c	E5	E5b
2007	C5	No Data	E5	G5c	E5	C5
2008	E4	No Data	E5	G5c	E5	C5
2009	E5 → C5	No Data	E5	G5c	E5	C5
2010	E5 → C4/5	No Data	E5	G5c	E5	C3/5
2011	C4/5 → F4/5	No Data	G5c	No Data	E5	C3/5
2012	F5	No Data	G5c	No Data	E5	C3/5
2013	F4	No Data	G5c	G4c	C5	F4/3
2014	F5/4	No Data	G4c	G4c	C5	F3
2015	F4	No Data	G4	G4/3c	C5	F3/4
2016	F4	No Data	G4c	G4c	E5/4	F4
2017	F4	No Data	G4c	G4c	E4/5	F4
2018	F4	No Data	G4c	G4c	E4/5	F4
2019	F5	No Data	G4c	G4c	E5	F4
Spring 2020	F5	C4	G4c	G4c	E4	F4
Fall 2020	F5	F5	G4c	G5c	E5	F4

Bankfull channel dimensions (cross-sectional area, width, depth) in the Church Creek study area showed departure from expected values, as derived from Maryland Coastal Plain regional relationships of bankfull channel geometry (McCandless 2003). Almost all dimensions were generally larger in the Church Creek study area (see Figures 4-11, 4-12, and 4-13), and were often more similar to relationships of bankfull channel geometry derived from gaged urban watersheds located in the Coastal Plain. These relationships were previously developed for an urban stream restoration project in Anne Arundel County (AADPW 2002). Recent dimensions have been slightly higher than previous assessment values. This reflects the higher level of imperviousness in the study area, as compared to the lower impervious levels in the drainage areas used to develop the regional relationship data. The results suggest that this stream has become enlarged as a result of the high imperviousness, and is both wider and deeper than stable C and E type channels located in rural/suburban watersheds of the coastal plain. It should be noted, however, that locating bankfull elevations in the field on actively eroding, previously stabilized, or incising channels is difficult and not recommended due to unreliable and/or misleading indicators, and instead bankfull elevations should be estimated using the aforementioned regional curves (Rosgen, personal communication, May 2011). Where bankfull indicators were suspect or questionable, the indicator approximating the rural/suburban regional curve for bankfull area was used to estimate bankfull elevations. Additionally, the Rosgen method is best used on streams that are free to adjust their lateral boundaries under the current discharge regime experienced by the system (Rosgen 1996). Given the high levels of rip rap and/or concrete rubble armoring found in the reaches containing cross-sections 2, 3 and 5, the accurate determination of the bankfull indicators in the field at these locations is problematic.

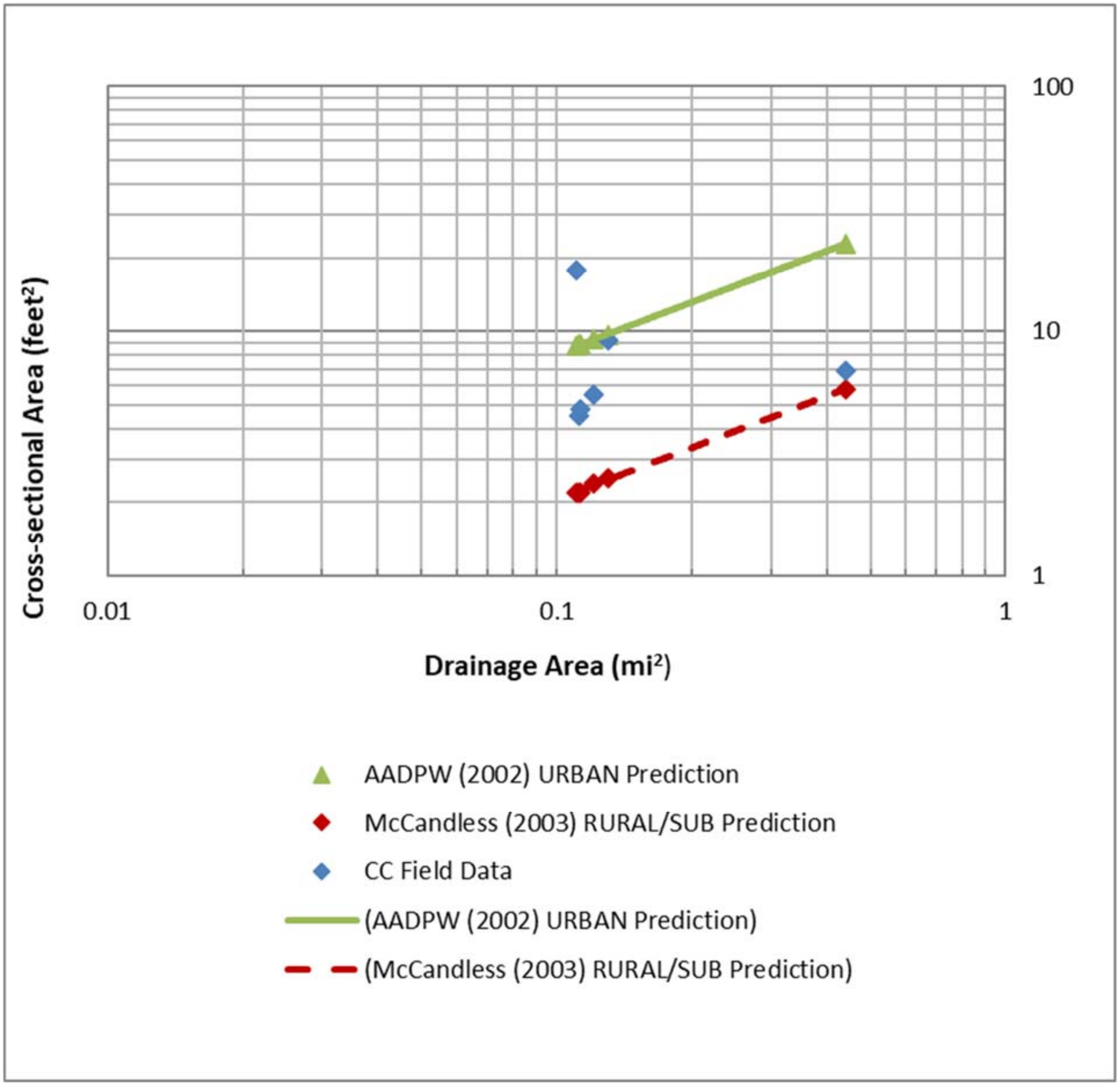

Figure 4-11. Comparison of bankfull channel cross-sectional area to drainage area (CC = Church Creek, Fall 2020 data)

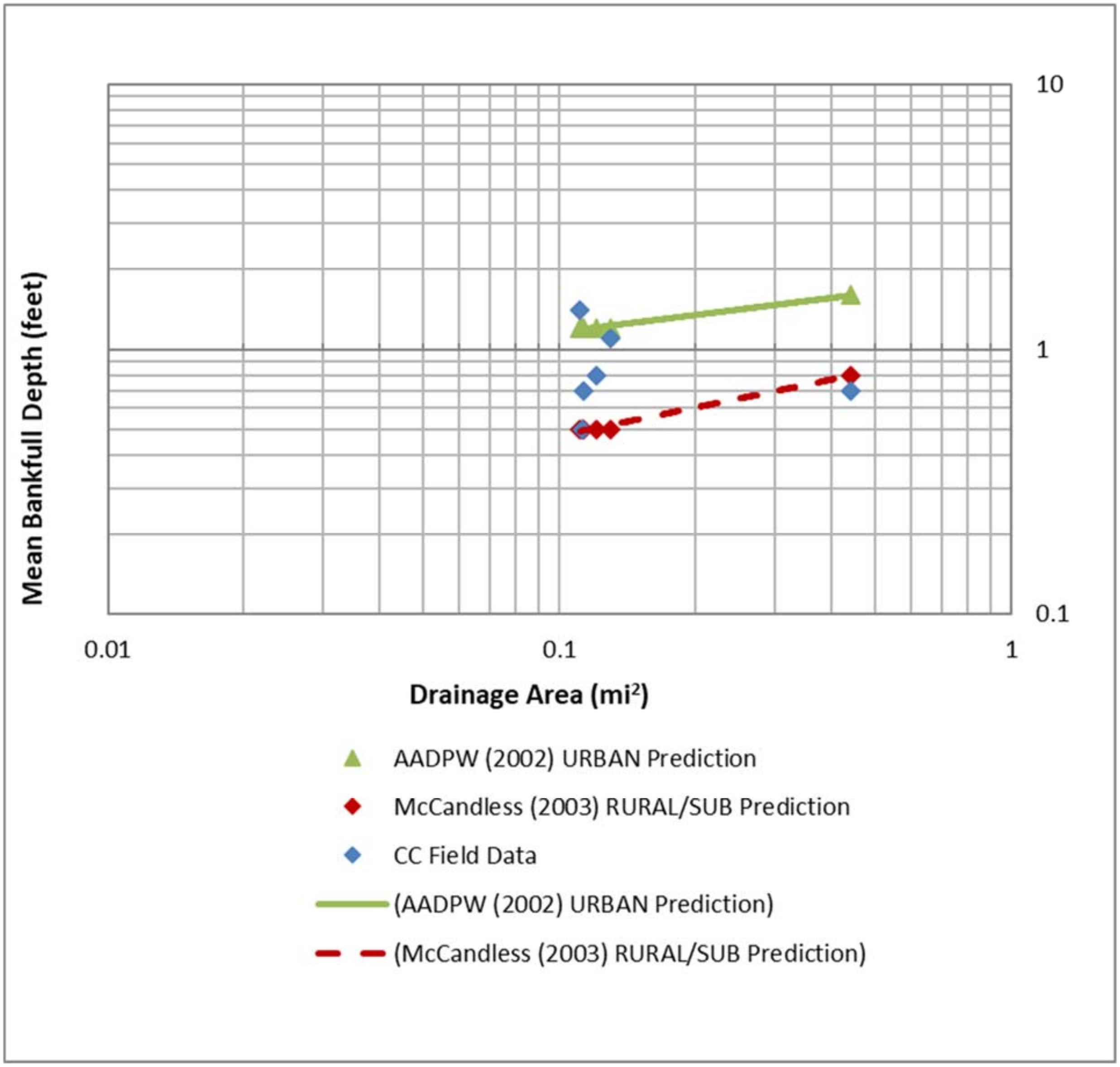

Figure 4-12. Comparison of mean bankfull depth to drainage area (CC = Church Creek, Fall 2020 data)

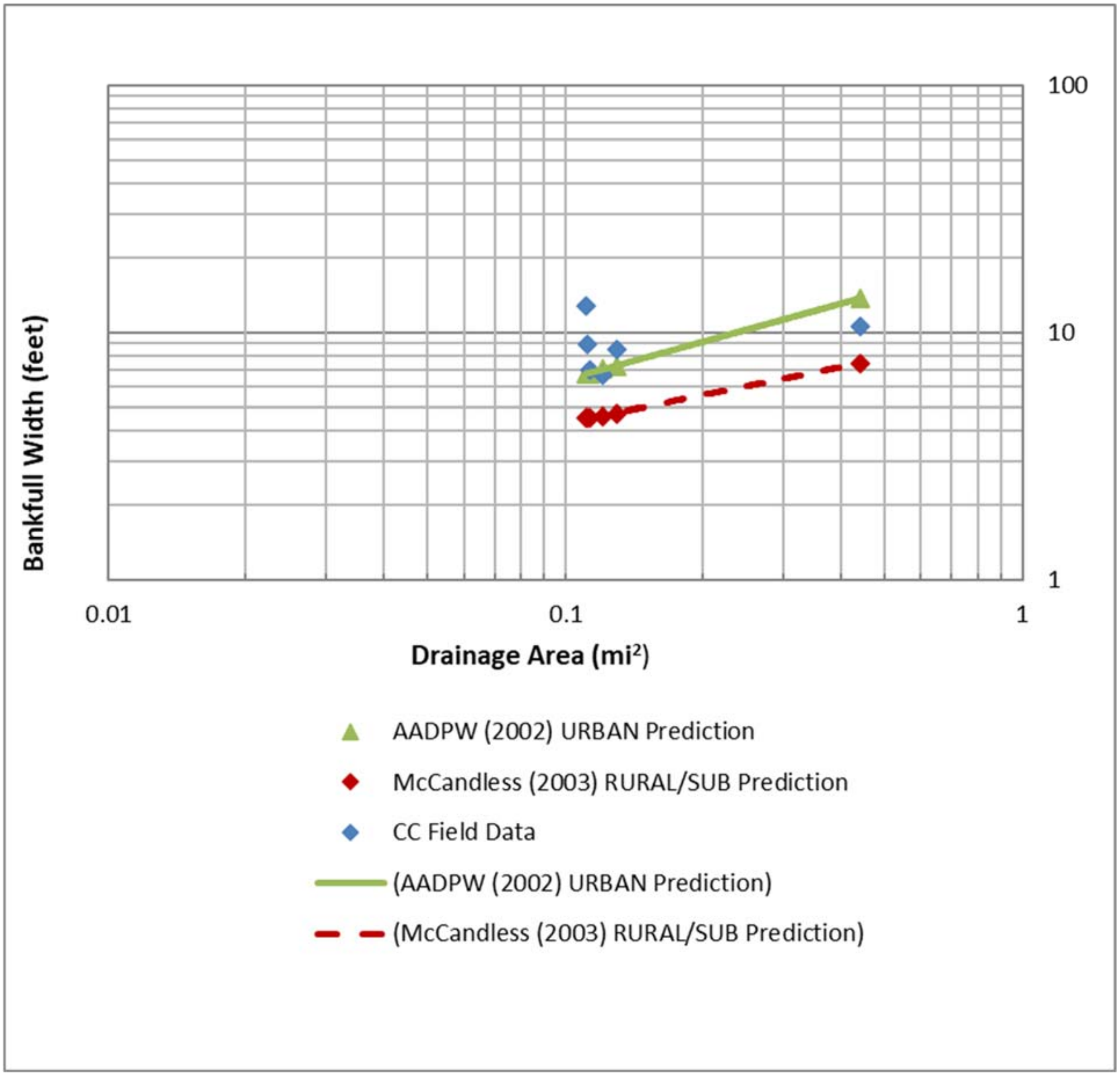

Figure 4-13. Comparison of bankfull width to drainage area (CC = Church Creek, Fall 2020 data)

In terms of percent change over time, four of the six cross-sections (XS-1, XS-1D, XS-2, XS-4) showed enlargement from channel erosion while the other two (XS-3, XS-5) showed aggradation as compared to baseline measurements (Table 4-10). Due to the replacement of XS-3 following channel restoration, data were compared to 2007 at this location only, comparisons at XS-1D were only made between the Spring and Fall 2020 surveys; all other comparisons were made to 2003 data. Cross-sectional area from 2011 through 2020 was calculated using the top of bank elevation from the baseline survey in order to standardize comparisons and reduce variability among more subjective bankfull elevation reference points, or even changes that can occur to top of bank elevation from year to year. It is important to note that calculations prior to 2011 did not use the baseline reference elevation, instead they used the corresponding year's top of bank elevation for calculating cross-sectional area, and consequently these values are not directly comparable to the cross-sectional areas reported in 2011 through 2020. Comparison of baseline cross-sectional area is, however, comparable to 2011 through 2020 since all calculations are made using the same top of bank elevation.

Table 4-10. Summary of cross-sectional area changes over time

Cross-section[(a)]	XS-1	XS-1D	XS-2	XS-3	XS-4	XS-5
July 2003	16.8	ND	8.9	ND	14.3	9.7
Jan 2005	20.7	ND	10.0	ND	14.4	9.9
March 2006	19.4	ND	8.0	ND	18.4	9.5
March 2007	19.4	ND	8.9	19.8	17.4	9.0
May 2008	20.1	ND	10.1	16.7	18.0	8.9
July 2009	19.6	ND	9.8	21.0	15.4	8.3
May 2010	19.8	ND	10.3	20.4	16.4	8.5
July 2011[(b)]	21.3	ND	15.9	20.6	7.8	10.5
April 2012[(b)]	21.6	ND	15.4	19.2	11.7	5.9
July 2013[(b)]	21.0	ND	15.5	20.2	11.7	6.9
June 2014 [(b)]	22.4	ND	16.2	20.6	6.8	6.7
May 2015 [(b)]	22.6	ND	16.4	18.6	9.2	6.7
March 2016 [(b)]	25.7	ND	23.0	18.7	15.7	6.6
February 2017 [(b)]	27.1	ND	18.7	18.2	13.3	6.5
April 2018 [(b)]	28.4	ND	21.4	19.3	14.2	6.8
March 2019 [(b)]	30.6	ND	19.8	18.6	14.5	7.3
March 2020 [(b)]	30.8	50.6	20.3	16.5	14.5	7.1
October 2020 [(b)]	33.1	52.2	20.2	18.7	14.9	7.2
% Change 2003-2020	97.0	3.2[(d)]	127.0	-5.6[(c)]	4.2	-25.8
% Change 2011-2020	55.4	3.2[(d)]	27.0	-9.2	91.0	-31.4

[(a)] All values listed here are for top of bank area and are listed in square feet
[(b)] Values obtained using reference elevations (top of bank) from baseline measurements
[(c)] % change from 2007
[(d)] % change from Spring 2020
ND = No Data

Using the current reference elevation comparison method, the upstream cross-sections (XS-1 and XS-2) showed fairly substantial enlargement, with increases of 97.0%, and 127.0% respectively, since baseline measurements began in 2003. Cross-sectional area comparisons since 2011 show more moderate channel enlargements of 55.4% for XS-1 and 27.0% for XS-2. The bed elevation at XS-1 appears to have dropped about 1.3 feet since 2003 with a substantial amount of bed scour occurring between 2014 and 2018 (Appendix D). Scouring near the right bank occurred between 2008 and 2009 but has remained stable since. The left bank however, has both widened and deepened since 2012 and as of 2020, this trend appears to be continuing. The channel at XS-2 has widened notably since 2003, with considerable erosion along the right bank. The left bank had been generally stable, showing minimal erosion until 2016. In 2016 the channel had both widened along the left bank and deepened mid channel, although in 2017 the channel returned to more narrow and shallow conditions seen before 2016. In 2018, there was slight widening of the channel on both the right and left banks. The left bank continued to exhibit erosion in 2019 and Spring 2020, while aggradation occurred along the right bank. The channel form remained stable during the Fall 2020 assessment (Appendix D).

Cross-section XS-3 had minimal changes in cross-sectional area through 2019, but showed significant aggradation in 2020, with a 5.6% decrease since baseline measurements in 2007 and 9.2% decrease between 2011 and 2020. Between 2009 and 2011, the XS-3 channel appeared to be enlarging, as the right bank and bottom of the right bank eroded and the cross-sectional area increased (Appendix D). Between 2011 and 2016 the right bank aggraded across the stream bed and the toe of the right bank, narrowing the stream channel (Appendix D). In 2017 erosion began occurring behind the armored right bank and some scouring was evident on both sides of the channel bed; however, these previously eroded areas were filled in by the time of the 2018 cross-section survey and remained intact in 2019 and Spring 2020. Significant erosion occurred along the right bank between the Spring and Fall 2020 surveys, with the measured loss of bank of approximately 2.2 feet over this seven-month period. Cross-section XS-3 continues to have yard waste (i.e., grass clippings, leaves, and branches) dumped along the left bank.

Cross-section XS-4 has had the most variation throughout the years. Between 2010 and 2011 cross-section XS-4 had shown moderate signs of aggradation, with a decrease in cross-sectional area of 8.6 ft^2. Within the next year, the channel bed eroded, particularly along the right hand side of the stream. In the 2013 survey, signs of aggradation were again present and the stream bed characteristics resembled those of the 2011 survey. In 2014 the stream bed remained elevated as in 2011 and 2013 however there was slight widening along the right bank. A debris jam at XS-4 which formed between 2011 and 2012 and caused sediment accumulation, was removed during stream restoration construction prior to the 2016 survey. Consequently, the channel scoured significantly and resulted in cross-sectional area increase of 6.5 ft^2. Channel scour at this cross-section slowed since the 2016 survey, although the left bank has exhibited erosion annually between 2014-2020. Cross-sectional area has increased only 4.2% between 2003 and 2020 but increased 91.0% between 2011 and 2020.

Cross-section XS-5 has been armored with cobble-sized rip rap in its bed to protect the sewer line. Between 2012 and 2013, XS-5 appeared eroded by several inches of sediment, most notably near the left bank. Cross-sectional area has decreased by 31.4% since 2011 and decreased by 25.8% since 2003. During the past four years since restoration was completed, however, there has been little change in both stream bed elevation and bank stability (Appendix D). Cross-sectional area has remained relatively stable from 2013 to 2020 with little to no change year to year.

4.3 GENERAL CONCLUSIONS

Water chemistry data collected in 2021 continued to show general, gradually decreasing pollutant levels at the Parole Plaza outfall and in Church Creek, but at concentrations that continued to exceed surface water criteria for certain parameters.

During the abbreviated FY2021 monitoring year, annual average EMCs for all parameters were generally higher at Church Creek than at Parole Plaza. Annual average EMCs for total phosphorous, nitrate-nitrite, and *E. coli* exceeded their corresponding criteria at both stations.

Concentrations of *E. coli* exceeded the water quality criterion in 81% of samples at Church Creek and in 75% of samples at Parole Plaza. Total phosphorus and combined nitrate and nitrite results exceeded the corresponding criteria 100% of the time at Church Creek, but only in 75% and 94% of samples, respectively, at Parole Plaza. Percentage exceedances for copper and zinc were higher at Parole Plaza than at Church Creek.

For most parameters, annual loads at Church Creek exceeded those at Parole Plaza during 2021 except for *E. coli* (reported as annual average EMC). The mean annual loading rates for all parameters at the Parole Plaza station were lower during post-redevelopment (2009 to 2021) than pre-redevelopment (2002-2006). A comparison of the post-redevelopment to pre-redevelopment loadings at the Church Creek station is not discussed because of the revision of the 2013 to 2020 loadings as a result of the revision of the rating curve.

At Parole Plaza, annual pollutant EMCs in 2021 decreased for most parameters (except for TPH, total phosphorus, BOD_5, and *E. coli*) continuing a trend of gradually declining values first recognized in 2006. Most average annual pollutant EMCs (except for lead, BOD_5, and *E. coli*) decreased at Church Creek in 2021, also continuing the general 2006 to present pattern. The period after the most recent stream restoration (2016) and stormwater pond retrofit (2017) projects in the Church Creek watershed coincided with a temporary decline in pollutant EMCs of most parameters in the 2017-2019 annual monitoring periods. Trends during the post-redevelopment period only (2009-2021) at Parole Plaza show gradual declines in annual average EMCs for nutrients, metals, TSS, and BOD_5, but not for *E. coli* or TPH, the latter of which was affected by a detection limit change. At Church Creek during the same period, negative slopes tended to be shallower or, in the case of lead, copper, and TSS, showed increasing trends. The reason for the increasing slopes may be due to increased traffic, continued development, or other unknown factors elsewhere in the Church Creek watershed. Water chemistry benefits of the stream restoration and stormwater retrofit could not be distinguished in the short-term (2009-2021) data.

The redevelopment of Parole Plaza had an overall beneficial water chemistry impact to the receiving tributary. In terms of average annual EMCs, the reduction in average pollutant levels between the pre-redevelopment (includes construction; 2004-2008) and post-redevelopment (2009-2021) phases ranged between 32% and 85% at Parole Plaza and 32% and 67% at Church Creek (note hardness and *E. coli* were not compared). A Student's t test shows that the only significant (α=0.05) reductions were at Parole Plaza for BOD_5, TSS, copper, and lead. The results indicate that the redevelopment had a significant beneficial effect on concentrations of selected pollutants discharged from the developed area. The improvement carried downstream to Church Creek; however, reductions in pollutant levels were less significant.

Although the stream channel has been stabilized along several reaches, some areas upstream of these restorations have exhibited continued channel enlargement. Since the inception of physical monitoring in 2003 (2007 at XS-3 and 2020 at XS-1D), cross-sectional areas have greatly increased at XS-1 by 97% and XS-2 by 127%. While only two surveys, conducted seven months apart, were available for comparisons at XS-1D, an increase in cross-sectional area of 3.2% was noted. Lastly, while the overall change in cross-sectional area at XS-3 from the beginning of monitoring to this most current survey remains negative, a loss of 2.2 feet of bank at this location documented in the Fall 2020 survey indicates that channel widening at this station has begun and may continue. Future monitoring at these locations would be needed to determine if these enlargements continue and indicate the need for consideration of additional restoration efforts at these locations. The positive effects of the completed stream restoration on biota are yet to be seen from these efforts (Versar 2020a); overall BIBI ratings have remained in the Very Poor to Poor categories since 2006 with no clear trend towards improvement evident. In 2016, stream restoration occurred at the Parole Plaza tributary confluence downstream of cross-section XS-4 and on the reach above the confluence and upstream of cross-section XS-5. All of the CC-04 and part of the CC-03 biological monitoring sites were within this restored reach of stream. Eventually the restoration project should result in less sediment transported downstream, increased stability at physical monitoring stations, and could positively affect the biota at monitoring stations through habitat improvement. In the four years since restoration was completed, cross-section XS-5, downstream of the restored reach has maintained stability in its geomorphic parameters including consistent cross-sectional area. Future monitoring efforts would be needed to evaluate the effects of this restoration.

5 REFERENCES

Anne Arundel County Department of Public Works (AADPW). 2002. Cypress Creek Tributary Assessment and Findings Report. Prepared by Bayland Consultants and Designers, Inc., and Clear Creek Consulting. 32 pp., plus Appendices.

Code of Maryland Regulations (COMAR), Title 26, Department of the Environment, Part 1, Vol. XXIII.

Greenhorne and O'Mara. 2005. *Annapolis Towne Centre @ Parole Stormwater Management Report.* Prepared for Annapolis Towne Centre @ Parole, LLC, Owings Mills, MD.

McCandless, T.L. 2003. *Maryland stream survey: Bankfull discharge and channel characteristics of streams in the Coastal Plain hydrologic region*. U.S. Fish and Wildlife Service, Annapolis, MD. CBFO-S03-02.

Mecklenburg, D. 2006. *The Reference Reach Spreadsheet*. Version 4.3 L. Ohio Department of Natural Resources.

Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

United States Environmental Protection Agency (U.S. EPA). 1974. National Water Quality Inventory. 1974 Report to the Congress. Volume II. United States Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C. EPA 440/9-74-001.

U.S. EPA. 1983. Final Report of the Nationwide Urban Runoff Program. United States Environmental Protection Agency, Water Planning Division. Washington, D.C. December.

U.S. EPA. 1986. Quality Criteria for Water 1986. United States Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC. May. EPA 440/5-86-001.

U.S. EPA. 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria Rivers and Streams in Nutrient Ecoregion IX. Office of Water, 4304. December 2000. EPA 822-B-00-019 [http://www2 .epa .gov/sites/production/files/documents/rivers9.pdf].

Versar, Inc. 2013. Chemical, Biological, and Physical Characterization of the Church Creek and Parole Plaza NPDES Monitoring Stations: 2013. Prepared for Anne Arundel County Department of Public Works. December 2013.

Versar, Inc. 2020a. Chemical, Biological, and Physical Characterization of the Church Creek and Parole Plaza NPDES Monitoring Stations: 2019-2020. Prepared for Anne Arundel County Department of Public Works. October 2020.

Versar, Inc. 2020b. Church Creek/Parole Plaza NPDES Water Chemistry Monitoring – Summer 2020 Quarter Report. Technical Memorandum Prepared by Versar, Inc., Columbia, MD for Janis Markusic, Anne Arundel County Department of Public Works. December 2020.

Versar, Inc. 2021a. Church Creek/Parole Plaza NPDES Water Chemistry Monitoring – Fall 2020 Quarter Report. Technical Memorandum Prepared by Versar, Inc., Columbia, MD for Janis Markusic, Anne Arundel County Department of Public Works. February 2021.

Versar, Inc. 2021b. Church Creek/Parole Plaza NPDES Water Chemistry Monitoring – Winter 2021 Quarter Report. Technical Memorandum Prepared by Versar, Inc., Columbia, MD for Janis Markusic, Anne Arundel County Department of Public Works. June 2021.

APPENDIX A

STORM EVENT HYDROGRAPHS, NARRATIVES, COMPOSITE SAMPLING METHOD TECHNICAL MEMORANDUM, AND UPDATED CHURCH CREEK RATING CURVE

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KCI TECHNOLOGIES

TECHNICAL MEMORANDUM

TO: Janis Markusic, AACO DPW

FROM: James Tomlinson

DATE: 5/12/08

SUBJECT: Proposed Modifications to Sampling Procedures
Church Creek/Parole Plaza NPDES Monitoring 2008
KCI Job Order No. 01-032333.38

Dear Ms. Markusic,

Monitoring at the Parole Plaza station has historically entailed collecting storm water samples from a 60" corrugated metal pipe (CMP) outfall draining the Parole Plaza site. The rising, peak, and falling limb of each storm event was sampled and analyzed in the lab. In the summer of 2007, a newly-installed 54" reinforced concrete pipe (RCP) was connected to the Church Creek drainage network (refer to Figure 1). The new 54" RCP drains the *Annapolis Towne Center at Parole* construction site and contains portions of the drainage that had historically been passing through the 60" CMP. Based on plan reviews, on-site discussions with County staff /inspectors, and discussions with Mr. Matthew Kelly of Greenhorne & O'Mara Inc. (Head Engineer) it was determined that runoff from the *Annapolis Towne Centre at Parole* site would be discharging from both the 60" CMP and 54" RCP outfalls under post-construction conditions.

In order to maintain consistency in the characterization of the watershed, samples are being collected from both pipes. As in the 2006-2007 reporting year, the 2007-2008 reporting year has also encountered the challenge of determining the active drainage configuration during each sampled event. To address this problem, samples were collected for each limb of an event and taken to the laboratory for each pipe separately. In 2007, storm samples were collected and analyzed for both outfall pipes for three storm events (9/11/07, 10/9/07, and 10/19/07) at the Parole Plaza station. In 2008, storm samples were collected and analyzed for both outfall pipes for two storm events (1/10/08 and 1/17/08) at the Parole Plaza station.

Stage/discharge relationships were developed for both pipes, to determine the discharge from each pipe based on field-measured depths. The rating tables were used to determine discharges and total flow volumes for each limb of the storm. The reported concentrations for each limb were then weighted by the flow for that limb of the storm to determine the event mean concentration for each pipe. The event mean concentrations for each pipe were then flow weighted again for the total discharge through each pipe to determine the total event mean concentration for the *Annapolis Towne Center at* Parole site.

In March 2008, the sampling methodology was modified such that only one flow-weighted composite sample per event limb is collected and analyzed at the lab. The goal of compositing the discharge from both pipes is to ensure a comprehensive analysis of the storm water leaving the *Annapolis Towne Center at Parole* site during and after construction. The flow-weighted composite sample for each limb of an event is determined by the combined discharge of the 60" CMP and 54"RCP outfalls. Stage/discharge relationships were developed for both pipes, to determine the discharge from each pipe based on field-measured depths. The relationships are based on modeled values and are currently being validated by field-measured data. A sample is collected for each limb of a storm by proportioning the appropriate volume of RCP/CMP sample into a sample container, based on each pipes contribution to the total runoff. To determine the appropriate amount of sample to collect from each pipe for each limb, the discharge from the CMP and RCP is computed and totaled. The CMP and RCP discharge is then divided by the total discharge to determine the percent contribution to the total discharge. Once the percent contribution is determined, then volumetric containers are utilized to proportion each pipe sample to create one composite sample. The composite sample is then distributed into the laboratory bottles.

At this time, three storm events (3/19/08, 4/20/08, and 4/26/08) have been sampled utilizing the flow-weighted composite method. Currently, no automated equipment is available for the RCP. Level, pH, and temperature are taken manually during sampled events. All of the flow data and discharge characteristics for each outfall pipe are recorded during the storm event into a laptop spreadsheet that automatically calculates the correct sample proportions. General notes, field-measured velocity data, and a hydrograph are also recorded on the laptop spreadsheet during the storm event (see Figure 2).

As discussed in the field on April 10, 2008, KCI feels that this is an appropriate method for maintaining consistency with the historical data, while reducing the costs of sampling and testing both outfalls individually.

If you have any questions or comments, please feel free to contact me at the number below.

Sincerely,

James A. Tomlinson, PE
Project Manager
(410) 316-7864

ND/jt

cc: Christopher Victoria, AACo DPW
Nathan Drescher/KCI

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Proposed Modifications to Sampling Procedures
Church Creek/Parole Plaza NPDES Monitoring 2008
KCI Job Order No. 01-032333.38
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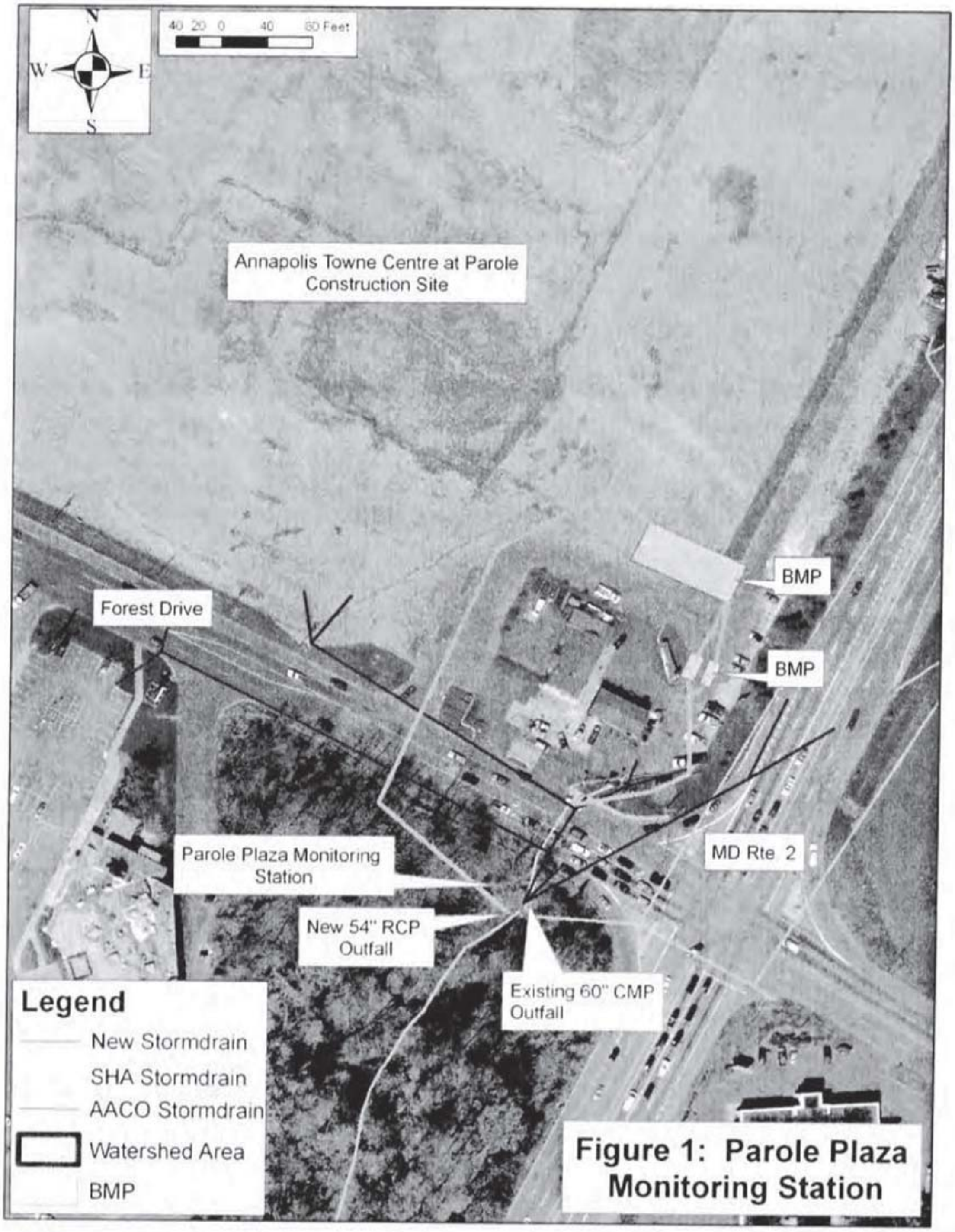

Figure 1: Parole Plaza Monitoring Station

Proposed Modifications to Sampling Procedures
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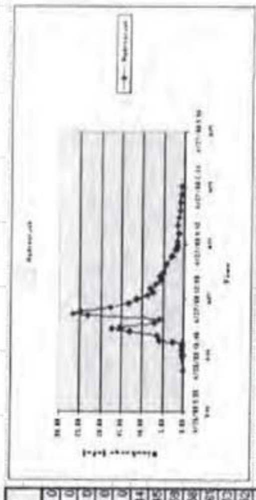
Figure 2

Parole Plaza Combined Hydrograph

Date	Time	CMP Level (ft)	RCP Level (ft)	CMP Q (cfs)	RCP Q (cfs)	RCP pH	RCP Temp Celsius	Combined Q (cfs)	RCP Prop. %	CMP Prop. %
4/26/08	4/26/08 10:30 PM	0.00	0.05	0.00	0.04	-	-	0.04	100	0
4/26/08	4/26/08 10:47 PM	0.00	0.15	0.00	0.19	6.70	15.40	0.19	100	0
4/26/08	4/26/08 10:50 PM	0.00	0.18	0.00	0.26	6.70	15.40	0.26	100	0
4/26/08	4/26/08 10:55 PM	0.00	0.16	0.00	0.21	6.60	15.80	0.21	100	0
4/26/08	4/26/08 11:00 PM	0.00	0.15	0.00	0.19	6.60	15.80	0.19	100	0
4/26/08	4/26/08 11:02 PM	0.10	0.15	0.15	0.19	6.00	16.00	[illegible]	56	44
4/26/08	4/26/08 11:05 PM	0.25	0.40	1.10	1.38	6.00	16.00	2.46	55	45
4/26/08	4/26/08 11:08 PM	0.41	0.52	3.36	2.37	5.80	16.10	5.74	41	59
4/26/08	4/26/08 11:15 PM	0.45	0.55	3.71	2.68	6.20	15.80	6.39	42	58
4/26/08	4/26/08 11:20 PM	0.65	0.75	7.95	5.06	6.10	15.50	13.01	39	61
4/26/08	4/26/08 11:22 PM	0.70	0.95	9.21	8.17	5.90	15.50	17.38	47	53
4/26/08	4/26/08 11:25 PM	0.65	0.90	7.95	7.31	5.90	15.60	15.26	48	52
4/26/08	4/26/08 11:30 PM	0.43	0.65	3.36	3.79	6.90	15.60	7.14	53	47
4/26/08	4/26/08 11:35 PM	0.40	0.58	2.85	2.98	7.00	15.60	5.83	51	49
4/26/08	4/26/08 11:40 PM	0.95	0.93	15.45	7.83	6.90	15.60	23.28	34	66
4/26/08	4/26/08 11:42 PM	0.85	1.20	13.74	12.95	7.00	15.60	[illegible]	48	52
4/26/08	4/26/08 11:45 PM	0.80	1.10	13.12	11.55	6.90	15.60	24.67	47	53
4/26/08	4/26/08 11:50 PM	0.72	0.93	9.79	7.83	7.10	15.80	17.62	44	56
4/26/08	4/26/08 11:55 PM	0.62	0.83	7.19	6.22	7.10	15.80	13.40	46	54
4/27/08	4/27/08 12:00 AM	0.57	0.77	6.04	5.34	7.20	15.30	11.38	47	53
4/27/08	4/27/08 12:05 AM	0.51	0.68	4.77	4.10	7.10	15.40	8.90	46	54
4/27/08	4/27/08 12:10 AM	0.46	0.64	3.88	3.66	7.40	15.30	7.53	49	51
4/27/08	4/27/08 12:15 AM	0.48	0.65	4.22	3.78	7.20	15.30	7.99	47	53
4/27/08	4/27/08 12:20 AM	0.42	0.65	3.19	3.78	8.00	15.30	6.97	54	46
4/27/08	4/27/08 12:25 AM	0.36	0.60	2.33	3.18	7.90	15.30	5.51	58	42
4/27/08	4/27/08 12:30 AM	0.38	0.60	2.59	3.18	7.80	15.30	5.77	55	45
4/27/08	4/27/08 12:35 AM	0.36	0.55	2.33	2.68	7.60	15.40	5.01	53	47
4/27/08	4/27/08 12:45 AM	0.30	0.55	1.55	2.68	7.30	15.30	4.23	63	37
4/27/08	4/27/08 12:55 AM	0.25	0.48	1.10	1.77	7.20	15.30	2.87	62	38
4/27/08	4/27/08 1:05 AM	0.18	0.40	0.55	1.36	7.30	15.30	1.91	71	29
4/27/08	4/27/08 1:10 AM	0.17	0.37	0.50	1.17	7.20	15.30	1.67	70	30
4/27/08	4/27/08 1:15 AM	0.16	0.35	0.45	1.05	7.40	15.30	[illegible]	70	30
4/27/08	4/27/08 1:25 AM	0.13	0.33	0.30	0.93	7.20	15.30	1.23	76	24
4/27/08	4/27/08 1:35 AM	0.13	0.40	0.30	1.36	7.30	15.30	1.66	82	18
4/27/08	4/27/08 1:45 AM	0.13	0.35	0.30	1.05	7.40	15.30	1.35	78	22
4/27/08	4/27/08 1:55 AM	0.13	0.30	0.30	0.74	7.20	15.30	1.04	71	29
4/27/08	4/27/08 2:05 AM	0.11	0.30	0.20	0.74	7.60	15.30	0.94	79	21
4/27/08	4/27/08 2:15 AM	0.10	0.25	0.15	0.53	7.30	15.30	0.68	78	22
4/27/08	4/27/08 2:25 AM	0.09	0.25	0.14	0.53	7.40	15.30	0.66	80	20



RCP - Velocity Probe

Depth	Velocity	SNR	Notes

CMP - Velocity Probe

Depth	Velocity	SNR	Notes

Comments

Pipe	Time	Comment
--	3:22 P M	CMP dry, RCP with small baseflow (0.05), Church normal
--	10:19 PM	Started to rain
	10:35 PM	Steady Light Rain/Thunder
	10:47 PM	RCP: Turbid flow
CMP	11:03 PM	smells bad, trash
CMP	11:50 PM	Muddy Water

Storm Event Narratives

Storm: July 30, 2020

The total rainfall for this event was 0.60 inches and lasted approximately two and a half hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, seven of the parameter event mean concentrations (EMCs) were greater than their respective long-term average EMCs measured during storms monitored for the program (i.e., since December 12, 2012). The EMC for total phosphorus (TP) exceeded the long-term average EMC by 59%. The concentrations for TP were 0.42 mg/L (rising), 0.37 mg/L (peak), and 0.21 mg/L (falling) during the storm event. The lead concentrations for the storm measured 15.2 µg/L (rising), 22.5 µg/L (peak), and 5.8 µg/L (falling); the EMC exceeded the average by 134%. The EMC for zinc exceeded the long-term average EMC by 21%. The zinc concentrations were 184 µg/L (rising), 168 µg/L (peak), and 64.2 µg/L (falling). Total suspended solids (TSS) exceeded its long-term EMC by 41% with concentrations of 120 mg/L (rising), 130 mg/L (peak), and 30 mg/L (falling). Nitrate-nitrite exceeded its long-term EMC by just 4%. Biological oxygen demand (BOD) exceeded its long-term EMC by 167% with concentrations of 10 mg/L (rising), 9 mg/L (peak), and 10 mg/L (falling). The concentrations for copper were 30.0 µg/L (rising), 25.6 µg/L (peak), and 11.9 µg/L (falling); the EMC exceeded the long-term average by 38%. The high rainfall in a relatively short period of time, resulting in a high volume of discharge, may have liberated higher than usual suspended solids from the watershed. Phosphorus (typically present in fertilizers and historically in cleaning products) and metals (deposited from motor vehicles and leached from building materials) tend to bind to sediment, so increased TP and metals concentrations may be a consequence of increased TSS concentrations. High BOD concentrations are linked to excess production and decay of organic matter in the watershed, which is a result of the presence of high concentrations of nutrients. Additionally, Versar staff reported an odor of pesticides with the discharge from the outfalls, which may indicate that excessive pesticides were present and could also indirectly lead to elevated BOD.

At Parole Plaza, four of the parameter EMCs were greater than their respective long-term EMCs. BOD exceeded its long-term EMC by 144% with concentrations of 47 mg/L (rising), 5 mg/L (peak), and 7 mg/L (falling). Zinc exceeded its long-term EMC by 34% with concentrations of 362 µg/L (rising), 194 µg/L (peak), and 149 µg/L (falling). Copper exceeded its long-term EMC by 15% with concentrations of 41.9 µg/L (rising), 26.0 µg/L (peak), and 17.8 µg/L (falling). The highest concentrations of TSS, BOD, and metals occurred during the rising limb, indicating that stored and deposited urban pollutants were mobilized during the initial phase of intense rainfall (0.41 inches in less than 15 minutes) and resulting runoff, and generally align with maximum concentration values at the Church Creek station. Note that there were no continuous water quality data recorded for the Parole Plaza station for most of this storm. Versar staff programming the sondes erroneously set the launch time in Eastern Standard Time (EST; via the laptop computer) instead of the prevailing Eastern Daylight Time. Most of the storm occurred before the sondes launched.

Storm: September 3, 2020

The total rainfall for this event was 0.62 inches. The storm lasted approximately five hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, eight parameters exceeded their long-term average EMCs. BOD exceeded the corresponding long-term average EMC by 90% with concentrations of 13 mg/L (rising), 4 mg/L (peak), and 7 mg/L (falling). TP concentrations were 0.36 mg/L (rising), 0.19 mg/L (peak), and 0.33 mg/L (falling); exceeding the long-term average EMC by 74%. TSS exceeded the long-term EMC by 72% with concentrations of 15 mg/L (rising), 50 mg/L (peak), and 110 mg/L (falling). Copper exceeded the long-term EMC by 18% with concentrations of 7.03 µg/L (rising), 6.6 µg/L (peak), and 20.7 µg/L (falling). Lead concentrations exceeded the long-term average EMC by 170% with concentrations of 5.8 µg/L (rising), 4.6 µg/L (peak), 19.7 µg/L (falling). Zinc concentrations were 52.0 µg/L (rising), 43.8 µg/L (peak), and 146 µg/L (falling). TPH was detected during the rising limb at Church Creek with a concentration of 6 mg/L. *Escherichia coli* exceeded its long-term average EMC by 84% with concentrations of 6,867 MPN/100 mL (rising), 12,033 MPN/100 mL (peak), and 11,199 MPN/100 mL (falling). The remaining three parameters did not exceed their long-term EMCs: hardness, nitrate-nitrite, and total Kjeldahl nitrogen. Except for TP and TPH, the maximum concentrations of the parameters discussed above occurred during the falling limb. Though the period of maximum rainfall intensity was similar to the July 30 storm (0.47 inches in less than 15 minutes), the rising limb concentrations may not have been highest because an initial passage of heavy rain, which occurred approximately two hours before the period of maximum rainfall intensity, may have flushed stored material out of the watershed. Additionally, peak flow rates during the period of maximum rainfall intensity were much higher than during the July 30 storm, possibly due to saturated ground from the first passage of (unrecorded) rain at approximately 16:50, which may have caused additional pollutants to be washed downstream and to be present during the falling limb sampling.

At Parole Plaza, just two of the parameters exceeded their respective long-term average EMCs. BOD exceeded its long-term EMC by 15% with concentrations of 4 mg/L (rising), 3 mg/L (peak), and 4 mg/L (falling). *E. coli* exceeded its long-term average EMC by just 10%. Concentrations of *E. coli* at the corrugated metal pipe (CMP) were 1,430 MPN/100 mL (rising), 1,576 MPN/100 mL (peak), and 4,106 MPN/100 mL (falling). At the reinforced concrete pipe (RCP), *E. coli* concentrations were much higher than at the CMP: 12,033 MPN/100 mL (rising), 8,164 MPN/100 mL (peak), 24,196 MPN/100 mL (falling). During this storm event, both the CMP and RCP showed slightly elevated pH values of between 7 and 8. Concentrations of pollutants at the Parole Plaza station, as they relate to runoff patterns, were different than those noted at Church Creek. Most parameters followed concentration patterns of highest concentrations occurring during the rising and peak limbs. However, the generally lower EMC values compared to long-term trends may indicate that urban pollutants stored in the catchment and onsite BMPs may have been released during the initial, unsampled phase of rain occurring about 16:50.

During the event, the Church Creek station experienced a brief loss of power from 16:55 to 18:55 EST, just before sampling. Consequently, all data, including level and rain gauge data, are missing from this interval. Additionally, likely during the outage period, the data cable from the YSI sonde in the pipe to the ISCO sampler was severed. Starting at 18:55 EST on September 3, 2020 the only data that were recorded by the ISCO sampler consisted of stream level and rainfall.

Storm: December 4, 2020

The total rainfall for this event was 1.62 inches. The storm lasted approximately 13 hours. These measurements were based on data from the Church Creek rain gauge.

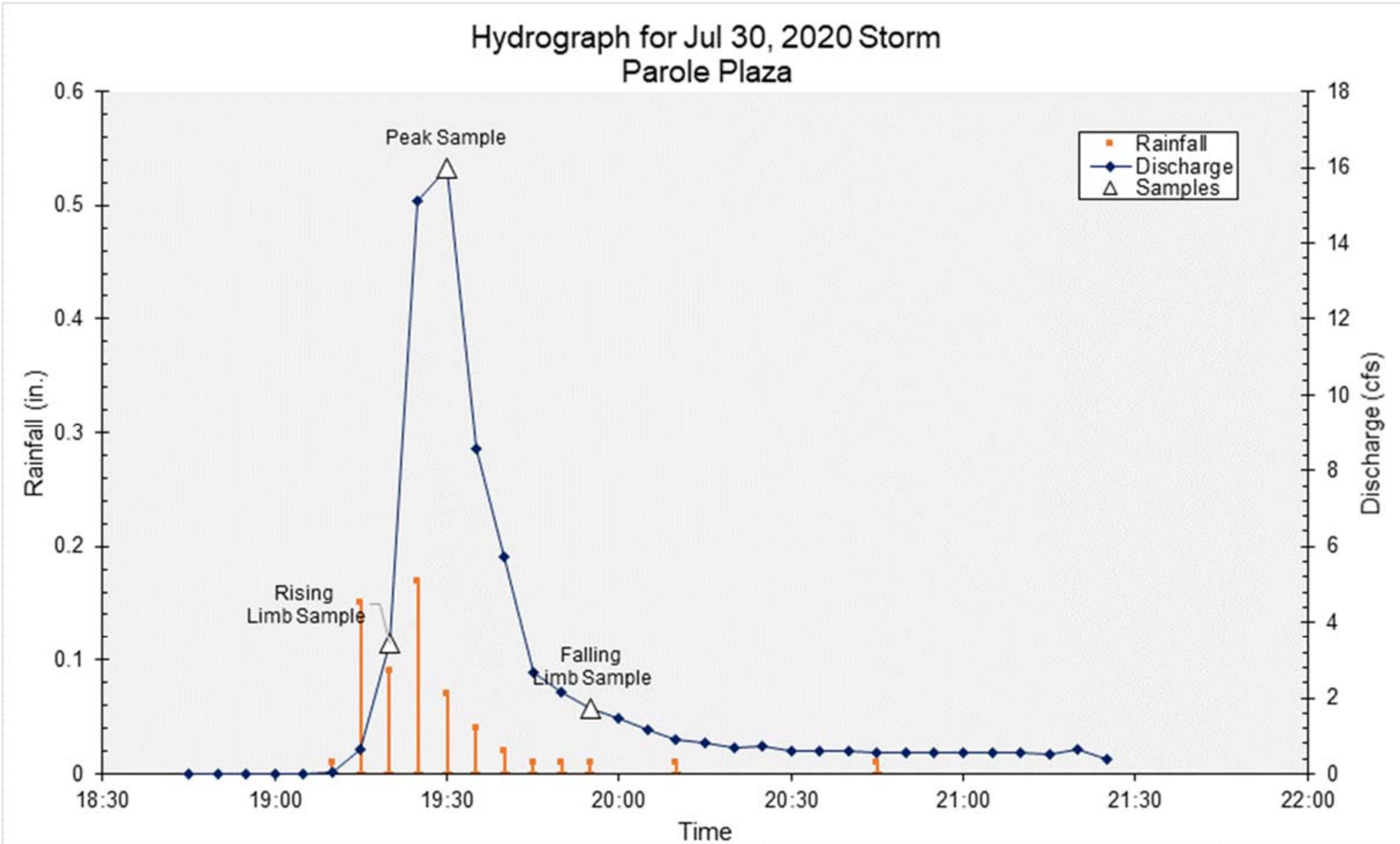
None of the parameter long-term EMCs were exceeded at either station during this storm event, indicating that the gradual nature of the storm did not cause inordinately high pollutant levels to be mobilized from impervious surfaces or the stream channel. Note that the EMC calculations may also have been affected by a change in relative discharge amounts for the limbs as a result of an update to the stage to discharge rating curve.

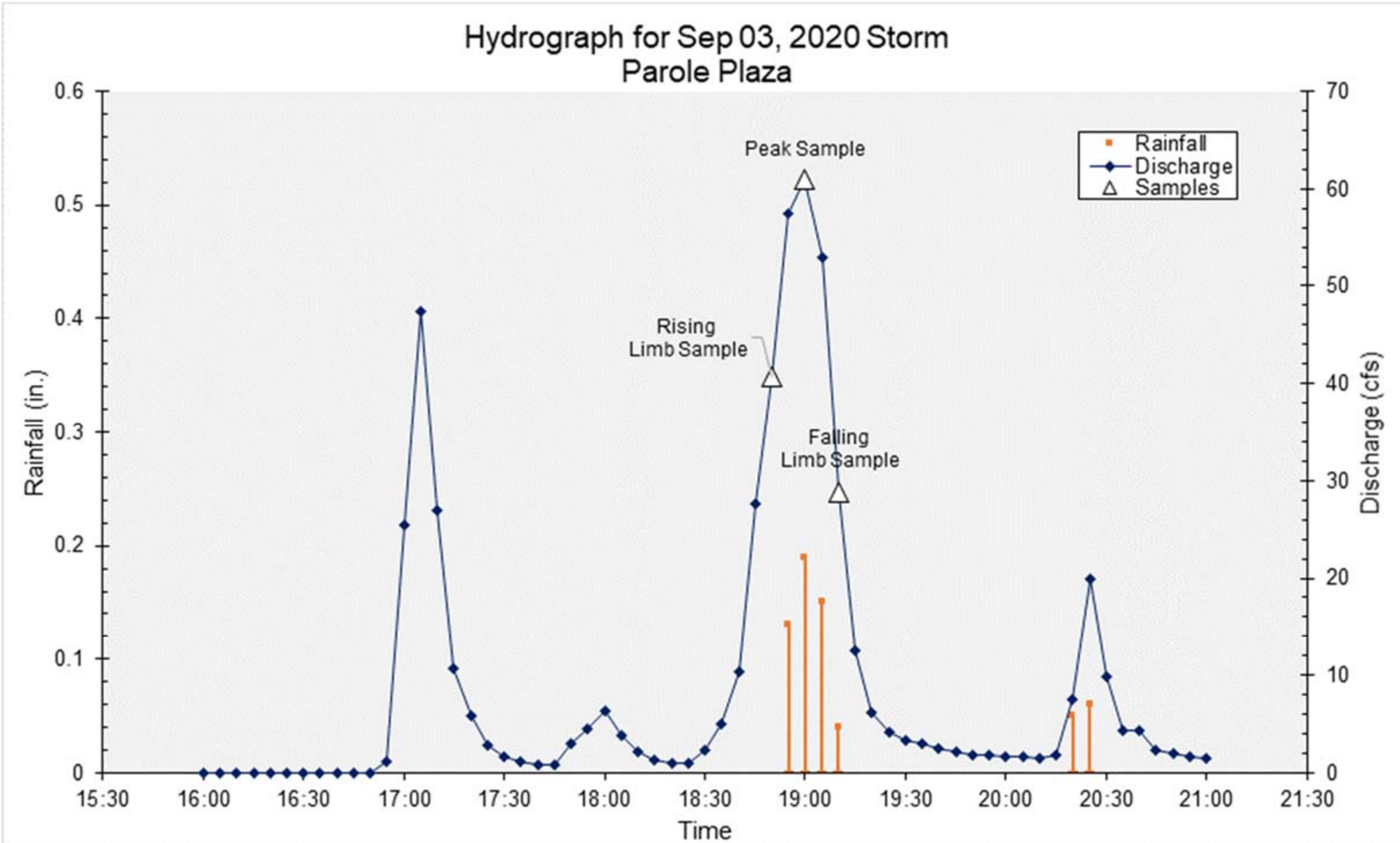
Storm: March 18, 2021

The total rainfall for this event was 0.19 inches and lasted approximately 5.5 hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, six of the parameters exceeded their respective long-term average EMCs. BOD exceeded the long-term average by just 3% with concentrations of 3 mg/L (rising), 5 mg/L (peak), and 2 mg/L (falling). Nitrate-Nitrite exceeded the long-term average by 67% with concentrations of 1.2 mg/L (rising), 0.74 mg/L (peak), and 0.51 mg/L (falling). Total phosphorus exceeded the long-term average by 14% with concentrations of 0.16 mg/L (rising), 0.24 mg/L (peak), and 0.12 mg/L (falling). Copper had concentrations of 11.9 µg/L (rising), 23.2 µg/L (peak), and 14.9 µg/L (falling), which together exceeded the long-term average by 63%. Zinc exceeded the long-term average by 22% with concentrations of 91.2 µg/L (rising), 105 µg/L (peak), and 87.4 µg/L (falling). Hardness exceeded the long-term average by 48% with concentrations of 140 mg/L (rising), 72 mg/L (peak), and 54 mg/L (falling).

At Parole Plaza, five of the parameters exceeded their respective long -term average EMCs. BOD exceeded the long-term average by 26% with concentrations of 18 mg/L (rising), 3 mg/L (peak), and 2 mg/L (falling). Nitrate-nitrite exceeded the long-term average by 26% with concentrations of 1.6 mg/L (rising), 0.45 mg/L (peak), and 0.54 mg/L (falling). Total phosphorus exceeded the long-term average by 18% with concentrations of 0.21 mg/L (rising), 0.13 mg/L (peak), and 0.11 mg/L (falling). The copper EMC exceeded the long-term average by 69% with concentrations of 81.1 µg/L (rising), 29.3 µg/L (peak), and 24.4 µg/L (falling). Zinc exceeded the long-term average by 21% with concentrations of 287 µg/L (rising), 156 µg/L (peak), and 126 µg/L (falling). Note that this storm was much smaller in size than the December event, but it occurred after a 17-day period of no precipitation, which may have allowed substantial amounts of fine particulate matter and pollutants to accumulate on surfaces. The resulting washoff of pollutants affected both the commercial area around Parole Plaza and the Church Creek watershed as a whole. Due to an error in synchronizing sondes with the field laptop computer prior to the storm event, no water quality data were collected for either pipe at this station. The error was discovered when attempting to extract data from the sondes after the storm event.


Hydrograph for Jul 30, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
18
16
14
12
10
8
6
4
2
0
18:30
19:00
19:30
20:00
20:30
21:00
21:30
22:00


Hydrograph for Sep 03, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
70
60
50
40
30
20
10
0
15:30
16:00
16:30
17:00
17:30
18:00
18:30
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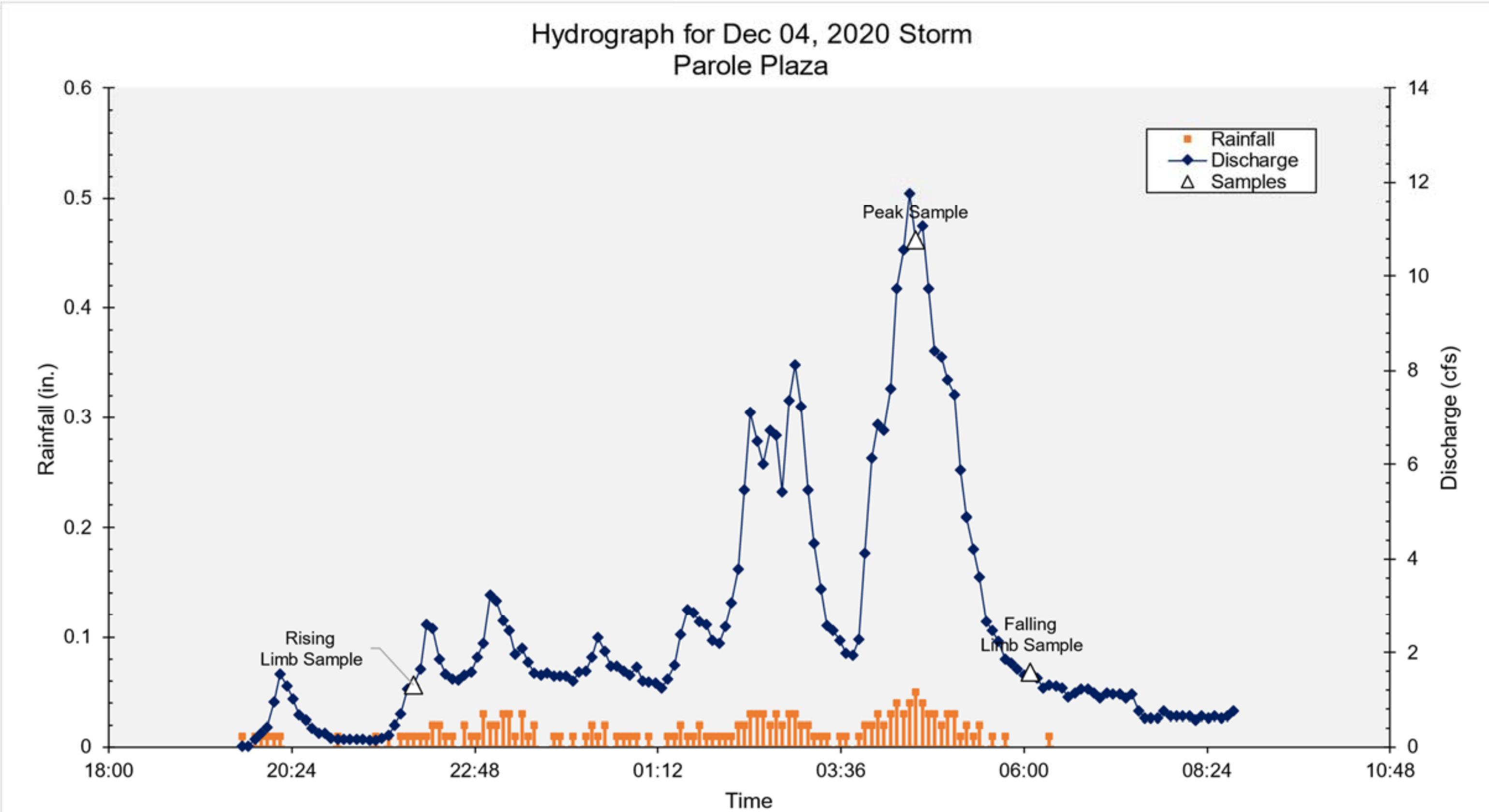
20:30
21:00
21:30


Hydrograph for Dec 04, 2020 Storm
Parole Plaza
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
14
12
10
8
6
4
2
0
18:00
20:24
22:48
01:12
03:36
06:00
08:24
10:48
Rainfall
Discharge
Samples
Rising
Limb Sample
Peak Sample
Falling
Limb Sample

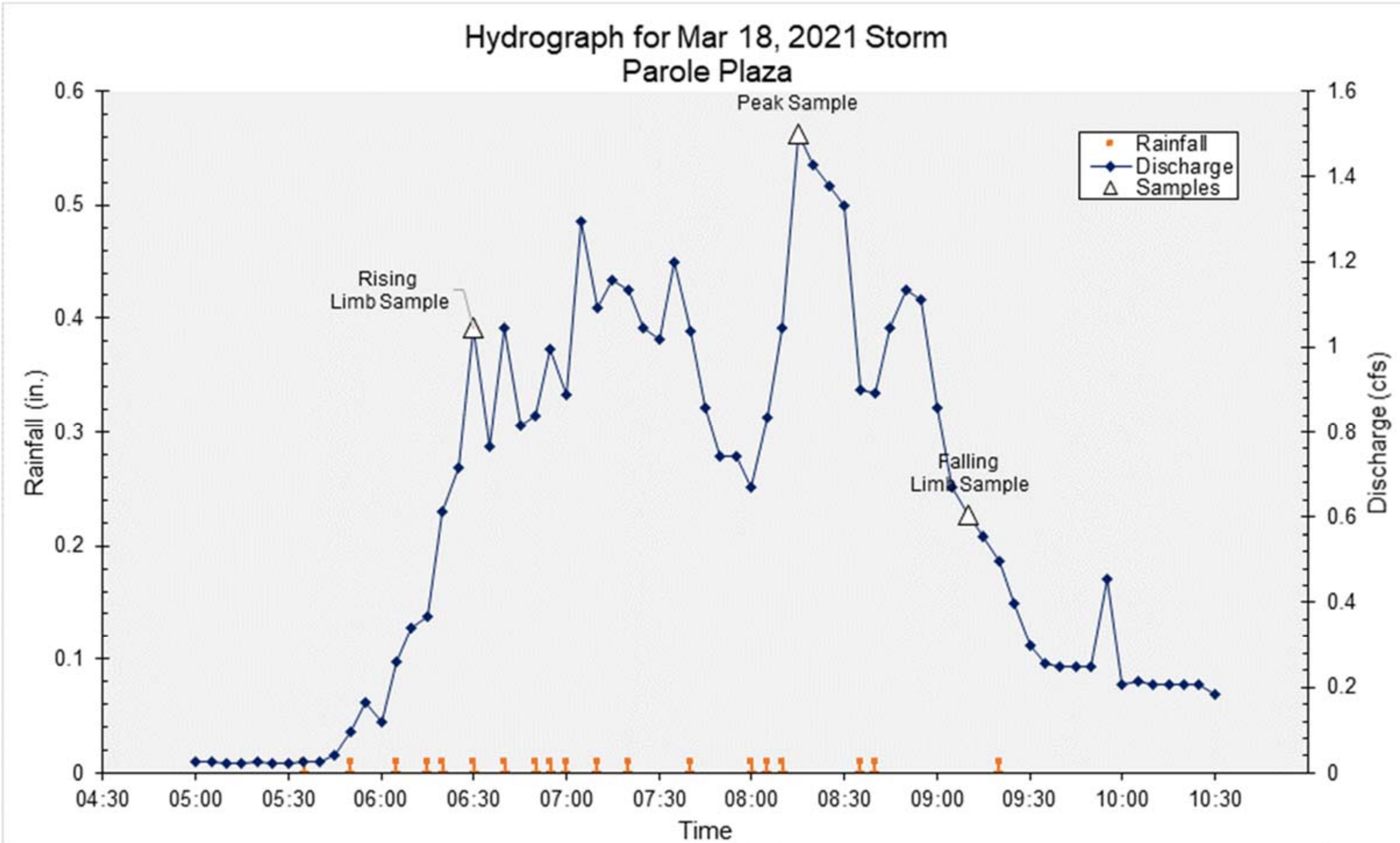
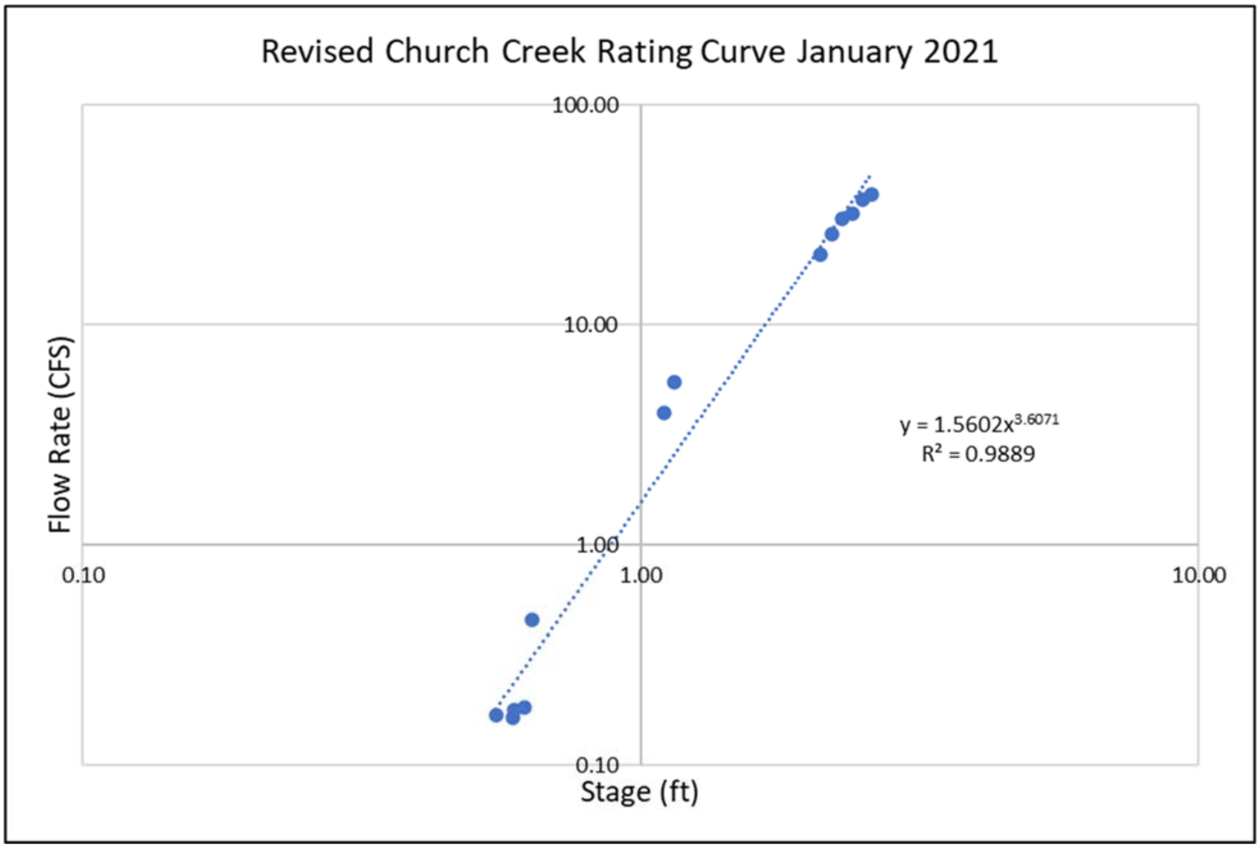
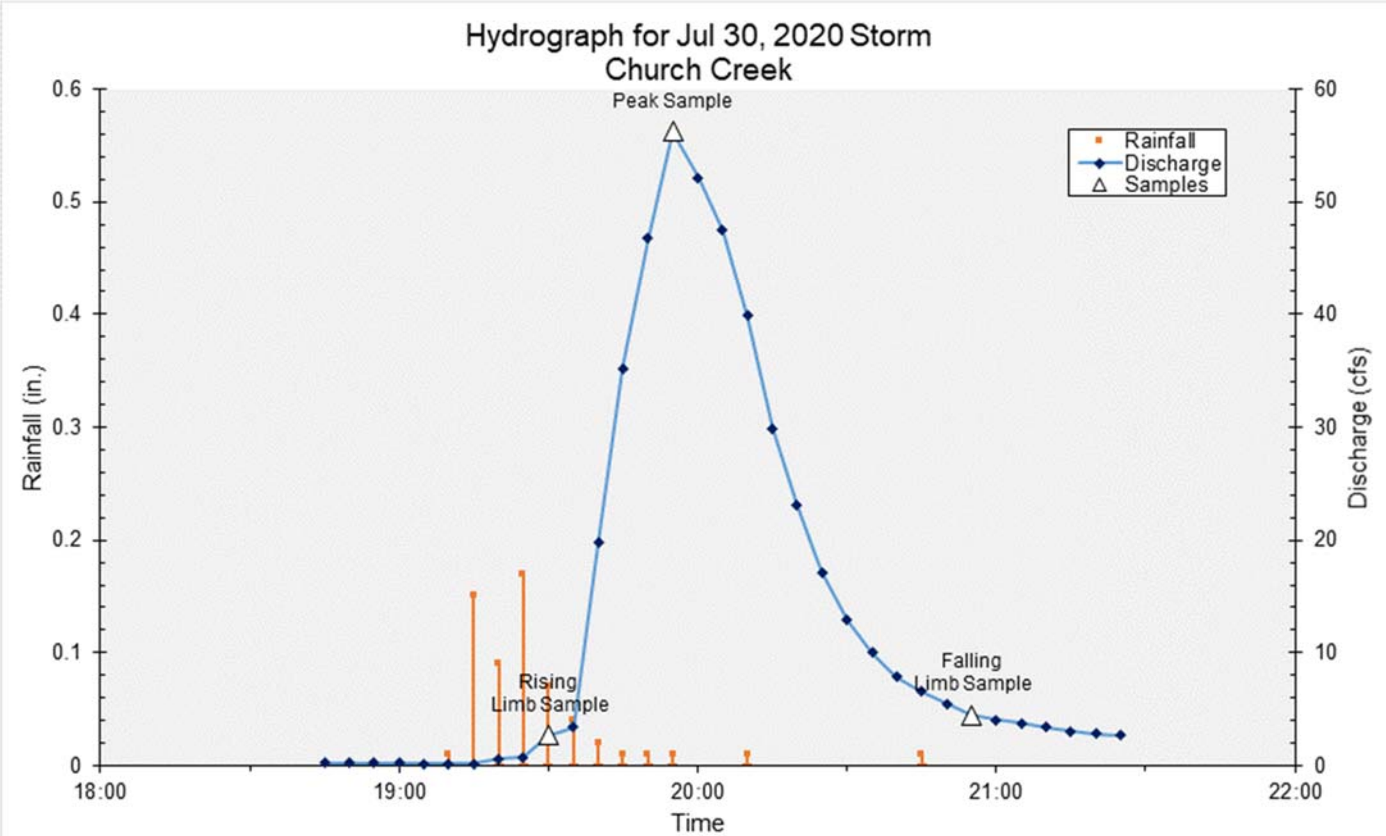
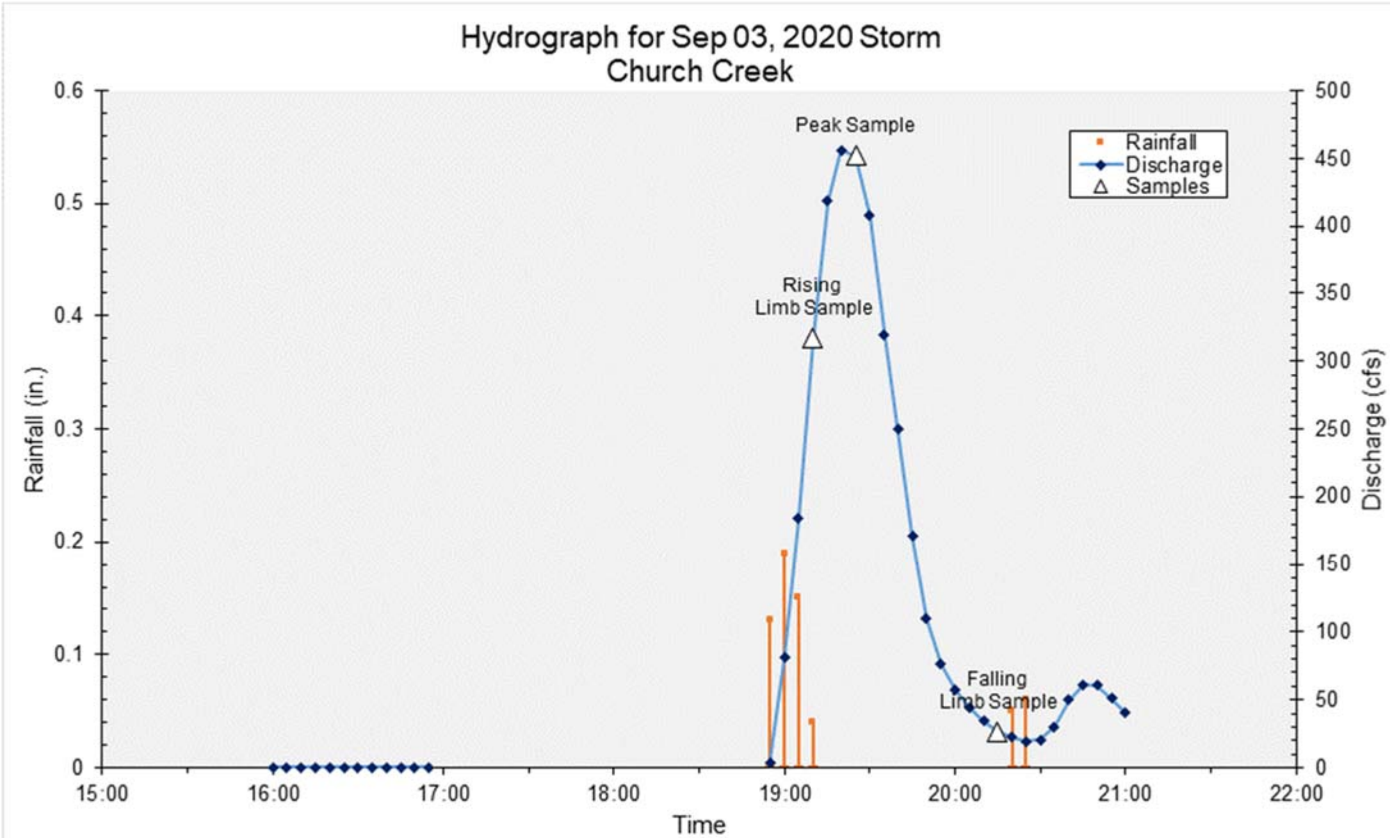

Hydrograph for Mar 18, 2021 Storm
Parole Plaza
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall
Discharge
Samples
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
04:30
05:00
05:30
06:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30

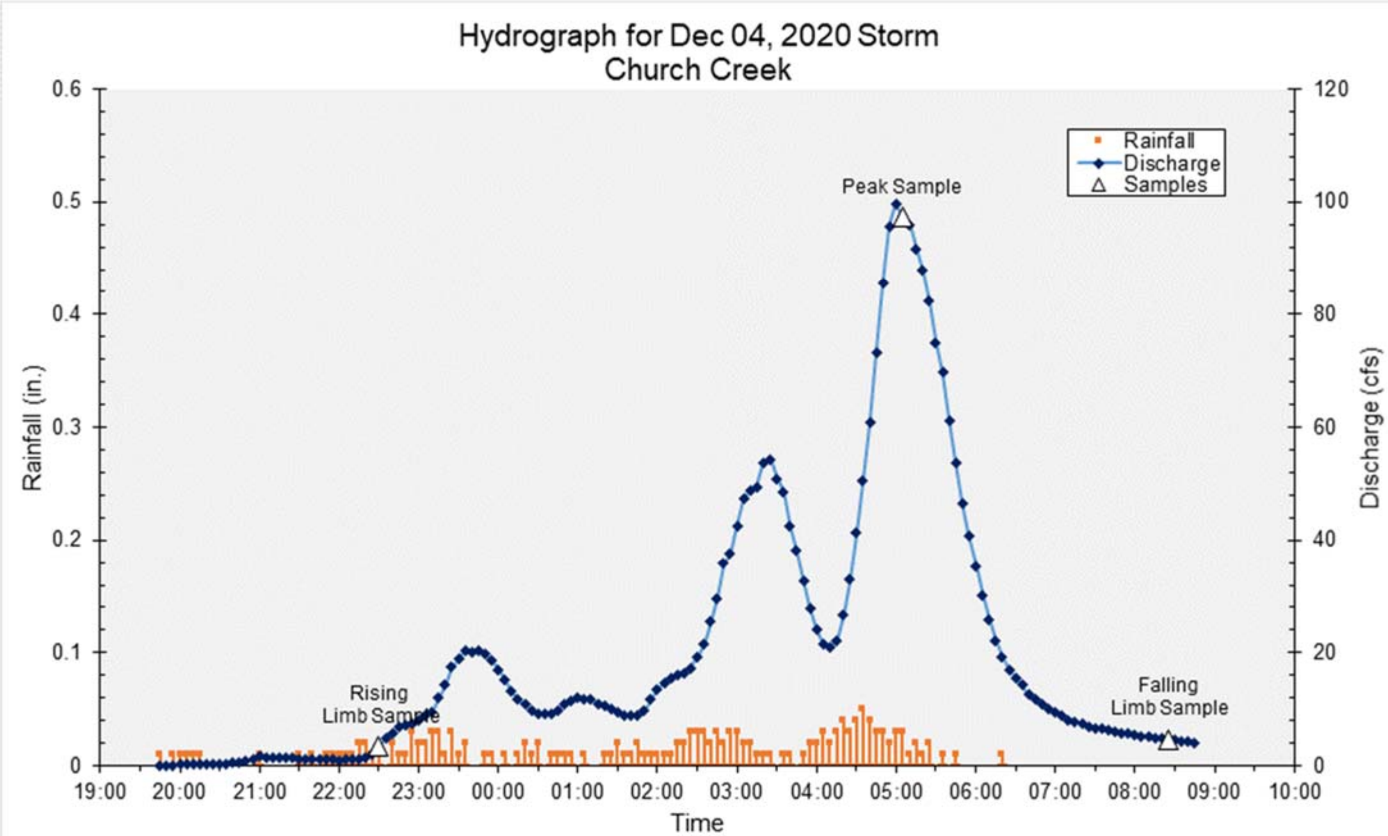
Table A-1. Updated Church Creek rating curve	
Stage (ft)	**Discharge (CFS)**
0.4	0.02
0.5	0.13
0.6	0.25
0.7	0.43
0.8	0.70
0.9	1.07
1	1.56
1.1	2.20
1.2	3.01
1.3	4.02
1.4	5.25
1.5	6.74
1.6	8.50
1.7	10.58
1.8	13.00
1.9	15.80
2	19.01
2.1	22.67
2.2	26.81
2.3	31.48
2.4	36.70
2.5	42.52
2.6	48.98
2.7	56.12
2.8	63.99
2.9	72.63
3	82.07
3.1	92.38
3.2	103.59
3.3	115.75
3.4	128.91
3.5	143.12
3.6	158.42
3.7	174.88

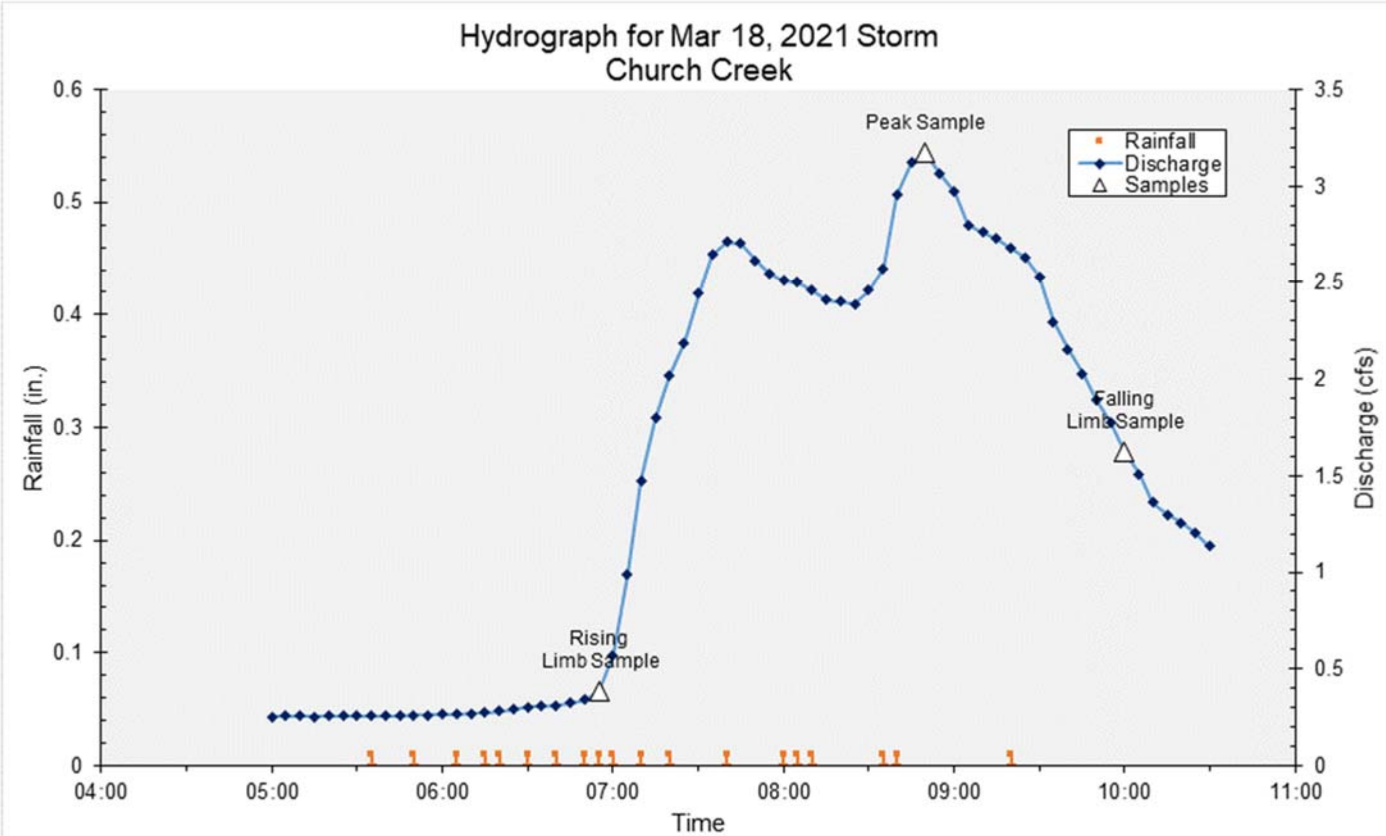

Revised Church Creek Rating Curve January 2021
100.00
10.00
1.00
0.10
0.10
1.00
10.00
Flow Rate (CFS)
Stage (ft)
y = 1.5602x^3.6071
R² = 0.9889



Hydrograph for Jul 30, 2020 Storm
Church Creek
Peak Sample
Rainfall
Discharge
Samples
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
60
50
40
30
20
10
0
18:00
19:00
20:00
21:00
22:00


Hydrograph for Sep 03, 2020 Storm
Church Creek
Rainfall (in.)
Discharge (cfs)
Time
Peak Sample
Rising Limb Sample
Falling Limb Sample
Rainfall
Discharge
Samples
0.6
0.5
0.4
0.3
0.2
0.1
0
500
450
400
350
300
250
200
150
100
50
0
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00


Hydrograph for Dec 04, 2020 Storm
Church Creek
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
120
100
80
60
40
20
0
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00


Hydrograph for Mar 18, 2021 Storm
Church Creek
Rainfall
Discharge
Samples
Peak Sample
Rising Limb Sample
Falling Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
3.5
3
2.5
2
1.5
1
0.5
0
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00

APPENDIX B

QA/QC INFORMATION

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Quality Assurance/Quality Control Summary for NPDES Monitoring Activities

This section describes all Quality Assurance/Quality Control (QA/QC) procedures implemented for this project including field sampling, laboratory sorting and subsampling, data entry, metric calculation, final IBI calculation, geomorphic field sampling, and classification of stream types.

Storm Monitoring

The field manager routinely reviews all QA/QC materials and provides them both verbally and in writing to all staff involved in storm events at the internal kickoff meeting at the start of each sampling year and during storm events. New Versar staff are briefed on all protocols prior to involvement in field work for Anne Arundel County. Project specific SOPs are also available at all times to all field staff in binders located at the project site. These SOPs are updated as necessary by the field crew leader and approved by either the project manager or the QA/QC officer. Verbal reminders of specific QA/QC policies – and any changes or updates – will be made by the field crew leader prior to staff deployment on all storm events. Additionally, staff are cross trained in all tasks involving stormwater monitoring in order to provide back-up to others on all QA/QC procedures.

Geomorphological Field Sampling and Assessments

Geomorphic assessment field crews have more than one year of experience conducting similar assessment using the Rosgen Stream Classification Methodology and final data QA/QC is performed by staff with two or more levels of Rosgen training.

Geomorphic assessment survey equipment is calibrated annually and regularly inspected to ensure proper functioning. Cross-section and profile data were digitally plotted and analyzed in Ohio Department of Natural Resources (ODNR) Reference Reach Spreadsheet Version 4.3L for accuracy.

Data Entry

All data entered were double checked by someone other than the person who performed the initial data entry. Any errors found during QA/QC were corrected to ensure 100% accuracy of the data.

Identification of Stream Types

All stream types were determined by hand based on the methods of the Rosgen Stream Classification (Rosgen 1996). Due to the natural variability, or continuum, of streams, adjustments in the values of Width Depth Ratio (+/- 2.0) and Entrenchment Ratio (+/-0.2) are allowed, which may result in assigning a different stream type. Therefore, all stream types assigned were checked and any necessary adjustments were made.

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APPENDIX C

ROSGEN CLASSIFICATION SCHEME

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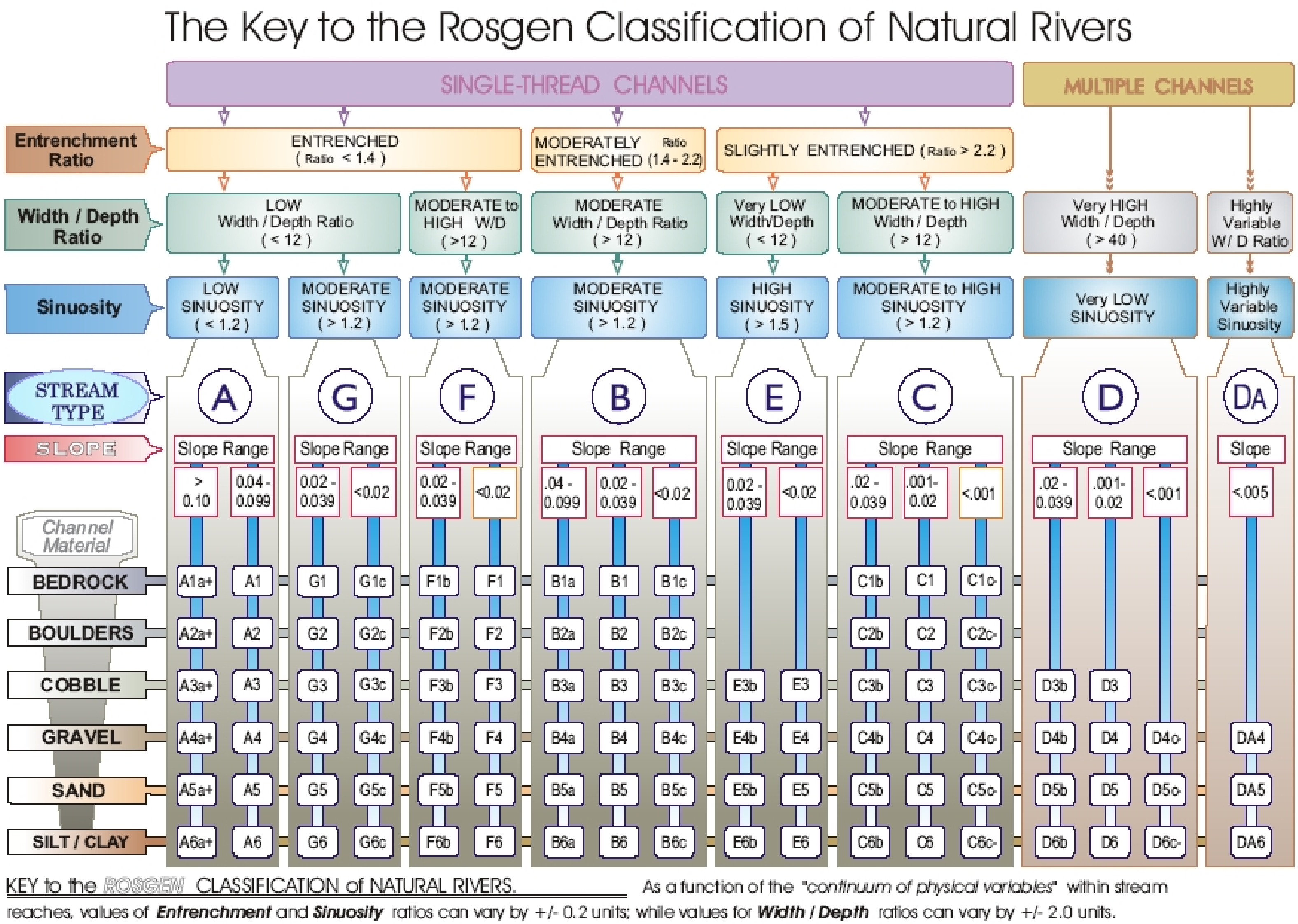

Source: Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

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APPENDIX D

GEOMORPHOLOGICAL DATA

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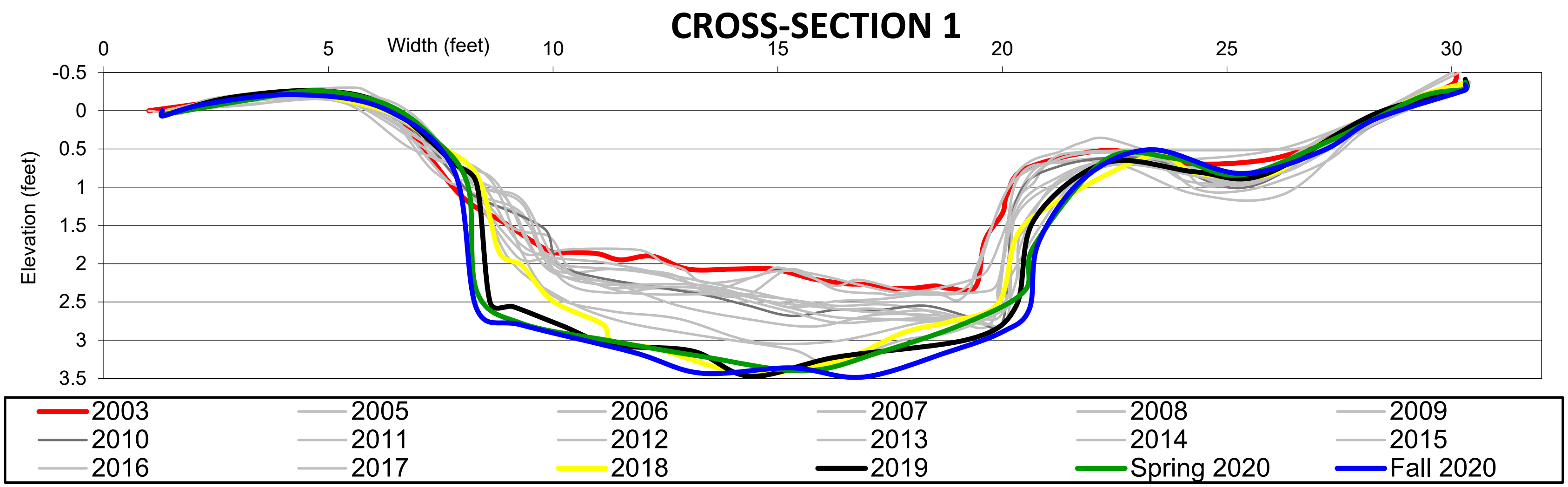
Church Creek
Fall 2020 Geomorphic Assessment Results Summary

Assessment Parameter	Cross-section					
	XS-1 Pool @ sta 3+70.5	XS-1D Riffle @ sta 5+24.8	XS-2 Riffle @ sta 6+81	XS-3 Pool @ sta 11+00	XS-4 Pool @ sta 13+53	XS-5 Glide @ sta 17+12
Classification	F5	F5	G4c	G5c	E5	F4
Bankfull Width (ft)	12.7	8.9	7.0	6.7	8.5	10.5
Mean Depth (ft)	1.4	0.5	0.7	0.8	1.1	0.7
Bankfull X-Sec Area (sq ft)	17.8	4.5	4.8	5.5	9.2	6.9
Width:Depth Ratio	9.1	17.6	10.1	8.0	7.8	15.9
Flood-Prone Width (ft)	13.9	12.2	9.1	8.9	9.6	14.8
Entrenchment Ratio	1.1	1.4	1.3	1.3	1.1	1.4
D50(mm)	1.2	0.38	7.7	1.3	1.1	25.0
Water Surface Slope (ft/ft)	0.0025	0.006	0.0093	0.013	0.0002	0.01
Sinuosity	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
Drainage Area (mi2)	0.111	0.112	0.113	0.121	0.130	0.441
Adjustments?	Sin ↑, W/D ↑, ER ↑	Sin ↑	Sin ↑	Sin ↑	Sin ↑, ER ↑	Sin ↑, ER ↓



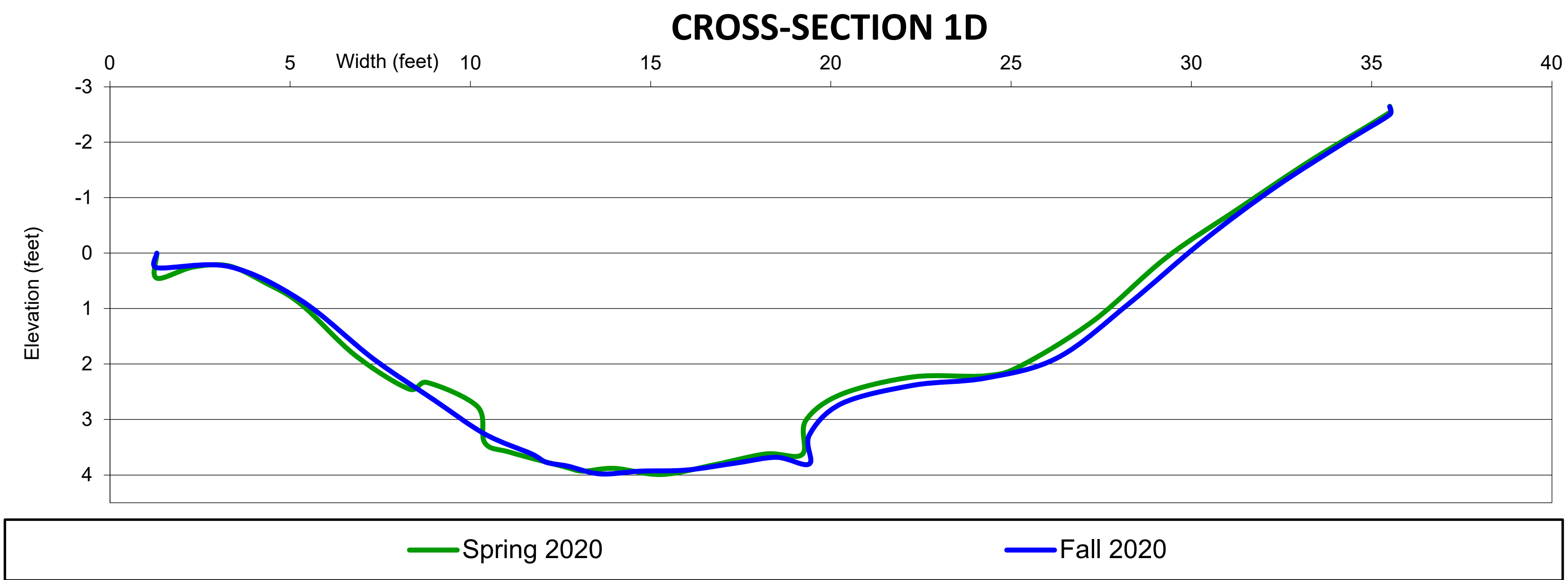
Upstream View

Downstream View

Left Bank View

Right Bank View

Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	12.7
Mean Depth (d_{bkf}) (feet)	1.4
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	17.8
Width/Depth Ratio (W_{bkf}/d_{bkf})	9.1
Width of Flood-prone Area (W_{fpa}) (feet)	13.9
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.1
Channel Materials D_{50} (millimeters)	1.2
Water Surface Slope (S)	0.0025
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, W/D ↑, ER ↑
STREAM TYPE	**F5**



Upstream View

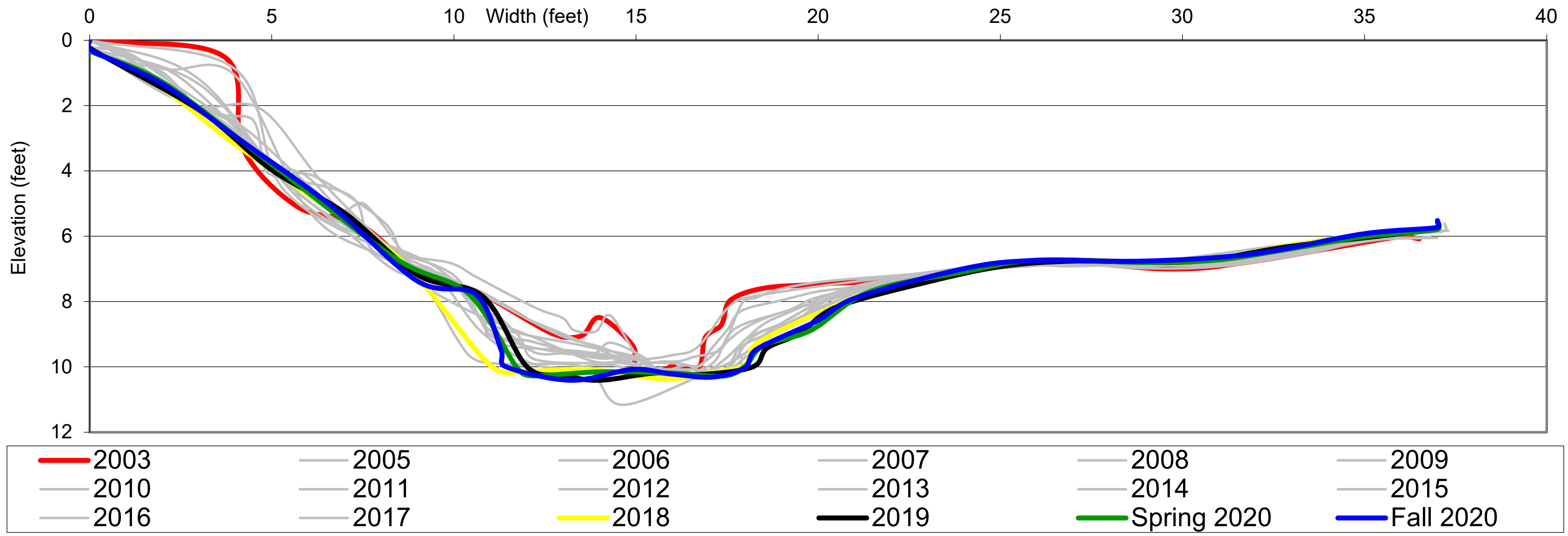
Downstream View

Left Bank View

Right Bank View

Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	8.9
Mean Depth (d_{bkf}) (feet)	0.5
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	4.5
Width/Depth Ratio (W_{bkf}/d_{bkf})	17.6
Width of Flood-prone Area (W_{fpa}) (feet)	12.2
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.4
Channel Materials D_{50} (millimeters)	0.38
Water Surface Slope (S)	0.006
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑
STREAM TYPE	**F5**

CROSS-SECTION 2



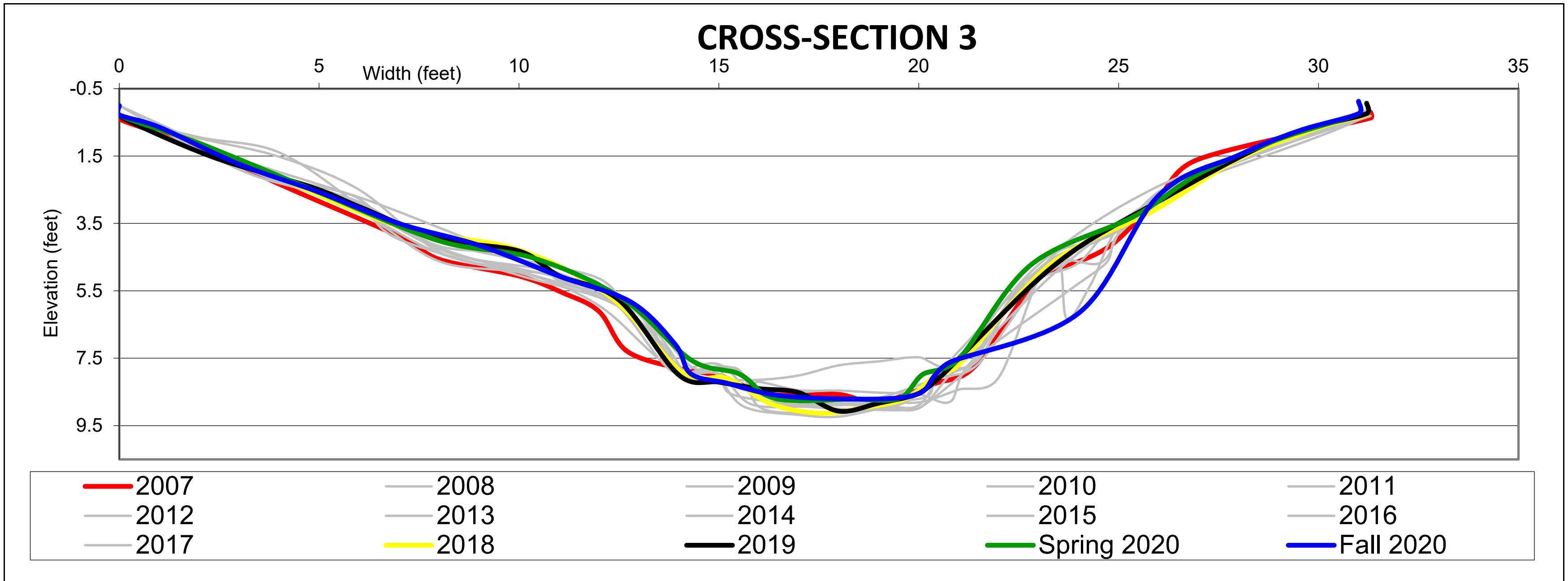
Upstream View

Downstream View

Left Bank View

Right Bank View

Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	7.0
Mean Depth (d_{bkf}) (feet)	0.7
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	4.8
Width/Depth Ratio (W_{bkf}/d_{bkf})	10.1
Width of Flood-prone Area (W_{fpa}) (feet)	9.1
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.3
Channel Materials D_{50} (millimeters)	7.7
Water Surface Slope (S)	0.0093
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑
STREAM TYPE	**G4c**



Upstream View

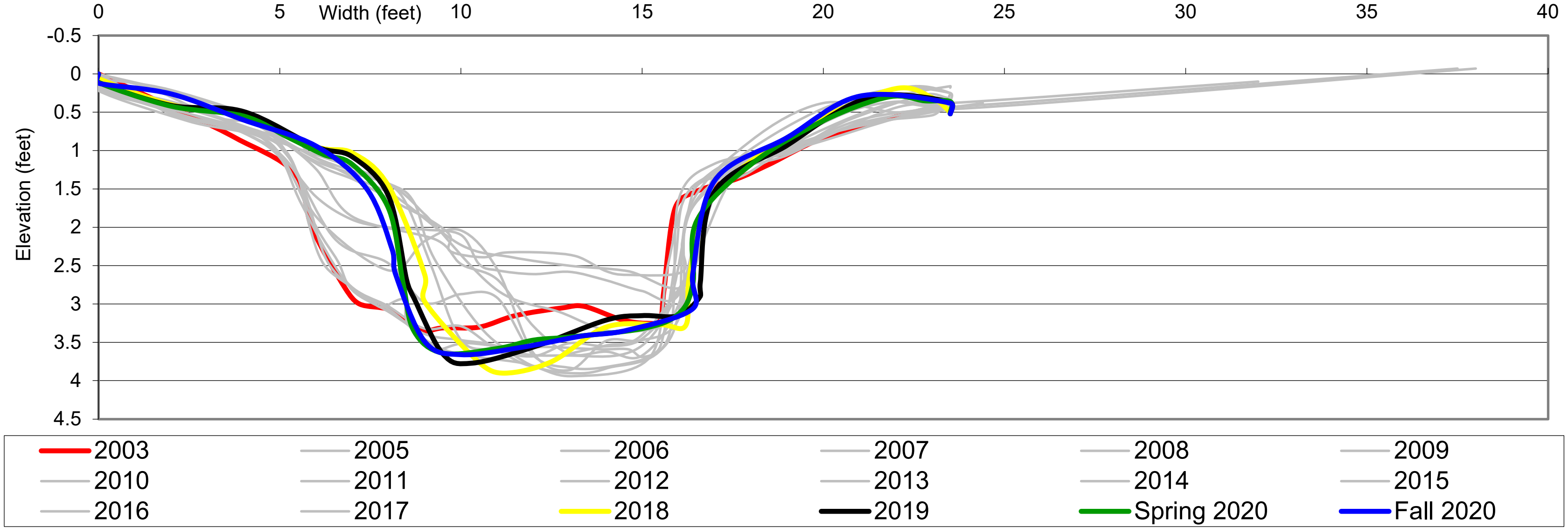
Downstream View

Left Bank View

Right Bank View

Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	6.7
Mean Depth (d_{bkf}) (feet)	0.8
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	5.5
Width/Depth Ratio (W_{bkf}/d_{bkf})	8.0
Width of Flood-prone Area (W_{fpa}) (feet)	8.9
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.3
Channel Materials D_{50} (millimeters)	1.3
Water Surface Slope (S)	0.013
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑
STREAM TYPE	**G5c**

CROSS-SECTION 4



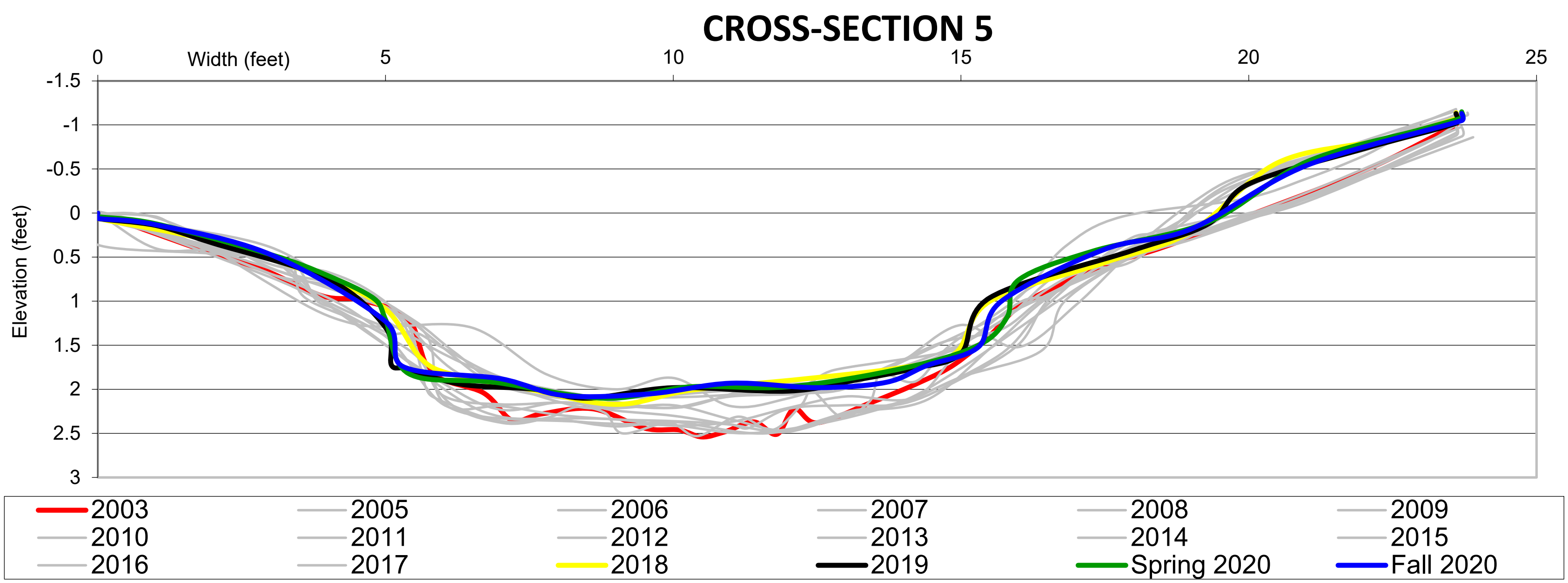

Upstream View


Downstream View


Left Bank View


Right Bank View

Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	8.5
Mean Depth (d_{bkf}) (feet)	1.1
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	9.2
Width/Depth Ratio (W_{bkf}/d_{bkf})	7.8
Width of Flood-prone Area (W_{fpa}) (feet)	9.6
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.1
Channel Materials D_{50} (millimeters)	1.1
Water Surface Slope (S)	0.0002
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, ER ↑
STREAM TYPE	**E5**



Upstream View

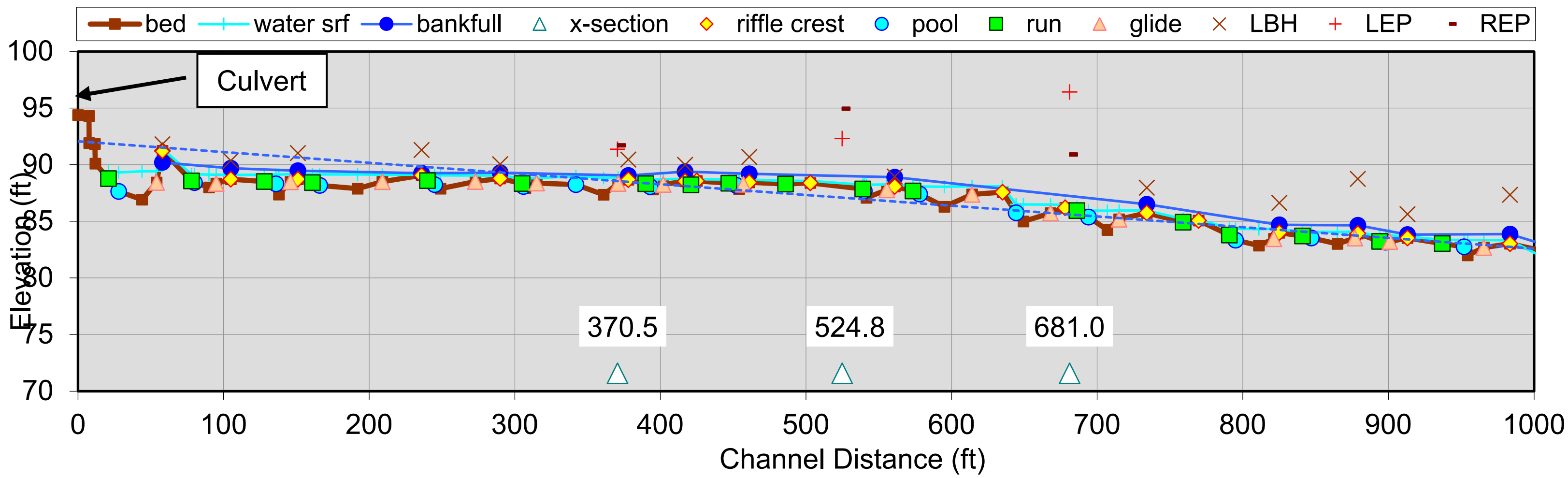
Downstream View

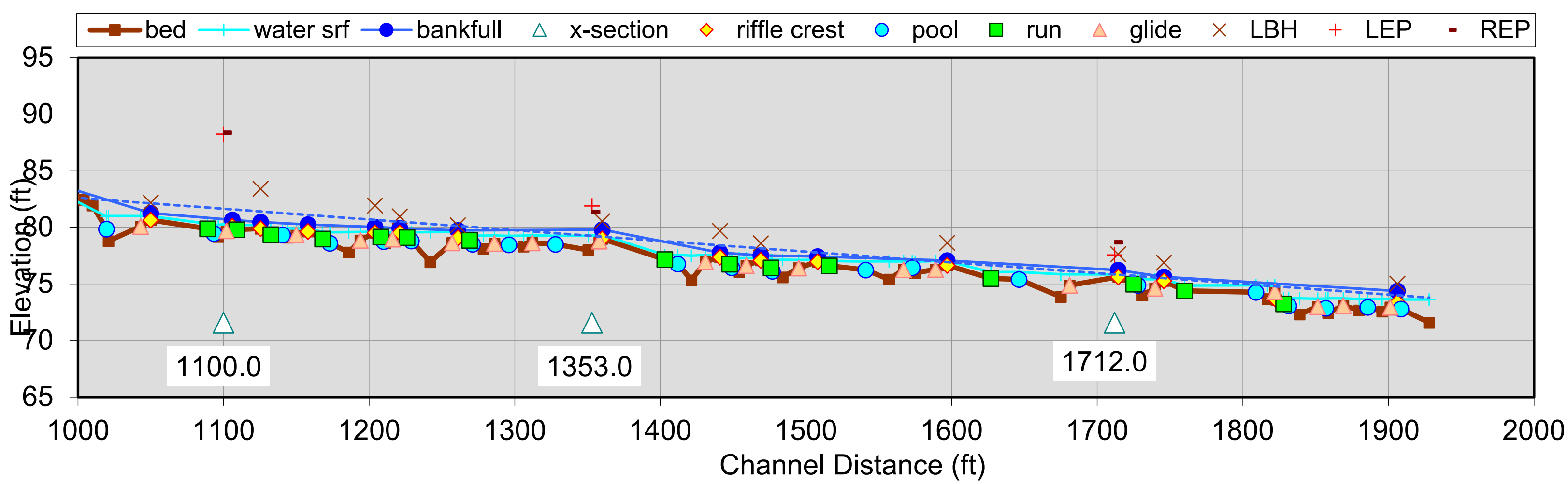
Left Bank View

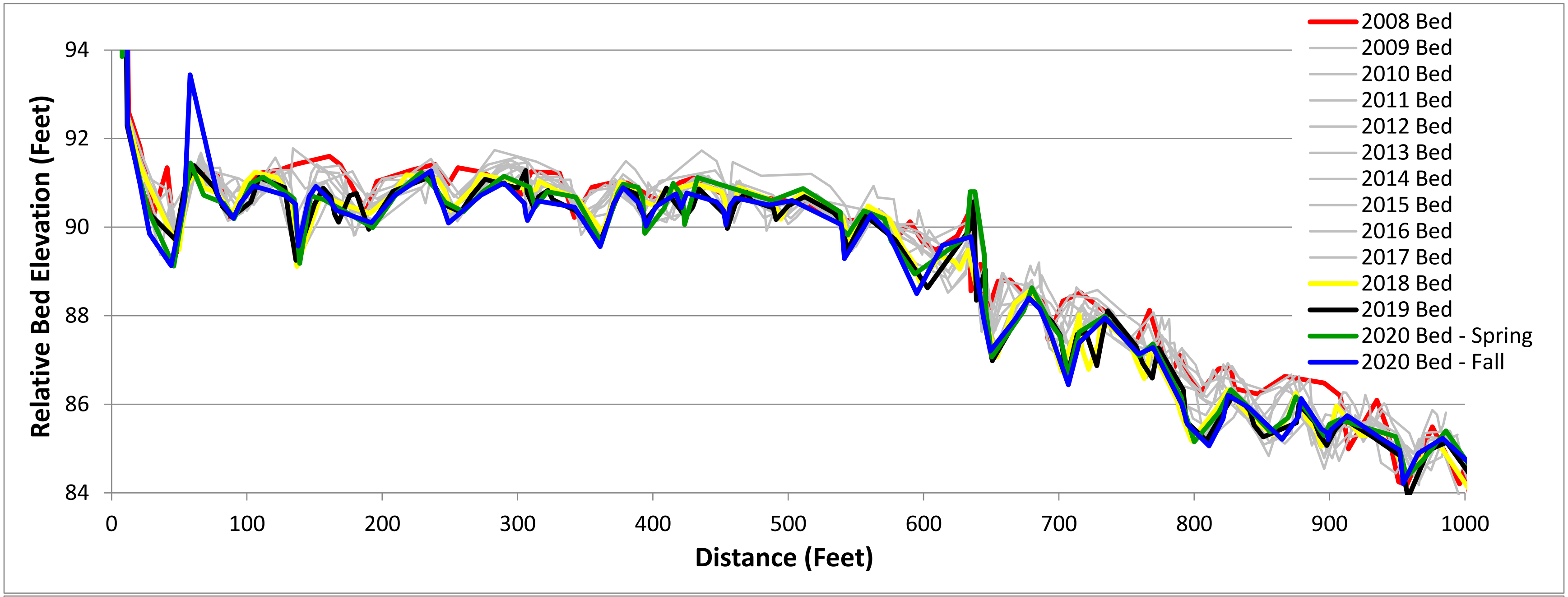
Right Bank View

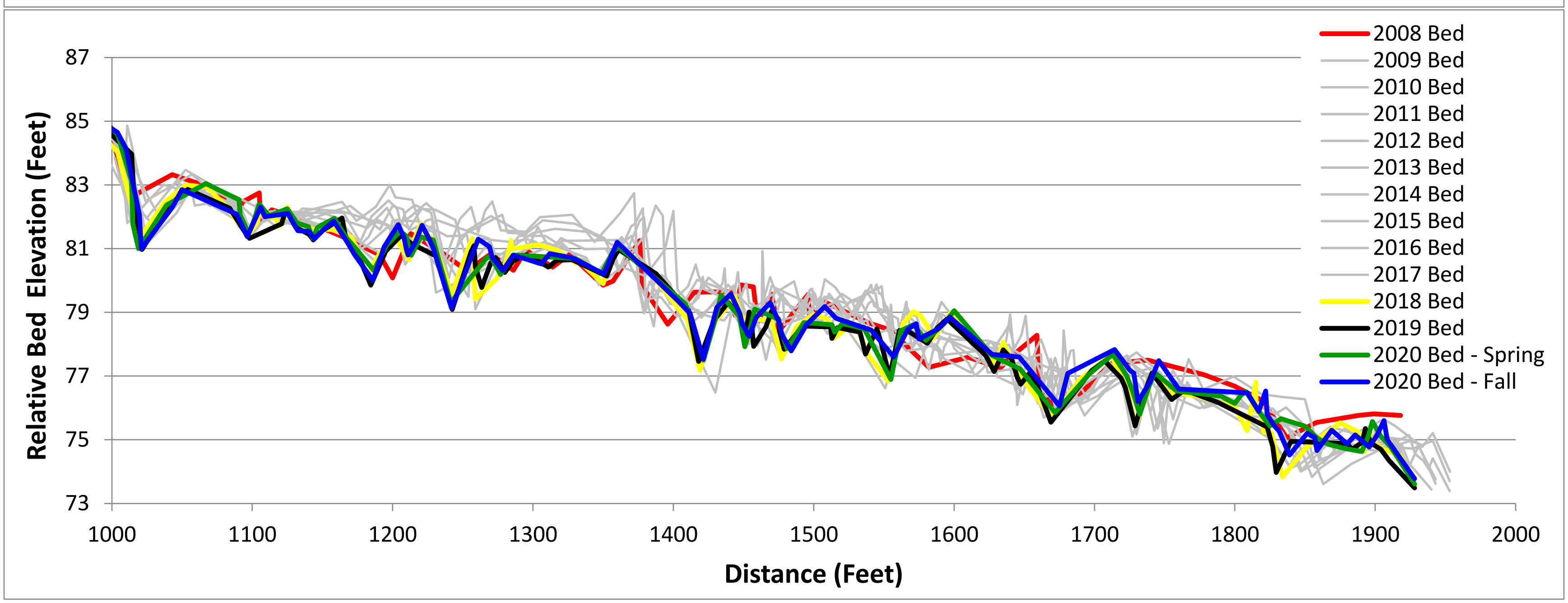
Fall 2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	10.5
Mean Depth (d_{bkf}) (feet)	0.7
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	6.9
Width/Depth Ratio (W_{bkf}/d_{bkf})	15.9
Width of Flood-prone Area (W_{fpa}) (feet)	14.8
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.4
Channel Materials D_{50} (millimeters)	25.0
Water Surface Slope (S)	0.01
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, ER ↓
STREAM TYPE	**F4**

Church Creek Longitudinal Profile






2008 Bed
2009 Bed
2010 Bed
2011 Bed
2012 Bed
2013 Bed
2014 Bed
2015 Bed
2016 Bed
2017 Bed
2018 Bed
2019 Bed
2020 Bed - Spring
2020 Bed - Fall
Relative Bed Elevation (Feet)
94
92
90
88
86
84
0
100
200
300
400
500
600
700
800
900
1000
Distance (Feet)


2008 Bed
2009 Bed
2010 Bed
2011 Bed
2012 Bed
2013 Bed
2014 Bed
2015 Bed
2016 Bed
2017 Bed
2018 Bed
2019 Bed
2020 Bed - Spring
2020 Bed - Fall
Relative Bed Elevation (Feet)
87
85
83
81
79
77
75
73
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Distance (Feet)

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APPENDIX E

CHEMICAL MONITORING RESULTS

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Anne Arundel County NPDES
Sampling Data – 2021 Reporting Year
Parole Plaza Station

Station	SampleDate	SampleTime	QuarterYear	Limb	Storm_Base	Depth	Duration	Intensity	Temperature	Flow	pH	BOD	TKN	Nitrate Nitrite	TP	TSS	Copper	Lead	Zinc	TPH	Hardness	*E. coli*
						Inches	Hours	in/hr	°F	CF	pH	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	MPN/100 mL
AP	7/30/2020	20:20	2020Q3	ST1	Storm	0.6	2.67	0.23		745		47	4.3	1.3	0.32	52	41.9	3.9	362	<5	86	1,949
AP	7/30/2020	20:30	2020Q3	ST2	Storm					7,448		5	<0.5	0.33	0.1	17	26.0	<2	194	<5	48	3,846
AP	7/30/2020	20:55	2020Q3	ST3	Storm					8,388		7	<0.5	0.38	0.12	11	17.8	<2	149	<5	31	2,108
AP	9/3/2020	19:50	2020Q3	ST1	Storm	0.62	5	0.12	79.43	64,242	7.9	4	<0.5	0.11	0.09	28	7.4	2.3	64	<5	24	6,633
AP	9/3/2020	20:00	2020Q3	ST2	Storm				78.07	32,498	8.0	3	<0.5	0.09	0.11	20	7.3	2.6	68	<5	16	6,293
AP	9/3/2020	20:10	2020Q3	ST3	Storm				78.04	29,336	7.9	4	<0.5	0.11	0.11	11	5.6	<2	55	<5	13	22,095
AP	9/28/2020	11:55	2020Q3	MM	Baseflow				70.94	4	7.2	5	<0.5	3.4	0.02	5	7.8	<2	101	<5	180	930
AP	10/28/2020	14:20	2020Q4	MM	Baseflow				63.32	2	6.3	<2	<0.5	5.2	<0.01	<1	3.7	<2	109	<5	320	2
AP	12/4/2020	22:00	2020Q4	ST1	Storm	1.62	13	0.12	53.20	3,791	7.0	4	<0.5	0.39	0.09	22	13.9	<2	118	<5	48	747
AP	12/5/2020	4:35	2020Q4	ST2	Storm				47.39	79,311	7.4	<2	<0.5	0.31	0.09	8	3.7	<2	54	<5	35	4,406
AP	12/5/2020	6:05	2020Q4	ST3	Storm				48.89	27,531	6.5	<2	<0.5	0.18	0.07	5	3.7	<2	40	<5	20	4,428
AP	12/30/2020	12:00	2020Q4	MM	Baseflow				55.76	2	6.7	<2	<0.5	5.2	<0.01	<1	2.5	<2	119	<5	300	<10
AP	2/25/2021	11:45	2021Q1	MM	Baseflow				55.94	7	7.2	<2	<0.5	4.6	<0.01	4	<2	<2	122	<5	320	>1
AP	3/18/2021	6:30	2021Q1	ST1	Storm	0.19	5.5	0.03		1,035		18	1.7	1.6	0.21	43	81.1	3.5	287	<5	57	28
AP	3/18/2021	8:15	2021Q1	ST2	Storm					6,148		3	<0.5	0.45	0.13	18	29.3	2.1	156	<5	30	3,488
AP	3/18/2021	9:10	2021Q1	ST3	Storm					3,540		2	<0.5	0.54	0.11	11	24.4	<2	126	<5	28	3,142

Anne Arundel County NPDES
Sampling Data – 2021 Reporting Year
Church Creek Station

Station	SampleDate	SampleTime	QuarterYear	Limb	Storm_Base	Depth	Duration	Intensity	Temperature	Flow	pH	BOD	TKN	Nitrate Nitrite	TP	TSS	Copper	Lead	Zinc	TPH	Hardness	*E. coli*
						Inches	Hours	in/hr	°F	CF	pH	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	MPN/100 mL
AC	7/30/2020	20:30	2020Q3	ST1	Storm	0.6	2.67	0.23	80.06	1,204	8.8	10	1.3	0.54	0.42	120	30.0	15.2	184	<5	52	520
AC	7/30/2020	20:55	2020Q3	ST2	Storm				79.70	40,408	8.8	9	1	0.48	0.37	130	25.6	22.5	168	<5	48	4,350
AC	7/30/2020	21:55	2020Q3	ST3	Storm				80.24	84,804	8.7	10	<0.5	0.43	0.21	30	11.9	5.8	64	<5	44	5,120
AC	9/3/2020	18:10	2020Q3	ST1	Storm	0.62	5	0.12		129,684		13	<0.5	0.24	0.36	15	7.0	5.8	52	6	24	6,867
AC	9/3/2020	20:25	2020Q3	ST2	Storm					377,932		4	<0.5	0.13	0.19	50	6.6	4.6	44	<5	13	12,033
AC	9/3/2020	21:15	2020Q3	ST3	Storm					512,742		7	0.7	0.27	0.33	110	20.7	19.7	146	<5	46	11,199
AC	9/28/2020	12:35	2020Q3	MM	Baseflow				70.34	117	7.2	2	<0.5	0.23	0.05	4	<2	<2	24	<5	68	331
AC	10/28/2020	13:50	2020Q4	MM	Baseflow				61.70	63	7.2	<2	<0.5	0.52	0.07	10	2.7	<2	39	<5	120	93
AC	12/4/2020	22:30	2020Q4	ST1	Storm	1.62	13	0.12	51.08	9,169	8.2	4	<0.5	0.89	0.28	41	22.4	13.6	136	<5	85	2,014
AC	12/5/2020	5:05	2020Q4	ST2	Storm				49.28	596,157	7.6	<2	<0.5	0.12	0.11	24	4.2	3.0	31	<5	18	1,414
AC	12/5/2020	8:25	2020Q4	ST3	Storm				49.28	327,469	7.4	<2	<0.5	0.21	0.09	12	3.4	<2	30	<5	27	1,483
AC	12/30/2020	13:15	2020Q4	MM	Baseflow				42.08	71	7.3	<2	<0.5	0.92	0.05	7	<2	<2	50	<5	120	<10
AC	2/25/2021	12:40	2021Q1	MM	Baseflow				50.00	87	7.0	<2	<0.5	0.8	0.04	6	<2	<2	55	<5	140	28
AC	3/18/2021	6:55	2021Q1	ST1	Storm	0.19	5.5	0.03	48.74	1,917	6.4	3	<0.5	1.2	0.16	27	11.9	<2	91	<5	140	2,419
AC	3/18/2021	8:50	2021Q1	ST2	Storm				48.74	15,680	7.2	5	<0.5	0.74	0.24	54	23.2	3.6	105	<5	72	2,481
AC	3/18/2021	10:00	2021Q1	ST3	Storm				50.00	10,414	7.1	2	<0.5	0.51	0.12	14	14.9	2.4	87	<5	54	1,050

Anne Arundel County NPDES
Quarterly Average Concentrations and Load Data – 2021 Reporting Year

Quarterly Average Concentrations															
Station	Quarter Year	Sum_Event_Flow	Temp	pH	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness	*E. Coli*
		CF	°F	pH	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	MPN/100 mL
Church Creek															
AC	2020Q3	1,146,891	80.06	8.7	7	0.5	0.24	0.28	74	14.0	12.2	96	3	33	10,281
AC	2020Q4	932,929	49.30	7.5	1	0.3	0.16	0.10	20	4.1	2.4	31	3	22	1,444
AC	2021Q1	28,098	49.21	7.1	4	0.3	0.69	0.19	37	19.3	3.0	97	3	70	1,939
Parole Plaza															
AP	2020Q3	142,662	78.75	7.9	4	0.3	0.14	0.10	21	8.8	2.0	77	3	22	9,299
AP	2020Q4	110,636	47.96	7.2	1	0.3	0.28	0.09	8	4.1	1.0	53	3	32	4,286
AP	2021Q1	10,731	55.94	7.2	4	0.4	0.59	0.13	18	32.7	1.9	159	3	32	3,038

Pollutant Load (Quarter Events)												
Station	Quarter Year	Sum_Event_Flow	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness
		CF	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
Church Creek												
AC	2020Q3	1,146,891	500	34	17	20	5,317	1.0	0.9	6.904	207	2,331
AC	2020Q4	932,929	60	15	9	6	1,162	0.2	0.1	1.829	146	1,271
AC	2021Q1	28,098	7	0	1	0	65	0.03	0.01	0.171	4	123
Parole Plaza												
AP	2020Q3	142,662	38	2	1	1	189	0.08	0.02	0.681	22	195
AP	2020Q4	110,636	8	2	2	1	53	0.03	0.01	0.365	17	219
AP	2021Q1	10,731	3	0	0	0	12	0.02	0.001	0.106	2	22

Pollutant Load (Quarter Total)												
Station	Quarter Year	Sum_Event_Flow	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness
		CF	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
Church Creek												
AC	2020Q3	10,178,256	4,437	304	152	178	47,186	8.9	7.8	61	1,840	20,691
AC	2020Q4	8,811,351	566	137	87	58	10,973	2.2	1.3	17	1,375	12,007
AC	2021Q1	4,210,582	983	66	180	50	9,772	5.1	0.8	26	657	18,443
Parole Plaza												
AP	2020Q3	1,960,475	517	33	17	13	2,598	1.1	0.2	9	306	2,681
AP	2020Q4	1,382,949	95	22	24	7	667	0.4	0.1	5	216	2,738
AP	2021Q1	2,195,186	564	53	81	18	2,479	4.5	0.3	22	343	4,404

Anne Arundel County NPDES
Annual Average Concentrations and Load Data – 2021 Reporting Year

Annual Average Concentrations															
Station	Year	Sum_Event_Flow	Temp	pH	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness	*E. Coli*
		CF	°F	pH	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	MPN/100 mL
Church Creek															
AC	2021	2,107,919	66.03	8.2	4	0.4	0.21	0.20	50	9.7	7.8	68	3	28	6,259
Parole Plaza															
AP	2021	264,029	64.92	7.6	3	0.3	0.22	0.10	15	7.8	1.6	70	3	26	6,944

Pollutant Load (Annual Events)													
Station	Year	Sum_Event_Flow	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness
		CF	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
Church Creek												
AC	2021	2,107,919	566	49	28	26	6,544	1.3	1.0	9	357	3,726
Parole Plaza												
AP	2021	264,029	48	4	4	2	255	0.1	0.03	1	41	436

Pollutant Load (Annual Total)												
Station	Year	Sum_Event_Flow	BOD	TKN	Nitrate Nitrite	Total Phos	TSS	Copper	Lead	Zinc	TPH	Hardness
		CF	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
Church Creek												
AC	2021	23,200,189	5,986	508	420	285	67,931	16.2	9.9	104	3,872	51,141
Parole Plaza												
AP	2021	5,538,610	1,176	108	123	38	5,744	5.9	0.6	36	864	9,823