CHEMICAL, BIOLOGICAL, AND PHYSICAL CHARACTERIZATION OF THE CHURCH CREEK AND PAROLE PLAZA NPDES MONITORING STATIONS: 2019 - 2020

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. Currently, monitoring is 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 subwatershed located within the larger South River watershed. This document describes the monitoring effort undertaken during County Fiscal Year 2020 (July 2019 through June 2020). 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. The chemical monitoring activities take place at two stations in the Church Creek subwatershed:

- 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 restoration and retrofit projects will be useful in assessing the cumulative effects of this work.

2 METHODS

2.1 CHEMICAL MONITORING

During the 2020 sampling period, July 2019 through June 2020, nine storm events were sampled and analyzed. 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 2019, 2020a, 2020b, and 2020c) 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. 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.

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 subwatershed

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 2019 through June 2020. 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, nine 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 two 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 2020 Sample Dates and Sample Type

Sample Date	Sample Type
July 11, 2019	S
September 17, 2019	B
September 26, 2019	B
October 16, 2019	S
November 23, 2019	S
December 27, 2019	B
December 29, 2019	S
January 25, 2020	S
March 13, 2020	S
March 25, 2020	S
April 12, 2020	S
June 11, 2020	S
June 25, 2020	B

B: Baseflow Event
S: Storm Event

Baseflow Monitoring

- **September 17, 2019**

Versar field crews decided to sample at baseflow conditions in the third week of September, to complete a second sampling event for the summer period. Staff had not monitored a storm in August due to little rainfall during that month, and forecasts did not predict a storm in the near future. The Versar field crew collected samples to document baseflow conditions at both stations on September 17.

- **September 26, 2019**

Versar field crews decided to sample at baseflow conditions in the final week of September, to complete a third sampling event for the summer period. Staff had not monitored a storm in September due to continuing dry conditions and forecasts did not predict a storm for the remainder of the month. The Versar field crew collected samples to document baseflow conditions at both stations on September 26.

- **December 27, 2019**

Versar field crews sampled at baseflow conditions in the final week of December, to complete a third sampling event for the fall period. Field teams had not monitored a storm in December because storms were forecast to be longer than project requirements. The Versar field crew collected samples to document baseflow conditions at both stations on December 27.

- **June 25, 2020**

On June 25, the field team collected baseflow samples to complete a third sampling event for the spring period. At Parole Plaza, staff observed flowing discharge only from the RCP in which field staff documented a water level of 0.02 feet. Staff measured 0.577 feet of water at the outfall at Church Creek.

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 11, 2019**

The total rainfall for this event was 1.28 inches. The storm lasted approximately six hours. These measurements were based on data from the Church Creek rain gauge.

- **October 16, 2019**

The total rainfall for this event was 1.14 inches. The storm lasted approximately six hours. These measurements were based on data from the Church Creek rain gauge.

- **November 23, 2019**

The total rainfall for this event was 0.61 inches. The storm lasted approximately eight and a half hours. These measurements were based on data from the Church Creek rain gauge.

- **December 29, 2019**

The total rainfall for this event was 0.52 inches. The storm lasted approximately nine hours. These measurements were based on data from the Church Creek rain gauge.

- **January 25, 2020**

The total rainfall for this event was 1.34 inches and lasted approximately eight hours. These measurements were based on data from the Church Creek rain gauge.

- **March 13, 2020**

The total rainfall for this event was 0.25 inches. The storm lasted approximately four and one half hours. These measurements were based on data from the Church Creek rain gauge.

- **March 25, 2020**

The total rainfall for this event was 0.22 inches. The storm lasted approximately four and one half hours. These measurements were based on data from the Church Creek rain gauge.

- **April 12, 2020**

The storm delivered 1.37 inches of total rainfall and lasted approximately 13 hours. These measurements were based on data from the Church Creek rain gauge.

- **June 11, 2020**

The total rainfall for this event was 0.41 inches; the storm lasted approximately four hours. These measurements were based on data from the Church Creek rain gauge.

Approximately 33.50 inches of precipitation was recorded at the Church Creek station during the 2020 reporting period. Rainfall was measured using a tipping bucket rain gauge located at the Church Creek station.

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.

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.

Table 2-5. Rainfall data for sampled storm events	
Date	**Rainfall (inches)**
July 11, 2019	1.28
October 16, 2019	1.14
November 23, 2019	0.61
December 29, 2019	0.52
January 25, 2020	1.34
March 13, 2020	0.25
March 25, 2020	0.22
April 12, 2020	1.37
June 11, 2020	0.41

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 operates continuously.

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:

- Versar staff downloaded data from the ISCO sampler and Global Water WL-16 loggers during maintenance visits and storm and baseflow sampling events. During the August 19 visit at Church Creek, the ISCO sampler was found to be running and the pump tubing was destroyed inside the housing. Staff removed the old tubing, replaced it with new tubing and subsequently tested the pump function. Additionally, the pH probe on the YSI sonde was replaced, all parameters were calibrated, and the time on the ISCO sampler was synchronized with the computer.

  At Parole Plaza during the August 7 maintenance visit, the Global Water WL-16 loggers were synchronized with the field laptop computer to ensure accurate documentation during sampling events. Going forward, the times measured by the loggers were synchronized with the computer during each maintenance visit as the loggers tend to drift from the actual time in the intervening time period. During the September 17 visit and baseflow sampling event at Parole Plaza, the batteries in the logger in the CMP were found to be dead and data logging had halted on September 14. Batteries were replaced and the logger was subsequently downloaded. The rain gauge documented no rain during this period, so the gap in data collection reflected dry conditions.

- Staff conducted routine maintenance at both stations on October 11, 16, and 30; November 13; and December 5 and 19, 2019. During most maintenance visits and storm events for Church Creek, Versar staff cleaned, calibrated, and performed quality control checks on the YSI sonde.

  During the October 11 visit at Parole Plaza, the level loggers in both the CMP and RCP could not communicate with the computer. Staff deduced and later confirmed that this problem was due to a recent update of the operating system on the field laptop. Upon returning to the office, the field team contacted Versar's Information Technology department to resolve the problem. Staff downloaded data from the loggers at Parole Plaza prior to the storm event on October 16. During the visit on October 30, the field team observed that the logger in the CMP was documenting readings far below the normal range. The team calibrated both level loggers to maintain consistency between the two outfalls.

- Staff conducted routine maintenance at both stations on January 2 and 15; February 12 and 24; and March 6 (aborted storm) and 27, 2020. During most maintenance visits and storm events for Church Creek, Versar staff cleaned, calibrated, and performed quality control checks on the YSI sonde. During the January 2 visit, staff was able to clear the intake for the ISCO sampler pump at the Church Creek station, which was an issue that staff noted during baseflow and storm sampling at the end of the previous quarter. Staff continued to periodically test sampler pump function on maintenance visits. During the March 27 visit at Church Creek, continuous water quality data collected during March were checked, following up on the connectivity issue discovered during the storm on March 25. Staff learned that the data connection between the sonde and the ISCO sampler had not been functioning beginning on March 1 at 9:45 a.m. The data had not been reviewed after downloading the sampler following attempted storms on March 6 and March 16 and staff had missed the error code showing on the sampler display. Staff remedied the problem by tightening the connection.

On February 24 at Parole Plaza, field staff discovered that the level logger in the corrugated metal pipe had not been relaunched after replacing batteries during the February 12 visit. There was 0.38 inches of rain during this period.

- Staff conducted routine maintenance at both stations on April 7 and 21; May 4 and 21; and June 2 and 25, 2020. During most maintenance visits and storm events for Church Creek, Versar staff cleaned, calibrated, and performed quality control checks on the YSI sonde. The stage loggers were calibrated as needed. During the May 4 visit, at Church Creek, pH was showing a value of -0.8; calibration was attempted but ultimately it was determined that the sonde has failed. Versar staff returned on May 7, 2020 with a sonde belonging to Versar which was then calibrated and installed in the outfall. On June 2, at Church Creek, staff discovered that the pH had dropped abruptly to 3.5 at 16:30 on May 31, 2020. Staff calibrated the sonde for both pH and conductivity. When the sonde was reconnected to the ISCO sampler, pH readings were displayed under the heading "0Data05." Data are still retrievable, just under a different heading. During the June 25 visit, the rain gauge at Church Creek was found clogged but no liquid was present in the funnel. There were two spikes in the level in the pipe on June 19 and June 22, but without corresponding rainfall.

2.2 BIOLOGICAL MONITORING

All biological assessment data were collected in accordance with the Anne Arundel County Biological Monitoring and Assessment Program: Quality Assurance Project Plan (Anne Arundel County 2017), which incorporates many elements of Maryland Department of Natural Resources' Maryland Biological Stream Survey (MBSS). 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 Sampling Locations

The study area is located in the northern portion of the Church Creek subwatershed, within the larger South River watershed in Anne Arundel County, Maryland (Figure 2-1). A total of four 75-meter biological monitoring sites are positioned along the study reach and are monitored annually. Three sites were established and first monitored in 2006; one site is located on the Parole Plaza Tributary just below Forest Drive, and two sites are located along the Church Creek mainstem, on either side of Solomons Island Road (Maryland State Highway 2). A fourth site, located just upstream of the confluence with the Parole Plaza Tributary, was added in 2007 to monitor the effects of runoff from the Festival at Riva shopping center.

2.2.2 Stream Habitat Evaluation

To support the biological monitoring, a visual assessment of physical habitat was completed at each monitoring site to evaluate the reach's ability to support aquatic life. Both the MBSS Physical Habitat Index (PHI; Paul et al. 2003) and the U.S. Environmental Protection Agency (U.S. EPA) Rapid Bioassessment Protocol (RBP) habitat assessment for low gradient streams (Barbour et al. 1999) were used to visually assess the physical habitat at each site in conjunction with the spring benthic monitoring. Both habitat assessments consist of a review of biologically significant habitat parameters that evaluate a stream's ability to support an acceptable level of biological health.

To calculate PHI at each site, six parameters were given a numerical score and a categorical rating: instream habitat, epifaunal substrate, remoteness, instream woody debris and rootwads, shading, and bank stability. The raw scores are then transformed into a scaled score (0-100 scale) as described in Paul et al. (2003), and the six scaled scores are averaged into an aggregate final PHI score. Narrative condition descriptions and scoring ranges for the PHI are displayed in Table 2-6.

The Rapid Bioassessment Protocol (RBP) habitat assessment consists of a review of ten biologically significant habitat parameters that assess a stream's ability to support an acceptable level of biological health: Epifaunal substrate/available cover, Embeddedness, Velocity/depth regime, Sediment deposition, Channel flow status, Channel alteration, Frequency of riffles/ bends, Bank stability, Vegetative protection, and Riparian vegetative zone width. In the field, each parameter was given a numerical score from 0-20 (20=best, 0=worst), or 0-10 (10=best, 0=worst) for individual bank parameters, and a categorical rating of optimal, suboptimal, marginal or poor (Barbour et al. 1999). As overall habitat quality increases, the total score for each site typically increases. The individual RBP habitat parameters for each reach were summed to obtain an overall RBP assessment score. Because adequate reference conditions currently do not exist for Anne Arundel County, the percent comparability was calculated based on western coastal plain reference site conditions obtained from work done in Prince George's County streams (Stribling et al. 1999). The percent of reference score, or percent comparability score, was then used to place each site into corresponding narrative rating categories. The ranges are shown in Table 2-7.

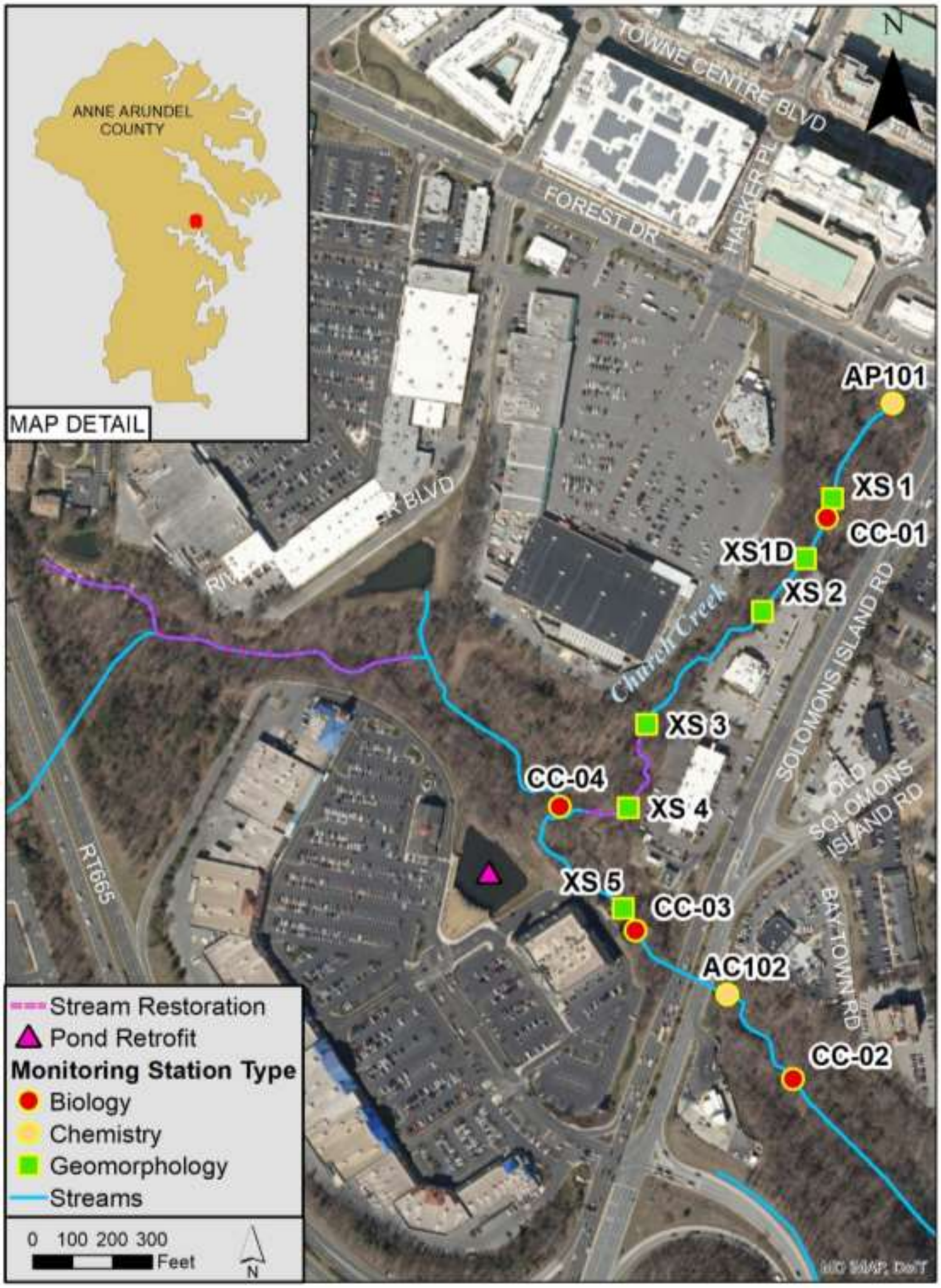

Figure 2-1. Church Creek and Parole Plaza study area, stream monitoring stations, and approximate stream restoration locations.

Table 2-6. Maryland Biological Stream Survey PHI scoring	
Score	**Narrative**
81-100	Minimally Degraded
66-80.9	Partially Degraded
51-65.9	Degraded
0-50.9	Severely Degraded

Table 2-7. EPA Rapid Bioassessment Protocol (RBP) scoring	
Percent of Reference Score	**Narrative**
90 - 100	Comparable to Reference
75.1 - 89.9	Supporting
60.1 - 75	Partially Supporting
0 - 60	Non-Supporting

2.2.3 Water Quality Measurement

In situ water quality was measured at each site with a YSI ProDSS multiparameter water quality sonde. Turbidity was measured once at the upstream end of the site, all other parameters were measured from three locations within each sampling reach (upstream end, mid-point, and downstream end) and results were averaged to minimize variability and better represent water quality conditions throughout the entire sampling reach. Data were compared to the standards listed in the *Code of Maryland Regulations (COMAR) 26.08.02.03-3 Water Quality* and shown in Table 2-8.

Table 2-8. Maryland COMAR water quality standards for Use I streams	
Parameter	**Standard**
pH	6.5 to 8.5
Dissolved Oxygen (mg/L)	Minimum of 5 mg/L
Conductivity (µS/cm)	No existing standard
Turbidity (NTU)	Maximum of 150 NTU and maximum monthly average of 50 NTU
Temperature (°C)	Maximum of 32 °C (90 °F) or ambient temperature, whichever is greater
Source: Code of Maryland Regulations (COMAR) 26.08.02.03-3-Water Quality	

2.2.4 Biological Sample Collection

Benthic macroinvertebrate samples were collected in April 2020 following the MBSS Spring index period protocols (MD DNR 2017) and as specified in *Anne Arundel County Biological Monitoring and Assessment Program: Quality Assurance Project Plan* (QAPP; Anne Arundel County 2017). This methodology emphasizes the community composition and relative abundance of benthic macroinvertebrates inhabiting the most taxonomically diverse, or productive, instream habitats. In this sampling approach, a total of twenty jabs are distributed among the most productive habitats present within the 75-meter reach and sampled in proportion to their occurrence within the segment. The most productive stream habitats are riffles followed by rootwads, rootmats, and woody debris and associated snag habitat; leaf packs; submerged macrophytes and associated substrate; and undercut banks. Other less preferred habitats include gravel, broken peat, clay lumps and detrital or sand areas in runs; however, of the aforementioned habitat types, those that are located within moving water are preferred over those in still water.

2.2.5 Biological Sample Processing and Identification

Benthic macroinvertebrate samples were processed and subsampled according to Maryland Biological Stream Survey methods described in the MBSS laboratory methods manual (Boward and Freidman, 2000) and as briefly summarized in the Anne Arundel County Biological Monitoring and Assessment Program: Quality Assurance Project Plan (Anne Arundel County 2017). Subsampling is conducted to standardize the sample size and reduce variation caused by field collection methods. In brief, the sample was washed of preservative in a 0.595 mm screen and spread evenly across a tray comprised of 100 numbered 5cm x 5cm grids. A random number between one and 100 was selected and the selected gird was picked entirely of macroinvertebrates under a bright light source. This process was repeated until a count of 120 was reached. The 120 organism target was used following MBSS methods to allow for specimens that are missing parts or are early instars, which cannot be properly identified.

The samples were taxonomically identified by Versar taxonomists certified by the Society for Freshwater Science (SFS) (formerly known as the North American Benthological Society, NABS). The taxonomic hierarchical level for most organisms was genus level when possible with the exception of Oligochaeta, which were identified to the family level. Early instars or damaged specimens were identified to the lowest possible level. Oligochaeta and Chironomidae specimens were permanently slide mounted for identification. Counts and identifications were recorded on a laboratory bench sheet and entered into a master database for analysis. A list of all taxa identified is provided in Appendix B: Master Taxa List.

2.2.6 Biological Data Analysis

Benthic macroinvertebrate data were analyzed using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The Benthic Index of Biotic Integrity (BIBI) approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The metrics selected fall into five major groups including taxa richness, composition measures, tolerance to perturbation, trophic classification, and habit measures.

Raw values from each metric are given a score of 1, 3, or 5 based on ranges of values developed for each metric. The results are combined into a scaled BIBI score ranging from 1.0 to 5.0 and a corresponding narrative rating is assigned. Table 2-9 shows the thresholds for the determination of the metric scoring. Three sets of metric calculations have been developed for Maryland streams based on broad physiographic regions: Coastal Plain, Piedmont and Combined Highlands. The Coastal Plain and Piedmont regions are divided by the Fall Line. The current study area is located within the Coastal Plain region. The metrics calculated for Coastal Plain streams are as follows:

Total Number of Taxa – Equals the richness of the community in terms of the total number of genera at the genus level or higher. A large variety of genera typically indicate better overall water quality, habitat diversity and/or suitability, and community health.

Number of EPT Taxa – Equals the richness of genera within the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). EPT taxa are generally considered pollution sensitive, thus higher levels of EPT taxa would be indicative of higher water quality.

Number of Ephemeroptera Taxa – Equals the total number Ephemeroptera Taxa in the sample. Ephemeroptera are generally considered pollution sensitive, thus communities dominated by Ephemeroptera usually indicate lower disturbances in water quality.

Percent Intolerant Urban – Percentage of sample considered intolerant to urbanization. Equals the percentage of individuals in the sample with a tolerance value of 0-3 out of 10. As impairment increases the percent of intolerant taxa decreases.

Percent Ephemeroptera – Equals the percent of Ephemeroptera individuals in the sample. Ephemeroptera are generally considered pollution sensitive, thus communities dominated by Ephemeroptera usually indicate lower disturbances in water quality.

Number Scraper Taxa – Equals the number of scraper taxa in the sample, those taxa that scrape food from the substrate. As the levels of stressors or pollution rise there is an expected decrease in the numbers of Scraper taxa.

Percent Climbers – Equals the percentage of the total number of individuals who are adapted to living on stem type surfaces. Higher percentages of climbers typically represent a decrease in stressors and overall better water quality.

All of the metric scores are summed and then averaged to obtain the final BIBI score. Table 2-10 shows the scores and narrative rankings of the MBSS BIBI. The biological assessment results are included in Appendix C. The QA/QC information is included in Appendix D.

Table 2-9. Biological condition scoring for the coastal plain metrics			
Metric	**Score**		
	5	**3**	**1**
Total Number of Taxa	≥ 22	14-21	< 14
Number of EPT Taxa	≥ 5	2-4	< 2
Number of Ephemeroptera Taxa	≥ 2	1.9-1.0	< 1.0
Percent Intolerant Urban	≥ 28	10-27	< 10
Percent Ephemeroptera	≥ 11	0.8-10.9	< 0.8
Number of Scraper Taxa	≥ 2	1.9-1.0	< 1.0
Percent Climbers	≥ 8.0	0.9-7.9	< 0.9

Table 2-10. Maryland Biological Stream Survey BIBI scoring		
BIBI Score	**Narrative Ranking**	**Characteristics**
4.0-5.0	Good	Comparable to reference conditions, stream considered to be minimally impacted, biological metrics fall within upper 50th percentile of reference site conditions.
3.0-3.9	Fair	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of minimally impacted streams.
2.0-2.9	Poor	Significant deviation from reference conditions, indicating some degradation. On average, biological metrics fall below the 10th percentile of reference site values.
1.0-1.9	Very Poor	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of minimally impacted streams, indicating severe degradation. On average, most or all metrics fall below the 10th percentile of reference site values.

2.3 PHYSICAL MONITORING

2.3.1 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.

2.3.2 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 E. As illustrated in Appendix E, 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 2-11 includes general descriptions of each Rosgen stream type. A summary of the stream types identified within this study is included in Appendix F.

Table 2-11. 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

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.

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 2020 as it was only requested to compare channel shape to XS-1; pebble counts will be collected in future surveys if the County decides to continue monitoring this cross-section. Reach-wide proportional counts were used. Each pebble count consists 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 are allocated across all feature types in the proportion at which they occur within the reach. The intermediate axis of each measured pebble is recorded. The goal of the pebble count is 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 is 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 did have variation in bed material size from feature to feature, a full pebble count was performed.

3 RESULTS

3.1 POLLUTANT CONCENTRATIONS

During this sampling period, 62 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	48	88
TKN (mg/L)	0.5	61	75
Nitrate + Nitrite (mg/L)	0.05	0	0
Total Phosphorus (mg/L)	0.01	0	38
TSS (mg/L)	1	0	13
Total Copper (µg/L)	2	0	13
Total Lead (µg/L)	2	37	100
Total Zinc (µg/L)	20	0	13
TPH (mg/L)	5	94	100
E. coli (MPN/100 mL)	1, 10, 100	0	0
Hardness (mg/L)	1	0	25

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 eight of the thirteen parameters measured during wet weather sampling in 2020. Four of the maximum wet weather values for the parameters were measured during the April 12 storm event. The maximum *E. coli* concentration at Parole Plaza was 24,196 MPN/100 mL and was observed during the October 16 storm. Chemical monitoring summaries can be found in Appendix G.

Table 3-2. Maximum dry weather values observed during sampling period		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)	70.90	66.02
pH	6.6	7.4
BOD_5 (mg/L)	3	BDL
TKN (mg/L)	0.8	0.7
Nitrate + Nitrite (mg/L)	0.85	5.60
Total Phosphorus (mg/L)	0.06	BDL
TSS (mg/L)	10	2
Total Copper (µg/L)	5	4
Total Lead (µg/L)	BDL	BDL
Total Zinc (µg/L)	54	158
TPH (mg/L)	BDL	BDL
E. coli (MPN/100 mL)	201	120
Hardness (mg/L)	220	340
BDL: Below Detection Limit		

Table 3-3. Maximum wet weather values observed during sampling period		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)	79.88	81.80
pH	6.8	10.7
BOD_5 (mg/L)	13	16
TKN (mg/L)	2.6	2.4
Nitrate + Nitrite (mg/L)	1.30	1.50
Total Phosphorus (mg/L)	0.66	0.38
TSS (mg/L)	210	220
Total Copper (µg/L)	116	83
Total Lead (µg/L)	24	16
Total Zinc (µg/L)	224	451
TPH (mg/L)	5	14
E. coli (MPN/100 mL)	17,329	24,196
Hardness (mg/L)	160	92
BDL: Below Detection Limit		

Table 3-4. Storm dates for wet weather maximum values			
Parameter	**Date of Storm**	**Site**	**Maximum Value**
Water Temperature (°F)	7/11/19	Parole Plaza	81.80
pH	1/25/20	Parole Plaza	10.7
BOD_5 (mg/L)	4/13/20	Parole Plaza	16
TKN (mg/L)	4/13/20	Church Creek	2.6
Nitrate + Nitrite (mg/L)	1/25/20	Parole Plaza	1.50
Total Phosphorus (mg/L)	10/16/19	Church Creek	0.66
TSS (mg/L)	6/11/20	Parole Plaza	220
Total Copper (µg/L)	6/11/20	Church Creek	116
Total Lead (µg/L)	4/12/20	Church Creek	24
Total Zinc (µg/L)	4/12/20	Parole Plaza	451
TPH (mg/L)	3/13/20	Parole Plaza	14
E. coli (MPN/100 ml)	10/16/20	Parole Plaza	24,196
Hardness (mg/L)	10/16/20	Church Creek	160

3.2 EVENT MEAN CONCENTRATIONS AND POLLUTANT LOADINGS

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

Table 3-5. Average EMCs observed during July 2019 to June 2020		
Parameter	**Church Creek**	**Parole Plaza**
Water Temperature (°F)	59.30	55.83
pH	6.4	8.9
BOD_5 (mg/L)	2	1
TKN (mg/L)	0.4	0.5
Nitrate + Nitrite (mg/L)	0.35	0.41
Total Phosphorus (mg/L)	0.21	0.09
TSS (mg/L)	62	28
Total Copper (µg/L)	12	21
Total Lead (µg/L)	7	3
Total Zinc (µg/L)	78	144
TPH (mg/L)	3	3
E. coli (MPN/100 mL)	5,009	5,466
Hardness (mg/L)	41	39

Summed, annual loads for the sampled events monitored during the July 2019 to June 2020 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 2019 to June 2020 sampling period

Parameter	Church Creek		Parole Plaza	
	Total	**Per Acre**	**Total**	**Per Acre**
BOD_5	925	3.28	42	0.39
TKN	179	0.63	16	0.15
Nitrate + Nitrite	141	0.50	14	0.13
Total Phosphorus	85	0.30	3	0.03
TSS	25,300	89.9	923	8.7
Total Copper	5	0.02	0.7	0.007
Total Lead	3	0.011	0.1	0.001
Total Zinc	32	0.11	5	0.05
TPH	1,109	3.94	89	0.84
Hardness	16,815	59.7	1,317	12.4

3.3 BIOLOGICAL ASSESSMENT

Biological and physical habitat assessments were completed on April 6, 2020, within the Spring Index Period of March-April as established by the MBSS. Presented below are the summary results for each assessment site. For full bioassessment data and results, refer to Appendix C. A complete taxonomic list can be found in Appendix B. QA/QC information is in Appendix D. As introduced in Section 1, the South River Federation (now Arundel Rivers Federation), in cooperation with the County, undertook restoration of Church Creek in the vicinity of the existing biological and physical monitoring sites beginning in late January 2016. 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. All of the CC-04 and part of the CC-03 biological monitoring sites were within the restored reach of the stream.

Physical habitat quality was evaluated using the MBSS PHI, and rated “Partially Degraded” for one site (CC-03) and “Degraded” for three sites (CC-01, CC-02, and CC-04; Table 3-7). Index scores ranged from a low of 60.45 at CC-02 to a high of 72.44 at CC-03. All sites received very low scores for remoteness due to the proximity of the stream channel to roads and development. The instream woody debris score was low to moderate for CC-02 and CC-03, but high for CC-01 and CC-04. The dewatered woody debris score was low for CC-01, CC-02, and CC-03, but high for CC-04. Instream habitat scores were rated “Marginal” at CC-01, CC-02, and

CC-04, and "Sub-Optimal" at CC-03. Epifaunal substrates scores were rated "Poor" for CC-01 and CC-04, "Marginal" at CC-02, and "Sub-Optimal" at CC-03. Individual parameter results are listed in Appendix C. Overall, PHI scores increased throughout the study area in 2020.

The RBP score was also used to evaluate the physical habitat quality and rated "Non-supporting" at CC-01, "Partially Supporting" at CC-02, and "Supporting" at CC-03 and CC-04 (Table 3-7). Scores ranged from 58 at CC-01 to 80 at CC-03. Low epifaunal substrate/cover, bank stability, vegetative protection, and bank stability scores were the primary driver of low RBP scores at CC-01 and CC-02. CC-03, the site with the highest RBP rating, had channel alteration, and channel flow status scores in the "Optimal" category and pool variability and sediment deposition in the "Suboptimal" category; there was no metric that scored in the "Poor" category for this site. Results at CC-04 showed an increase in epifaunal substrate, pool substrate, and sediment deposition scores, rating this site in the "Optimal" category, an increase from the "Suboptimal" category in 2019. Overall, RBP scores throughout the study area indicate that physical habitat conditions at some sites could limit the potential for healthy, stable biological communities, similar to what was found using the PHI.

Table 3-7. PHI and RBP physical habitat assessment results – April 2020

Site	PHI Score	PHI Narrative Rating	RBP Score	RBP Narrative Rating
CC-01	64.30	Degraded	58	Non-Supporting
CC-02	60.45	Degraded	67	Partially Supporting
CC-03	72.44	Partially Degraded	80	Supporting
CC-04	63.70	Degraded	77	Supporting

BIBI score narrative ratings at the Church Creek sites ranged from "Very Poor" at CC-01, to "Poor" at CC-02, CC-03, and CC-04 with scores between 1.86 and 2.71, indicating a highly impaired benthic macroinvertebrate community. Low BIBI scores were driven by low metric scores for Number of EPT taxa, Number of Ephemeroptera, Percent Ephemeroptera, and Percent Intolerant to Urban at all sites. Only one EPT taxon was found at each of CC-02 and CC-04 in 2020, with the remaining two sites being absent of EPT taxa. The Percent Clingers metric received average to high scores for all sites. The sub-samples at each station contained between 12 and 18 taxa and the majority of individuals were from the pollution tolerant Naididae and Tubificidae families and Polypedilum genus, accounting for over 42% of all sub-sampled individuals. Poor habitat conditions and marginal water quality parameters may contribute to low BIBI scores at the Church Creek sites. BIBI scores and ratings are summarized in Table 3-8.

Table 3-8. Benthic macroinvertebrate assessment results – April 2020		
Site	**BIBI Score**	**Narrative Rating**
CC-01	1.86	Very Poor
CC-02	2.43	Poor
CC-03	2.43	Poor
CC-04	2.71	Poor

To supplement the biological assessment data, *in situ* water quality parameters were measured at each biological monitoring site prior to sample collection. Table 3-9 shows the water quality data for each site. Temperature, turbidity, dissolved oxygen, and pH at the four sampling locations were within Maryland COMAR water quality values for Use I streams. Church Creek conductivity values were elevated, particularly at CC-01, compared to most coastal plain streams, and exceeded the 75th percentile of values (i.e., 307 µS/cm) measured during Round One (2004-2008) of the Countywide Biological Monitoring and Assessment Program (Hill and Pieper, 2011), as well as higher than the range of those found in other urban, or highly impervious, drainage areas in Maryland (MD DNR, 2001, 2003, 2005; KCI, 2009; Hill and Crunkleton, 2009). Stream conductivity is affected by inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations, many of which are generally found at elevated concentrations in urban streams (Paul and Meyer, 2001). Increased stream ion concentrations (measured as conductivity) in urban systems are typically a result of runoff over impervious surfaces, passage through pipes, and exposure to other infrastructure (Cushman 2006). Seasonal use of road salt has most likely caused conductivity values to be high.

Table 3-9. *In situ* water quality results – April 2020					
Site	**pH**	**Temperature**	**Dissolved Oxygen**	**Turbidity**	**Conductivity**
	SU	**°C**	**mg/L**	**NTU**	**µS/cm**
CC-01	6.72	17.80	9.66	12.9	1147
CC-02	6.64	12.90	8.17	12.4	583
CC-03	7.17	15.70	8.47	15.5	584
CC-04	6.92	19.30	7.12	16.2	508

3.4 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 E and 2020 data for Church Creek sites are in Appendix F. 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 survey provides 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 0.85-foot difference. In 2020, geomorphic assessment parameters continue 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 83.3% 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, at the County's request, Versar surveyed an additional cross-section during the 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; should monitoring of this cross-section be continued in the future, pebble count measurements can be included in subsequent surveys. Based upon the 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 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). The lack of sinuosity in the channel has likely resulted 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 change has been documented at XS-3 but the erosion behind the armored bank documented in the 2016 and 2017 surveys has aggraded in recent years.

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 E4 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 7.6% and has increased by 1.4 % 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 1.5 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 2020, sediment coarsened substantially again compared to measurements in 2019, with a D_{50} particle size of 56 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 2017 and 2020, the cross-sectional area and the width/depth ratio remained similar.

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4 DISCUSSION

Results from the July 2019-June 2020 study period are discussed in the following section. Water quality, biological, 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	5	4
Zinc (µg/L)	120	120	54	158*
Total P	0.0225		0.06*	BDL
BOD_5	7		3	BDL
Nitrate + Nitrite	0.095		0.85*	5.60*
TSS	500		10	2
TKN	None		0.8	0.7
TPH	None		BDL	BDL
*E. coli*** (MPN/100 mL)	126		201*	120
Hardness	None		220	340

* 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 and combined nitrate and nitrite at Parole Plaza and for total phosphorus, combined nitrate and nitrite, and *E. coli* at Church Creek during baseflow sampling. The decrease in exceedances of the water quality criteria at Parole Plaza during baseflow sampling in 2020, in contrast to 2019, plus the prevalence of below detection limit results, indicates that potentially illicit discharge-causing conditions noted in late FY2018, manifested during dry weather flow, may have been rectified. 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* frequently exceeded criteria at both sampling stations, as was the case in 2019.

Table 4-4 shows the percentage of wet weather samples for which criteria were exceeded. *E. coli* concentrations exceeded the water quality criterion in 96 percent of samples at Church Creek and in 85 percent of samples at Parole Plaza, down slightly from 2019. Total phosphorus and combined nitrate and nitrite results exceeded the corresponding criteria 100% of the time at both stations, as was the case in 2019. Percentage exceedances for copper, zinc, and BOD_5 were higher at Parole Plaza than at Church Creek, similar to 2019.

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	24	16
Copper (µg/L)	13	116*	83*
Zinc (µg/L)	120	224*	451*
Total P	0.0225	0.66*	0.38*
BOD_5	7	13*	16*
Nitrate + Nitrite	0.095	1.30*	1.50*
TSS	500	210	220
TKN	None	2.6	2.4
TPH	None	5	14
*E. coli*** (MPN/100 mL)	126	17,329*	24,196*
Hardness	None	160	92

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

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	37	67
Zinc (µg/L)	120	19	63
Total P	0.0225	100	100
BOD_5	7	4	22
Nitrate + Nitrite	0.095	100	100
TSS	500	0	0
TKN	None	NA	NA
TPH	None	NA	NA
*E. coli** (MPN/100 mL)	126	96	85
Hardness	None	NA	NA

* Used most restrictive standard for *E. coli* as a conservative approach: water contact recreation criterion
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 2020 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 the outfall pipe at the Parole Plaza location. During 2020, percent exceedances for zinc and copper increased at Parole Plaza in contrast to 2019 whereas the exceedances remained comparable at Church Creek. The average size of monitored storm events in 2020 was 0.79 inches, down from 0.98 inches in 2019. 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 EMCs (encompassing both storm event and baseflow concentrations) 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 2019. During 2020, the EMC for zinc at Parole Plaza exceeded the criterion but did not do so in 2019. Copper and lead exceeded the corresponding chronic criteria in 2020 at both stations (with copper at Parole Plaza exceeding both the chronic and acute criteria) whereas only copper at Parole Plaza and lead at Church Creek exceeded chronic criteria in 2019.

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

Parameter (mg/L, except as noted)	Chronic Criteria	Acute Criteria	Church Creek	Parole Plaza
Lead (µg/L)	2.5	65	7*	3*
Copper (µg/L)	9	13	12*	21*
Zinc (µg/L)	120	120	78	144*
Total P	0.0225		0.21*	0.09*
BOD_5	7		2	1
Nitrate + Nitrite	0.095		0.35*	0.41*
TSS	500		62	28
TKN	None		0.4	0.5
TPH	None		3	3
*E. coli*** (MPN/100 mL)	126		5,009*	5,466*
Hardness	None		41	39

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

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 2020

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
2002-2006 Mean	8,544	59,548	535	974	438	104	23	11	NA	2,186,095
2009-2020 Mean	1,694	13,431	48	282	170	48	1	7	16,692	8,851
2002-2020 Mean	5,726	72,612	272	588	313	80	8	17	16,692	8,757[(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 2020

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	43,980	180,946	899	3,326	2,782	558	27	57	314,179	2,399
2014	31,969	299,830	1,065	12,177	6,019	551	27	78	646,801	8,638
2015	19,643	344,419	1,057	5,743	3,148	665	35	99	455,627	2,100
2016	46,587	335,422	1,026	6,648	3,081	818	41	92	344,729	8,049
2017	23,557	230,599	855	4,699	2,044	468	34	71	257,816	5,597
2018	19,360	358,077	1,135	3,182	2,137	491	38	75	244,708	6,813
2019	19,742	257,269	1,072	2,624	2,432	487	31	67	236,796	5,275
2020	13,720	373,867	1,231	2,569	2,080	469	44	73	246,112	5,009
2002-2006 Mean	22,329	131,034	1,178	2,143	963	228	52	25	NA	4,810,490
2009-2020 Mean	32,197	274,483	1,179	5,919	2,980	586	33	68	325,659	5,058
2002-2020 Mean	43,387	406,313	1,656	6,029	25,328	659	51	86	325,659	4,736[(b)]

[(a)] Units of Fecal Coliform and *E. coli* are MPN/100 mL.
[(b)] Mean *E. coli* value, does not include pre-2007 Fecal Coliform data.

When compared to the 2019 reporting year, 2020 loading rates decreased for BOD, TKN, nitrate-nitrite, and zinc at the Church Creek Station. At the Parole Plaza Station, 2020 reporting year loading rates decreased for all sampled parameters when compared to 2019. Annual mean concentrations of *E. coli* were lower in 2020 at both stations.

A comparison of mean annual loading rates for the pre-redevelopment period (2002-2006) with the post-redevelopment period (2009 to 2020), indicates the mean loading rates for all parameters at the Parole Plaza station were lower during the post-redevelopment period. At the Church Creek station, all mean post-redevelopment parameters except for lead and *E. coli* (compared to fecal coliform) exceeded the mean pre-redevelopment (2002-2006) annual loads. Because annual average EMCs for most parameters have gradually declined since 2004 (see discussion below), the likely explanation for the higher annual loadings during the post-redevelopment period is higher average annual flow volume during the post-redevelopment period compared to the pre-redevelopment period. Total quarterly and storm event discharge values have been stable since 2012.

Seasonal pollutant loads in 2020 are provided in Table 4-8. At Church Creek, the seasons in which the highest pollutant loads occurred were fall, spring, and winter. Zinc, TSS, and hardness were higher in the winter; BOD, nitrate-nitrite, and *E. coli* were higher in the fall; and phosphorus, TKN, and copper were higher in the spring. At Parole Plaza, most parameters were at their highest during the spring except for *E. coli* and BOD, which were highest in Fall, and TSS, which was highest during the winter.

Table 4-8. Seasonal loading rates, in pounds, observed at the Church Creek and Parole Plaza sampling stations in 2020

Season	BOD_5	TSS	TP	TKN	NO_3+NO_2	Zinc	Lead	Copper	Hardness	*E. coli**
Church Creek										
Summer	3,812	89,467	241	645	365	92	12	13	34,256	6,281
Fall	4,533	56,820	288	492	638	125	7.9	17	62,161	8,063
Winter	1,706	118,007	268	384	508	131	12	17	77,216	919
Spring	3,669	109,573	434	1,048	569	122	12	26	72,479	4,623
Parole Plaza										
Summer	58	1,063	3	18	16	4	0.08	1	1,049	3,687
Fall	93	1,640	6	32	23	10	0.1	1	1,475	10,992
Winter	63	2,744	5	17	14	7	0.1	1	3,105	551
Spring	74	1,343	7	42	37	13	0.3	2	3,482	4,562

***** 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) and 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 2020 at the Parole Monitoring Station. Nearly every concentration rose substantially between 2006 and 2007, coinciding with the majority of the site work at the Towne Centre. These concentrations fell notably in 2008, as the site stabilized. This downward trend continued in 2009. The reduction in pollutant concentrations stabilized in 2010 and 2011, extending to the present, indicating that the discharge had possibly reached a post-construction baseline. The rise in TPH during 2013 was due to an increase in the detection limit, and may not be associated with an actual increase in concentration, as greater than 95% of TPH concentrations fell below the detection limit. 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. At Parole Plaza, annual pollutant concentrations in 2020 increased slightly for most parameters after three successive years of declining values. Concentrations of BOD, TPH, and *E. coli* slightly decreased in 2020. Overall, except for *E. coli*, there is evidence of a moderate downward trend in EMC values at Parole Plaza since approximately 2006. For *E. coli*, while the trend is highly variable, annual EMCs appear to be generally increasing despite lower concentrations in 2019 and 2020.

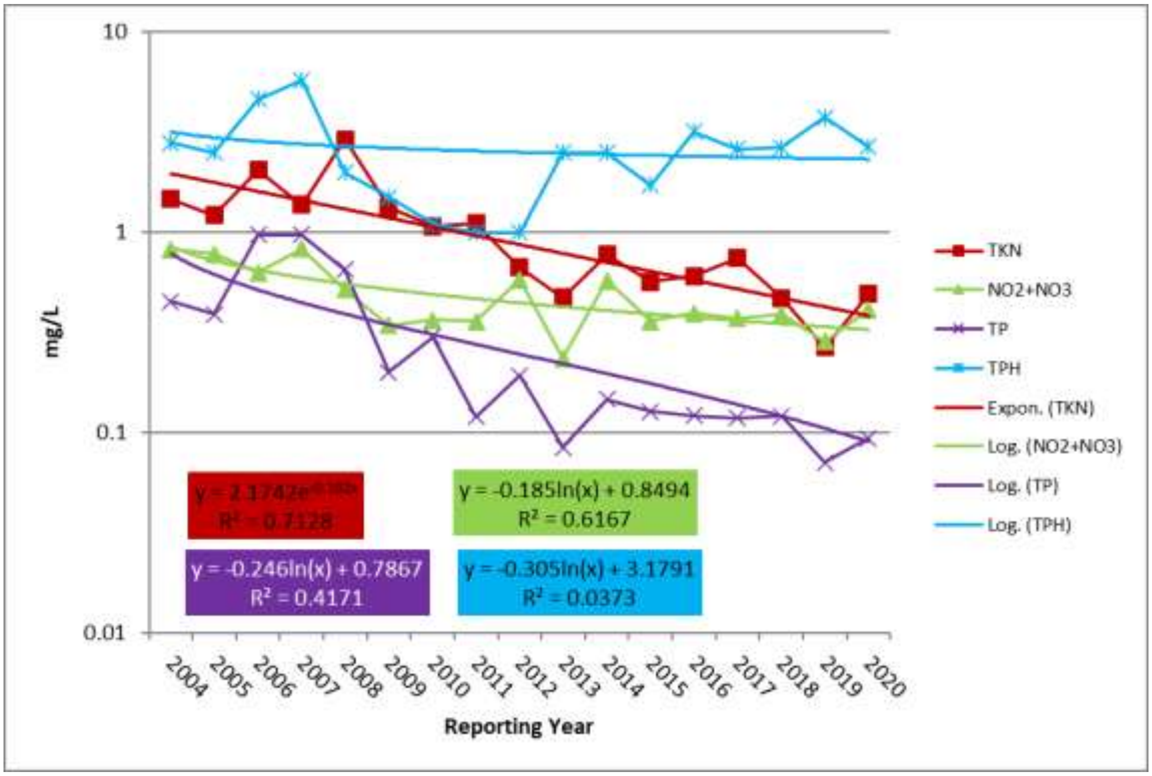

Figure 4-1. Parole Plaza station long-term monitoring: annual EMCs (TKN, NO_3+NO_2, TP, TPH; mg/L)

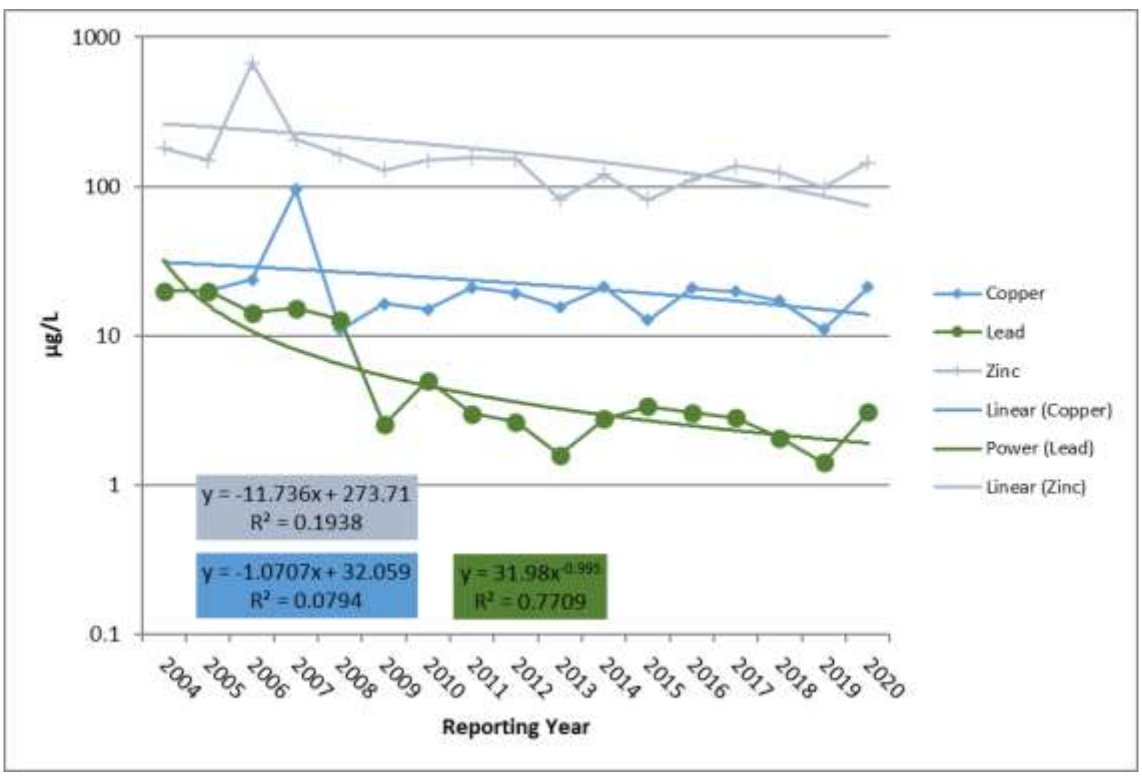

Figure 4-2. Parole Plaza station long-term monitoring: annual EMCs (Cu, Pb, Zn; µg/L)

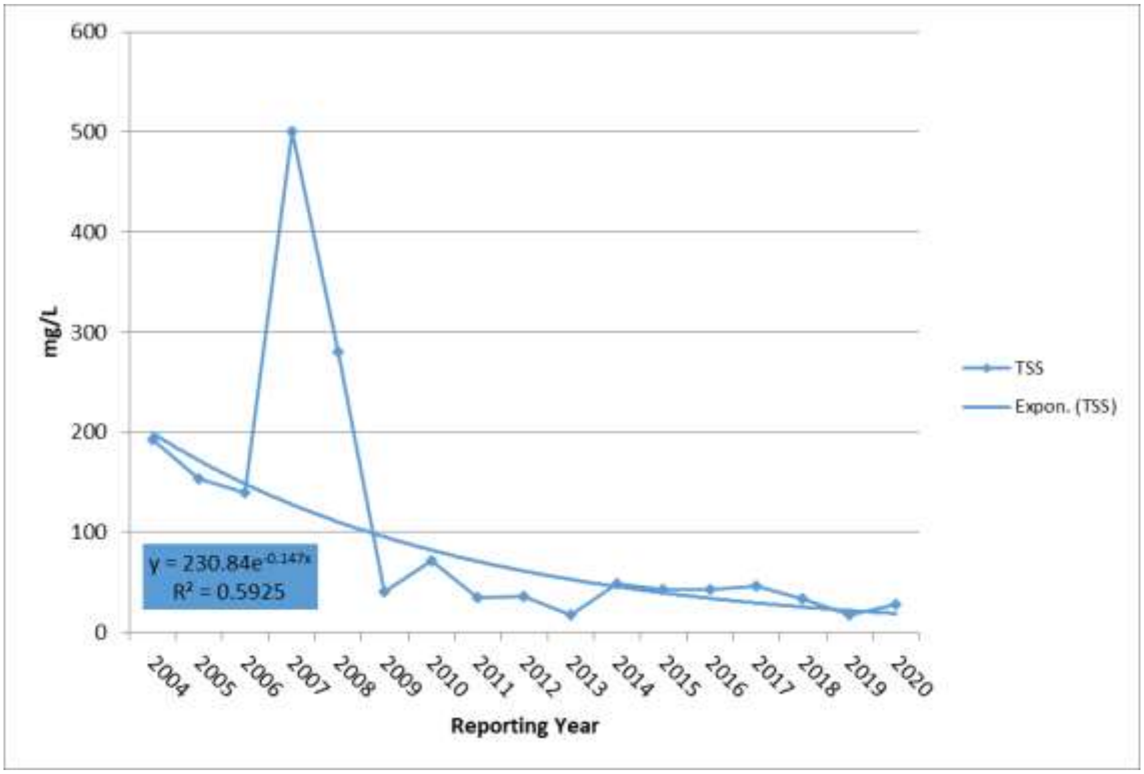

Figure 4-3. Parole Plaza station long-term monitoring: annual EMCs (TSS; mg/L)

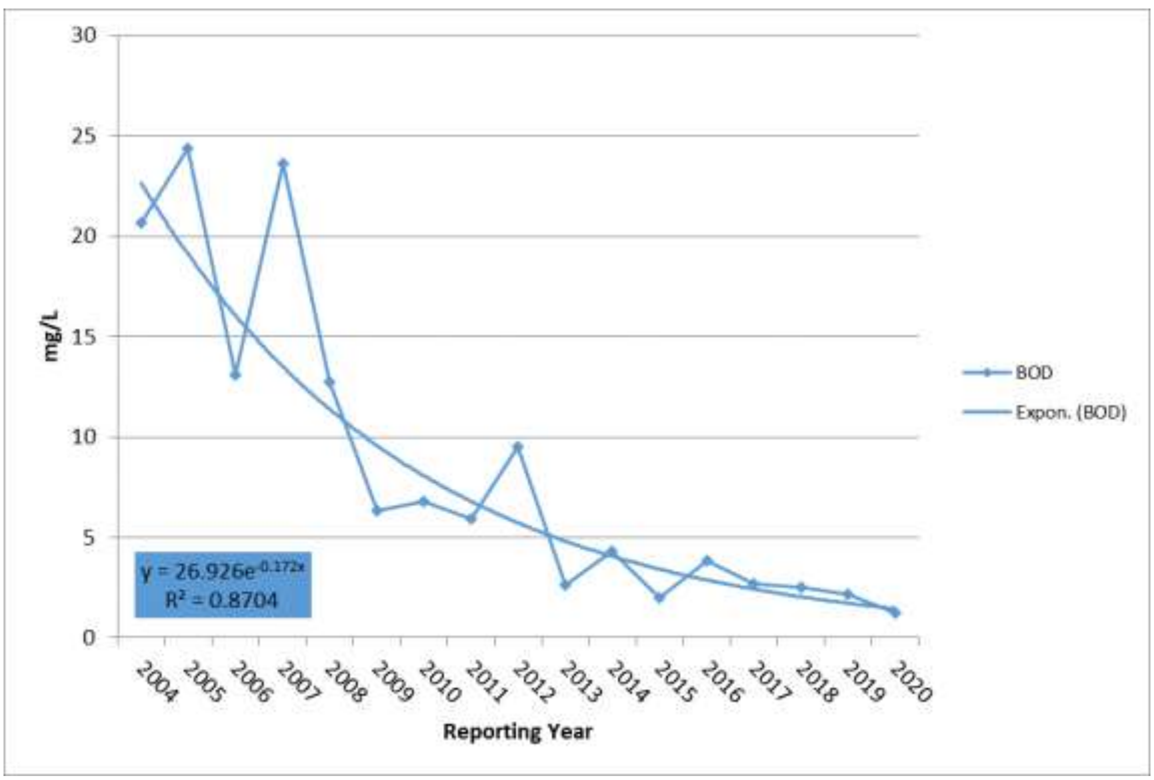

Figure 4-4. Parole Plaza station long-term monitoring: annual EMCs (BOD_5; mg/L)

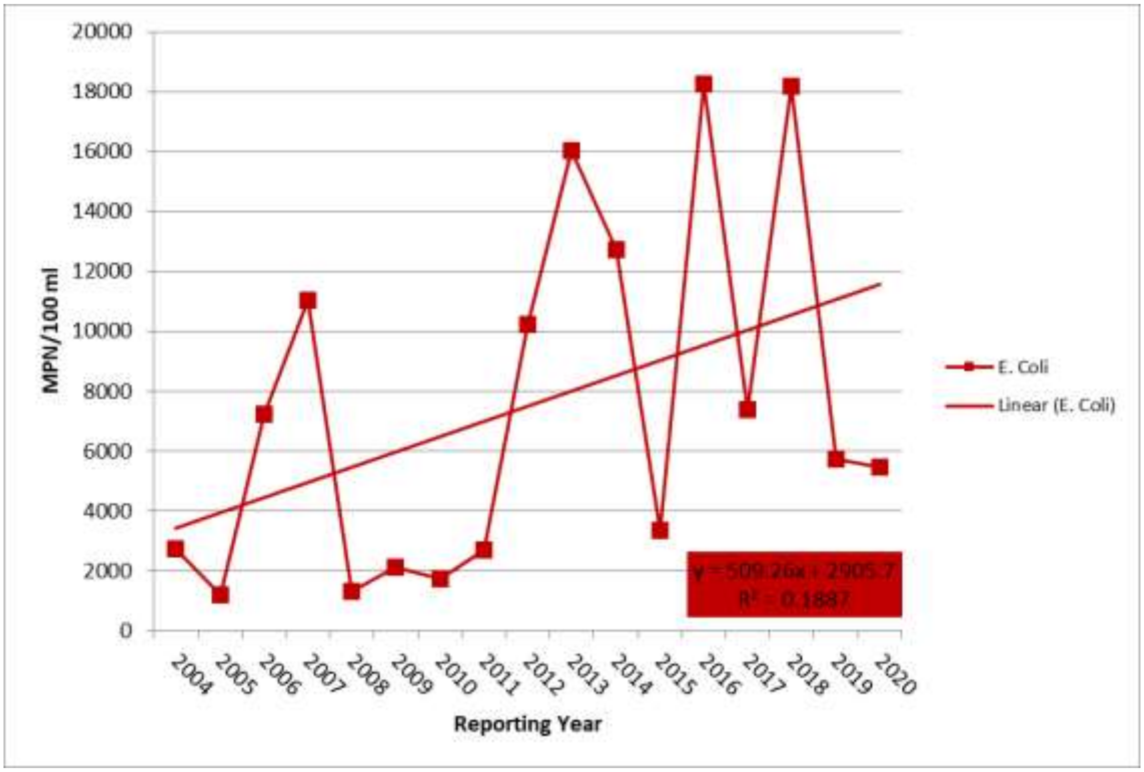

Figure 4-5. Parole Plaza station long-term monitoring: annual EMCs (*E. coli*; MPN/100 mL)

Figures 4-6 through 4-10 show trends in average annual EMCs for the Church Creek monitoring station. Most pollutant concentrations increased at Church Creek in 2020 compared to 2019 EMCs except for TPH and *E. coli*. 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).

Annual EMCs of most parameters during the current monitoring period, though higher than in 2019, fell within the normal variability of historical (2004 to present) values. Notably, annual EMCs for total phosphorus, lead, and TSS in 2020 were the highest since 2010 or earlier. Similar to Parole Plaza, annual average concentrations 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 as a result of effects of construction of the additional stream restoration and retrofit projects. Overall, similar to Parole Plaza, EMCs are generally trending downward, except for *E. coli*. The upward trend in *E. coli* at this station appears to be weaker than the trend observed at Parole Plaza.

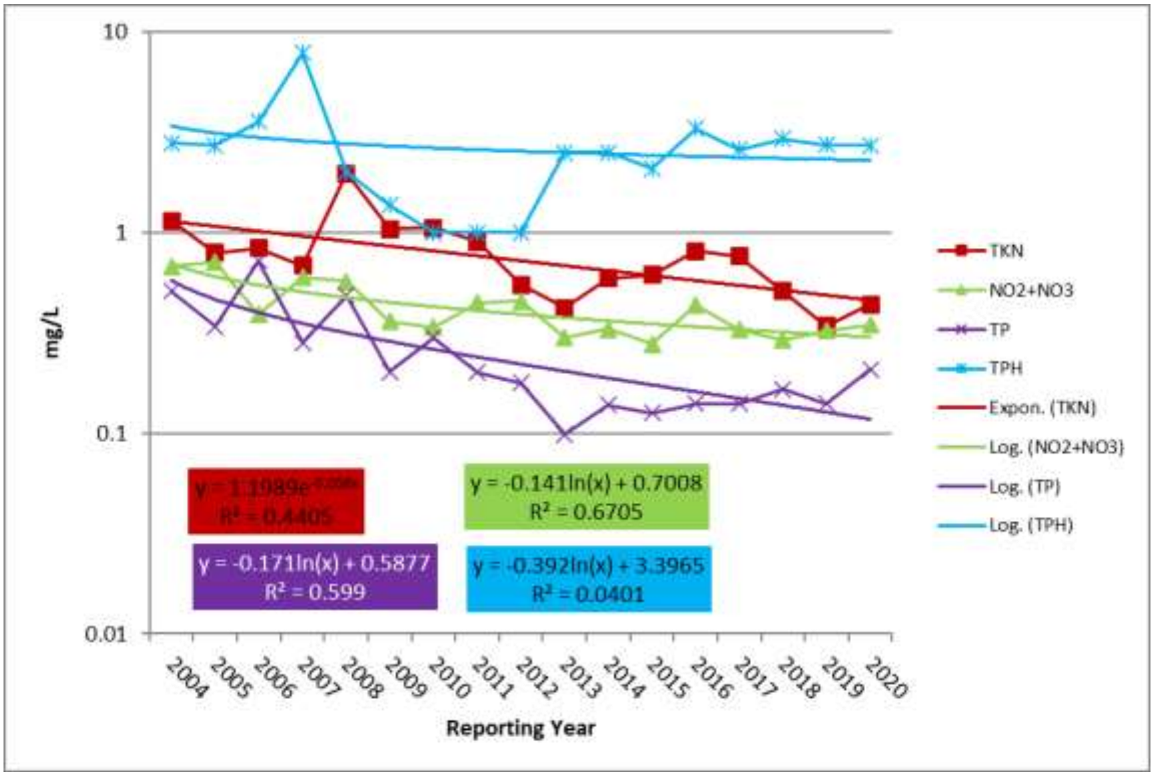

Figure 4-6. Church Creek station long-term monitoring: annual EMCs (TKN, NO_3+NO_2, TP, TPH; mg/L)

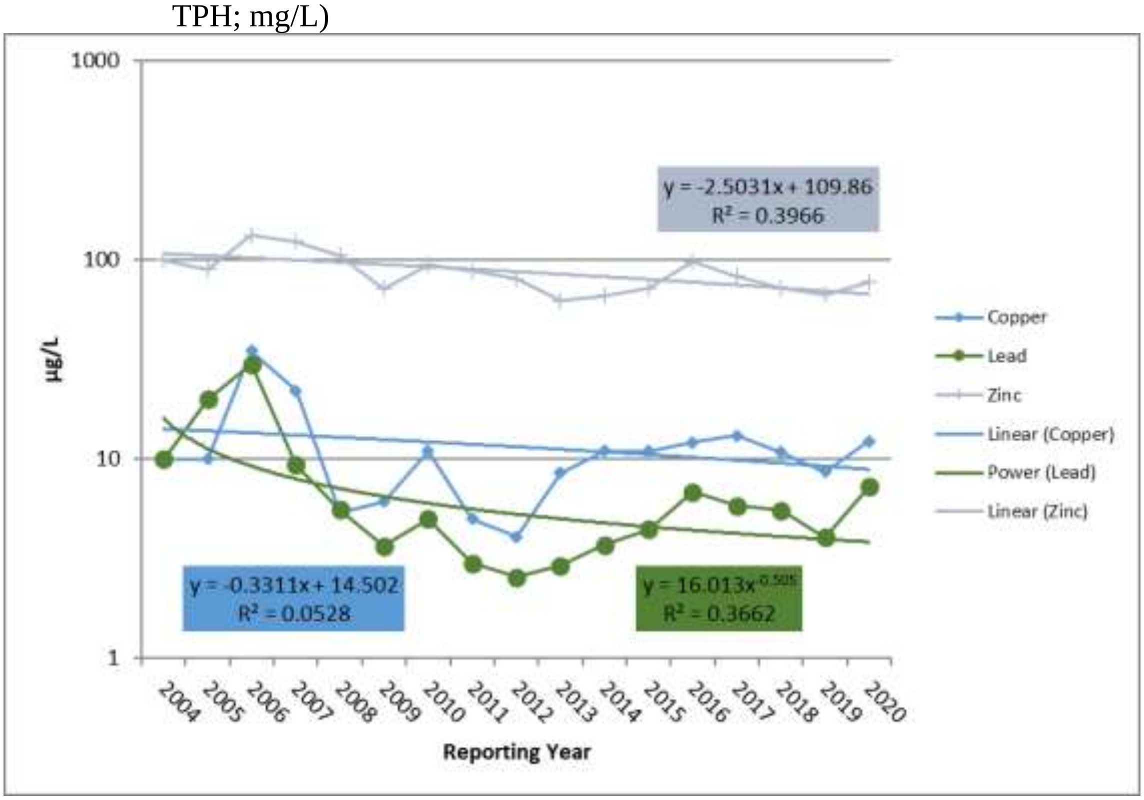

Figure 4-7. Church Creek station long-term monitoring: annual EMCs (Cu, Pb, Zn; µg/L)

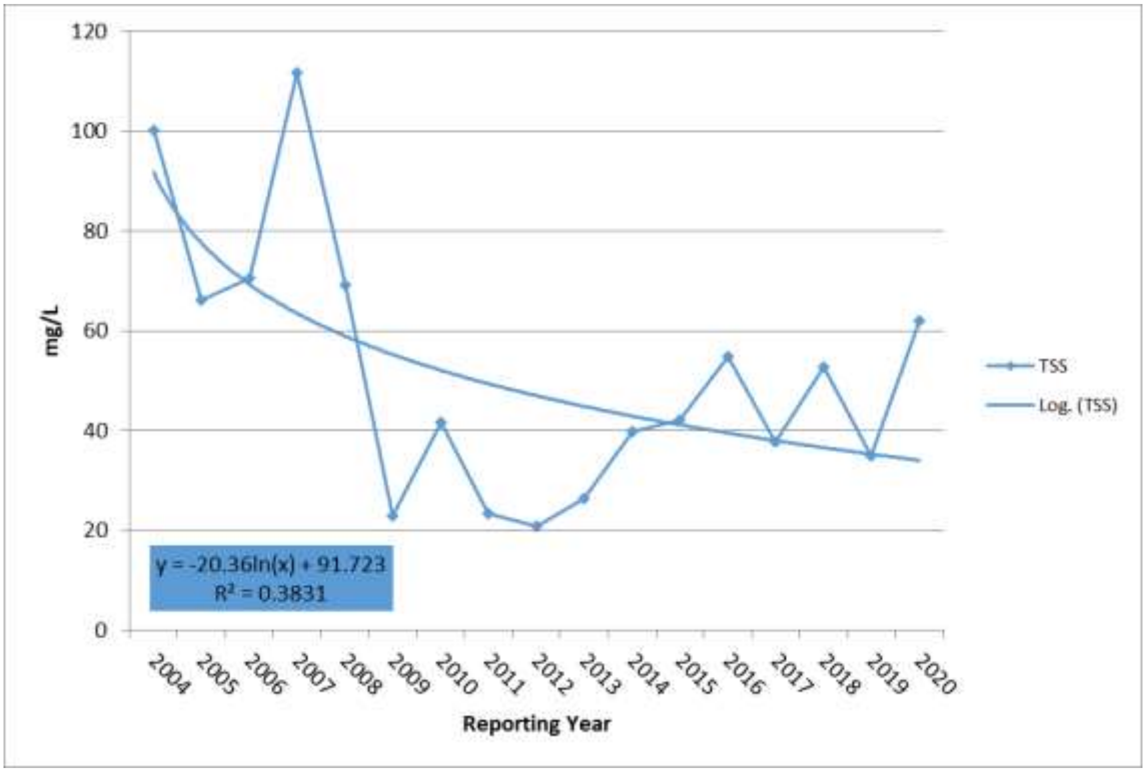

Figure 4-8. Church Creek station long-term monitoring: annual EMCs (TSS; mg/L)

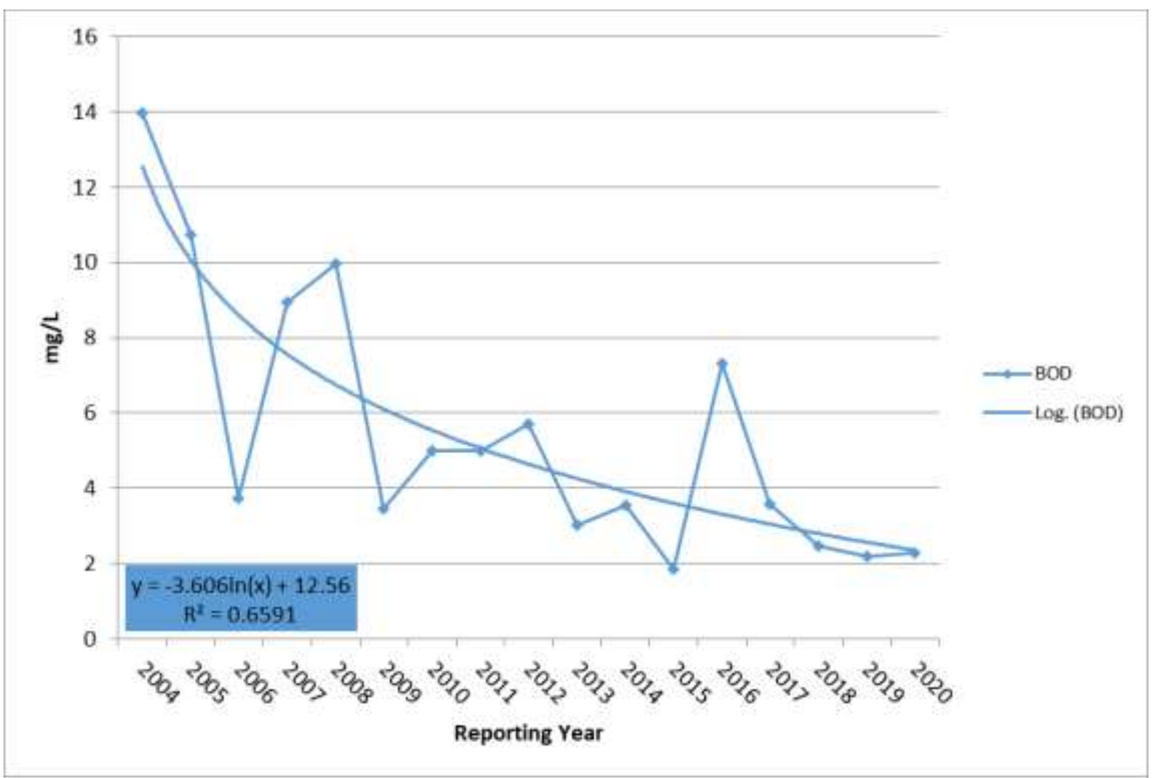

Figure 4-9. Church Creek station long-term monitoring: annual EMCs (BOD_5; mg/L)

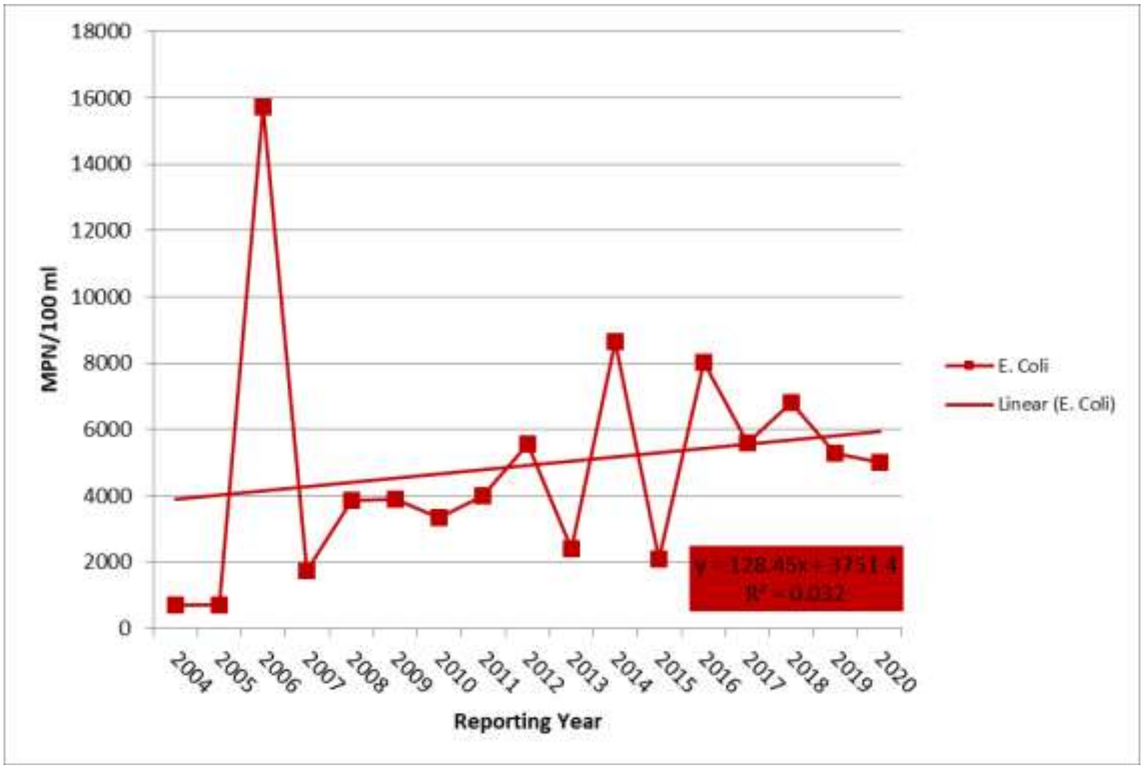

Figure 4-10. Church Creek station long-term monitoring: annual EMCs (*E. coli*; MPN/ 100 mL)

4.2 PHYSICAL HABITAT AND BIOLOGICAL CONDITIONS

Physical habitat and biological conditions within the Church Creek study area continue to be impaired by urbanization within the surrounding watershed. Stream physical habitat appears to have stayed the same or slightly increased from the previous year (Table 4-9, Figure 4-11, Figure 4-12), but remains degraded throughout the entire study reach. PHI scores increased at all four sites in 2020 but did not change any of the associated narrative ratings from those observed in 2019. Similarly, RBP scores at three sites increased in 2020, which were sufficient to shift the associated narrative rating into a higher category than that observed in 2019 at two of these sites—CC-02 and CC-04—while CC-01 remained in the Non-supporting category; RBP score and narrative rating stayed the same at site CC-03 from 2019 to 2020. Increases in epifaunal substrate, pool substrate, and sedimentation scores were the driving factors in the increased narrative ratings between 2019 and 2020. Also, urban stressors such as hydrologic alteration (i.e., increased runoff, increased frequency of peak flows, reduced infiltration) within the watershed have resulted in a reduction of stable banks and marginal to suboptimal instream habitat, which may limit the capacity of the stream to support a diverse and healthy macroinvertebrate community. In addition, elevated conductivity levels reflect high levels of dissolved solids during baseflow conditions, which typically indicate the presence of water quality stressors.

Table 4-9. PHI and RBP scores from 2006 to 2020

Site		CC-01	CC-02	CC-03	CC-04
2006	PHI Score	51.1	55.4	56.8	No Data Collected
	Rating	Degraded	Degraded	Degraded	
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2007	PHI Score	61.2	59.1	65.7	60.8
	Rating	Degraded	Degraded	Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2008	PHI Score	57.1	56.8	66.6	62.6
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2009	PHI Score	73.2	59.6	69.2	65.2
	Rating	Partially Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2010	PHI Score	64.3	53.9	65.0	62.3
	Rating	Degraded	Degraded	Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2011	PHI Score	67.4	55.3	66.9	61.5
	Rating	Partially Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2012	PHI Score	69.2	51.5	62.5	58.3
	Rating	Partially Degraded	Degraded	Degraded	Degraded
	RBP Score	No Data Collected	No Data Collected	No Data Collected	No Data Collected
	Rating				
2013	PHI Score	63.0	53.5	66.6	57.5
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	76	64	82	73
	Rating	Supporting	Partially Supporting	Supporting	Partially Supporting
2014	PHI Score	65.85	56.16	70.79	61.01
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	70	65	81	70
	Rating	Partially Supporting	Partially Supporting	Supporting	Partially Supporting
2015	PHI Score	66.35	52.93	66.68	62.70
	Rating	Partially Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	67	59	66	66
	Rating	Partially Supporting	Non-supporting	Partially Supporting	Partially Supporting
2016	PHI Score	64.80	58.47	68.64	62.70
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	71	61	62	76
	Rating	Partially Supporting	Partially Supporting	Partially Supporting	Supporting

Table 4-9. Continued					
Site		**CC-01**	**CC-02**	**CC-03**	**CC-04**
2017	PHI Score	67.41	60.97	71.72	67.92
	Rating	Partially Degraded	Degraded	Partially Degraded	Partially Degraded
	RBP Score	74	61	70	78
	Rating	Partially Supporting	Partially Supporting	Partially Supporting	Supporting
2018	PHI Score	67.29	56.87	73.06	75.82
	Rating	Partially Degraded	Degraded	Partially Degraded	Partially Degraded
	RBP Score	62	57	70	77
	Rating	Partially Supporting	Non-supporting	Partially Supporting	Supporting
2019	PHI Score	58.49	57.38	66.67	60.44
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	51	60	80	69
	Rating	Non-supporting	Non-supporting	Supporting	Partially Supporting
2020	PHI Score	64.30	60.45	72.44	63.70
	Rating	Degraded	Degraded	Partially Degraded	Degraded
	RBP Score	58	67	80	77
	Rating	Non-supporting	Partially supporting	Supporting	Supporting

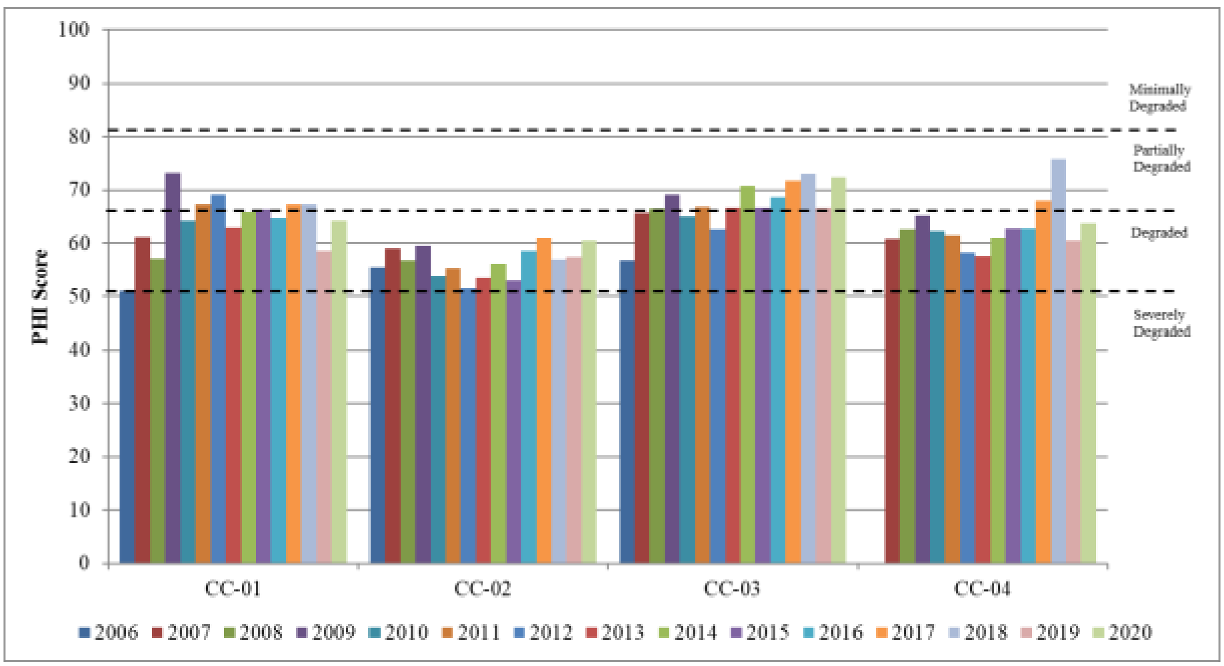

Figure 4-11. Comparison of PHI scores from 2006 to 2020

In 2013 and 2014, the updated MBSS PHI methods (Paul et al. 2003) were used to calculate PHI instead of the original MBSS methods which had been used in the Church Creek watershed reports from previous years. Scores for 2006-2012 shown in Table 4-9 and Figure 4-11 were calculated using the original method, while scores for 2013-2020 were calculated using the updated method.

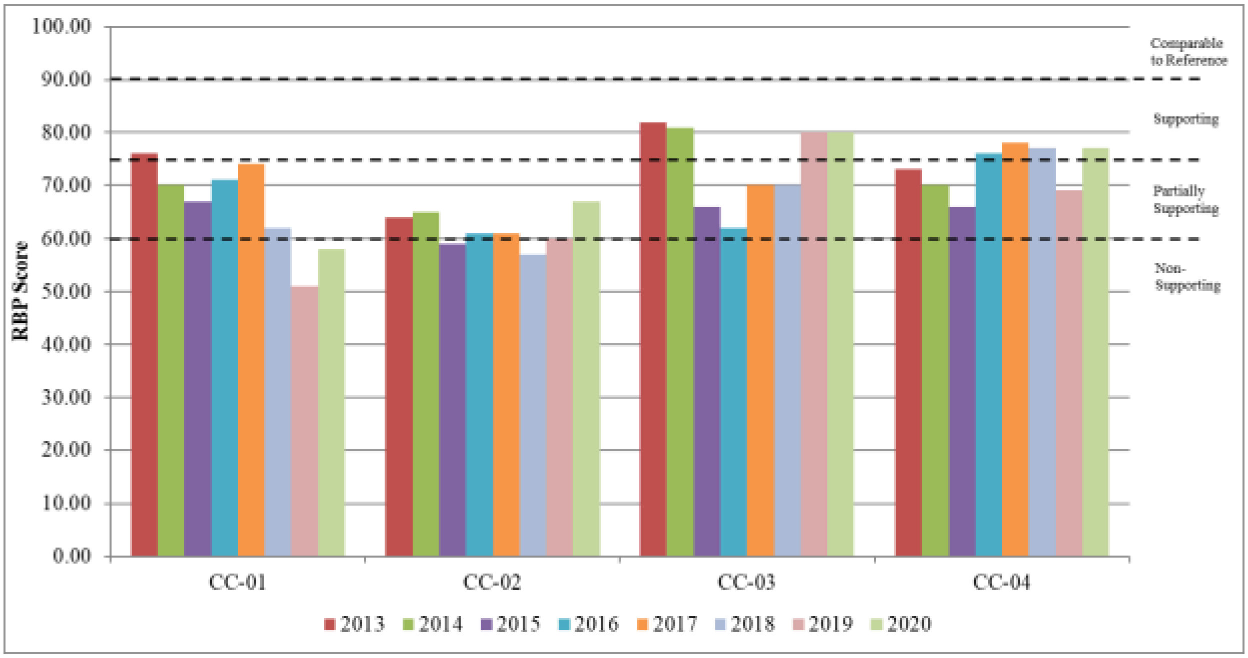

Figure 4-12. Comparison of RBP scores from 2013 to 2020

Biological impairment is evident within this watershed as reflected by the macroinvertebrate communities found throughout the study reach. A comparison of BIBI scores from 2006 through 2020 (Table 4-10) shows no substantial change in biological conditions throughout the study reach. Low BIBI scores can be explained by the lack of pollution-sensitive taxa (reflected in both the EPT taxa metric and the pollution intolerant taxa metric), as well as by generally low taxonomic diversity. While BIBI scores tend to fluctuate from year to year, overall classifications have changed very little with sites consistently rating either "Poor" or "Very Poor"; no clear trends have been established (Figure 4-13). It appears that the biological community continues to be limited by the presence of urban stressors and degraded physical condition of the stream, and annual shifts in BIBI scores are likely related to random and systematic variability inherent in the assessment process.

Table 4-10. BIBI scores from 2006 to 2020

Site		CC-01	CC-02	CC-03	CC-04
2006	BIBI Score	1.86	2.43	1.86	No Data
	Rating	Very Poor	Poor	Very Poor	Collected
2007	BIBI Score	1.00	1.86	2.71	2.71
	Rating	Very Poor	Very Poor	Poor	Poor
2008	BIBI Score	2.43	2.43	2.43	2.14
	Rating	Poor	Poor	Poor	Poor
2009	BIBI Score	1.86	1.86	2.14	2.43
	Rating	Very Poor	Very Poor	Poor	Poor
2010	BIBI Score	1.29	1.86	1.57	2.14
	Rating	Very Poor	Very Poor	Very Poor	Poor
2011	BIBI Score	1.57	1.86	1.57	2.14
	Rating	Very Poor	Very Poor	Very Poor	Poor
2012	BIBI Score	1.86	2.43	1.57	2.43
	Rating	Very Poor	Poor	Very Poor	Poor
2013	BIBI Score	1.57	2.43	1.86	1.29
	Rating	Very Poor	Poor	Very Poor	Very Poor
2014	BIBI Score	1.57	1.86	1.29	1.57
	Rating	Very Poor	Very Poor	Very Poor	Very Poor
2015	BIBI Score	1.57	1.57	2.14	1.86
	Rating	Very Poor	Very Poor	Poor	Very Poor
2016	BIBI Score	1.86	1.57	2.14	2.71
	Rating	Very Poor	Very Poor	Poor	Poor
2017	BIBI Score	2.14	2.14	2.43	1.86
	Rating	Poor	Poor	Poor	Very Poor
2018	BIBI Score	1.57	1.29	2.14	2.14
	Rating	Very Poor	Very Poor	Poor	Poor
2019	BIBI Score	1.57	2.14	1.86	1.86
	Rating	Very Poor	Poor	Very Poor	Very Poor
2020	BIBI Score	1.86	2.43	2.43	2.71
	Rating	Very Poor	Poor	Poor	Poor

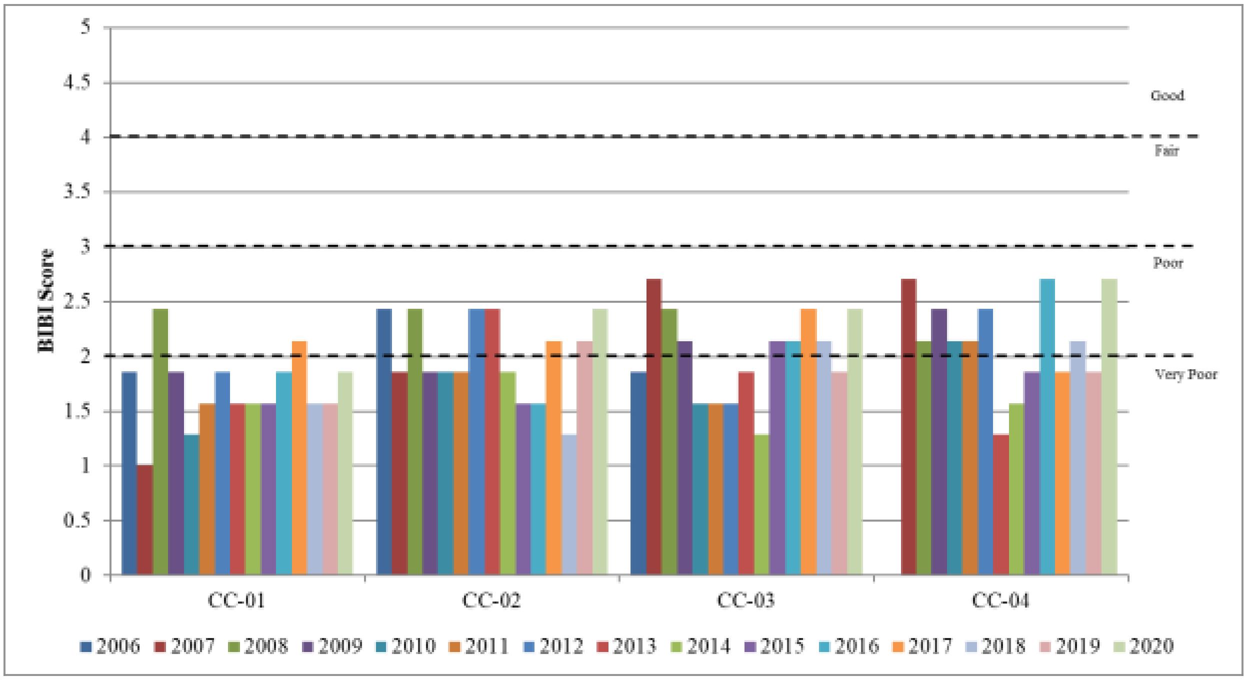

Figure 4-13. Comparison of BIBI scores from 2006 to 2020

4.3 GEOMORPHIC CONDITIONS

The Church Creek study area has a very high percentage of impervious surface cover (approximately 64 percent), and only one reach was classified as a C channel (the newly established XS-1D in 2020), which are generally considered stable stream types due to adequate floodplain connectivity. Four 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 the only change seen at XS-4, from an E5 to an E4 due to coarsening substrate. Evolution of channel type over the course of the study at each cross-section is presented in Table 4-11. 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 4-11. 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
2020	F5	C4	G4c	G4c	E4	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 4-14, 4-15, and 4-16), 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.

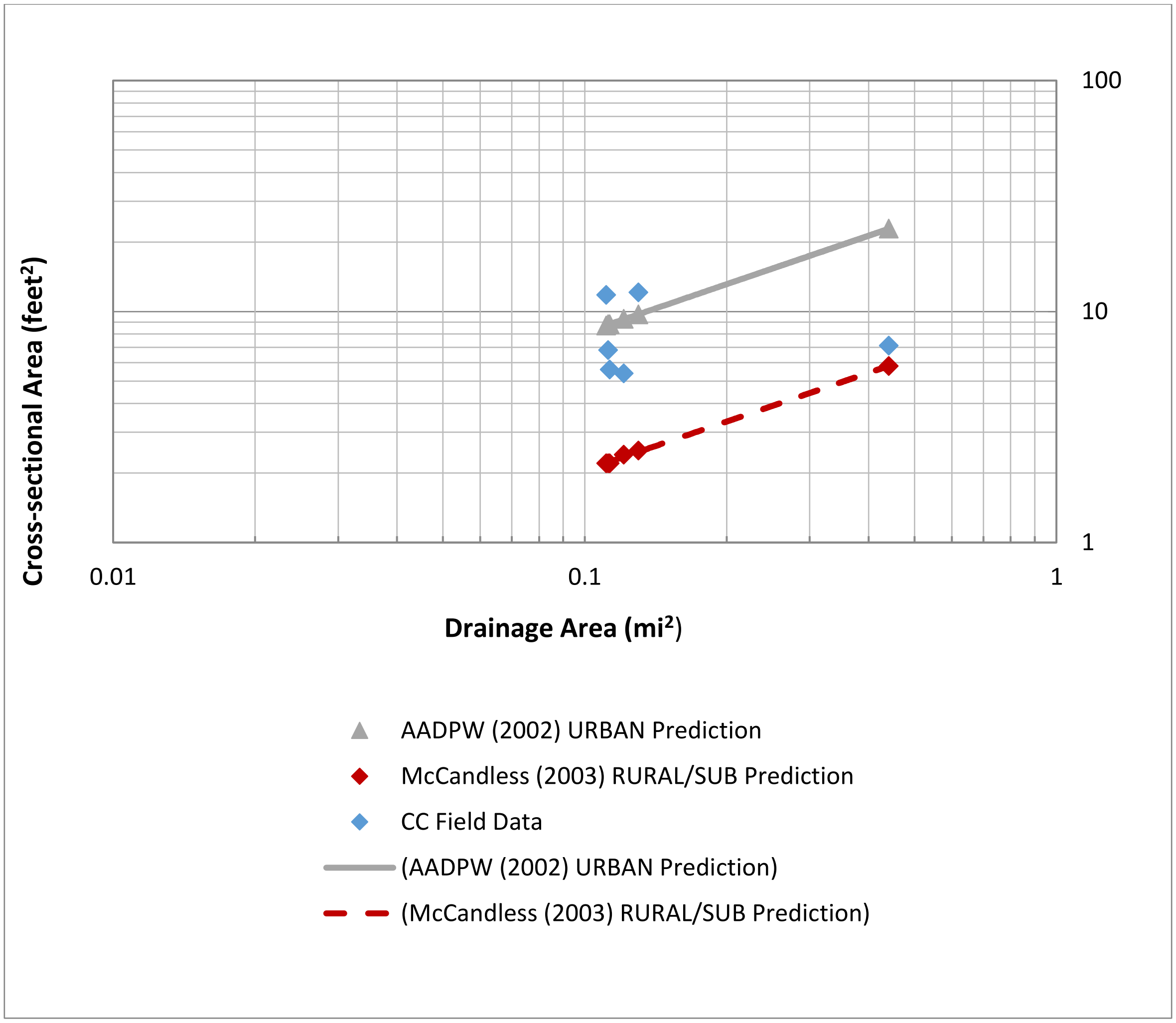

Figure 4-14. Comparison of bankfull channel cross-sectional area to drainage area (CC = Church Creek, 2020 data)

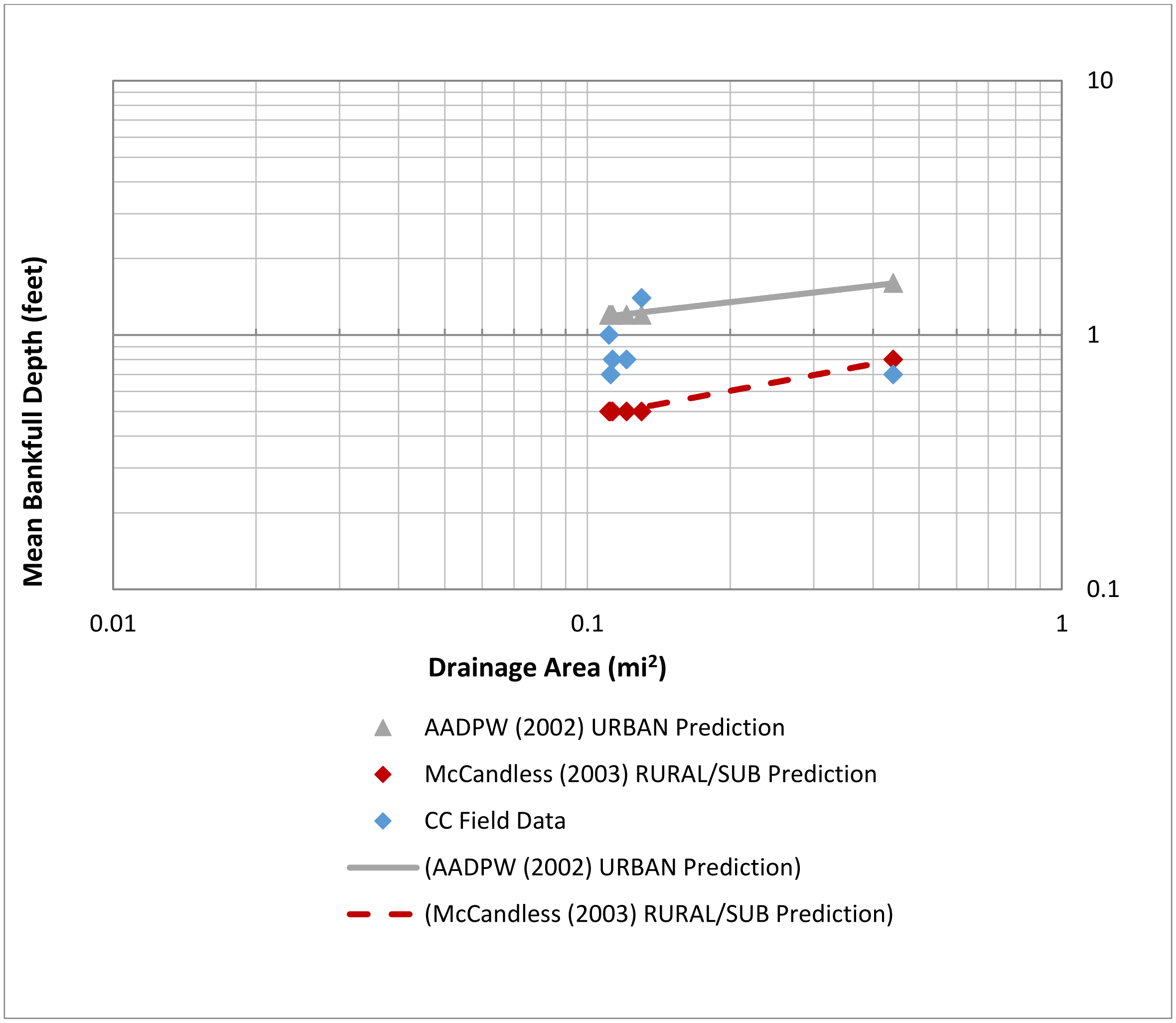

Figure 4-15. Comparison of mean bankfull depth to drainage area (CC = Church Creek, 2020 data)

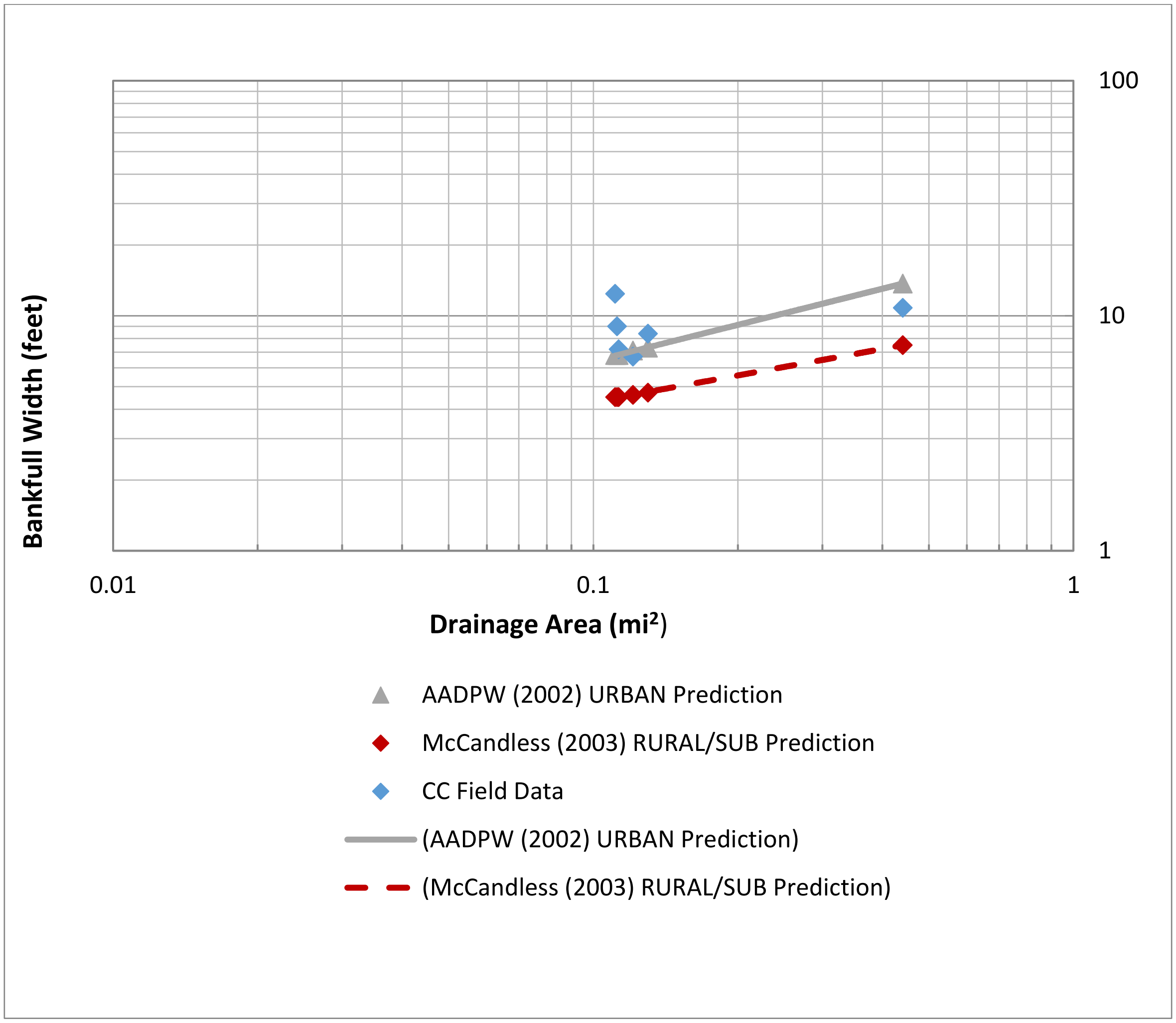

Figure 4-16. Comparison of bankfull width to drainage area (CC = Church Creek, 2020 data)

In terms of percent change over time, three of the five cross-sections (XS-1, 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 4-12). Due to the replacement of XS-3 following channel restoration, data were compared to 2007 at this location only, whereas 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 4-12. Summary of cross-sectional area changes over time

Cross-section[a]	XS-1	XS-2	XS-3	XS-4	XS-5
July 2003	16.8	8.9	ND	14.3	9.7
Jan 2005	20.7	10.0	ND	14.4	9.9
March 2006	19.4	8.0	ND	18.4	9.5
March 2007	19.4	8.9	19.8	17.4	9.0
May 2008	20.1	10.1	16.7	18.0	8.9
July 2009	19.6	9.8	21.0	15.4	8.3
May 2010	19.8	10.3	20.4	16.4	8.5
July 2011[b]	21.3	15.9	20.6	7.8	10.5
April 2012[b]	21.6	15.4	19.2	11.7	5.9
July 2013[b]	21.0	15.5	20.2	11.7	6.9
June 2014 [b]	22.4	16.2	20.6	6.8	6.7
May 2015 [b]	22.6	16.4	18.6	9.2	6.7
March 2016 [b]	25.7	23.0	18.7	15.7	6.6
February 2017 [b]	27.1	18.7	18.2	13.3	6.5
April 2018 [b]	28.4	21.4	19.3	14.2	6.8
March 2019 [b]	30.6	19.8	18.6	14.5	7.3
March 2020 [b]	30.8	20.3	16.5	14.5	7.1
% Change 2003-2020	83.3	128.1	-16.7[c]	1.4	-26.8
% Change 2011-2020	44.6	27.7	-19.9	85.9	-32.4

[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
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 83.3%, and 128.1% respectively, since baseline measurements began in 2003. Cross-section area comparisons since 2011 show more moderate channel enlargements of 44.6% for XS-1 and 27.7% for XS-2. The bed elevation at XS-1 appears to have dropped about 1.1 feet since 2003 with a substantial amount of bed scour occurring between 2014 and 2018 (Appendix F). 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 2020, while aggradation occurred along the right bank (Appendix F).

Cross-section XS-3 had minimal changes in cross-sectional area through 2019, but showed significant aggradation in 2020, with a 16.7% decrease since baseline measurements in 2007 and

-19.9% change 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 F). Between 2011 and 2016 the right bank aggraded across the stream bed and the toe of the right bank, narrowing the stream channel (Appendix F). 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 2020. 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 1.4% between 2003 and 2020 but increased 85.9% 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 30.5% since 2011 and decreased by 24.7% 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 F). Cross-sectional area has remained relatively stable from 2014 to 2020 with little to no change year to year.

4.4 GENERAL CONCLUSIONS

Water chemistry data collected in 2020 continue to show general, gradually decreasing pollutant levels at the Parole Plaza outfall and in Church Creek, but at concentrations that continue to exceed surface water criteria for certain parameters.

During the 2020 monitoring year, annual average EMCs for just under half of the parameters, BOD_5, total phosphorus, TSS, lead, and hardness, were 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. The EMC for zinc at Parole Plaza exceeded the criterion; copper and lead exceeded the corresponding chronic criteria in 2020 at both stations (with copper at Parole Plaza exceeding both the chronic and acute criteria).

Concentrations of phosphorus and combined nitrate and nitrite exceeded surface water criteria in 100% of wet weather samples collected at both Church Creek and Parole Plaza in 2020. *E. coli* concentrations exceeded the water quality criterion in 96 percent of samples at Church Creek and in 85 percent of samples at Parole Plaza. Percentage exceedances for copper, zinc, and BOD_5 were higher at Parole Plaza than at Church Creek.

For most parameters, annual loads at Church Creek exceeded those at Parole Plaza during 2020 except for *E. coli*. The mean annual loading rates for all parameters at the Parole Plaza station were lower during post-redevelopment (2009 to 2020) than pre-redevelopment (2002-2006). However, at the Church Creek station, all mean annual post-redevelopment parameters except for lead and *E. coli* (compared to fecal coliform) exceeded the mean annual pre-redevelopment loads, likely due to higher annual flow volume during the post-redevelopment period than the pre-redevelopment period.

At Parole Plaza, annual pollutant concentrations in 2020 increased for most parameters (except for TPH, BOD_5, and *E. coli*) after three successive years of declining values. Most average annual pollutant concentrations (except for TPH and *E. coli*) increased at Church Creek in 2020. Annual EMCs for total phosphorus, lead, and TSS at Church Creek in 2020 were the highest since 2010 or earlier. Overall, the moderate downward trends in EMC values at both Parole Plaza and Church Creek since approximately 2006, except for *E. coli*, continue. 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 concentrations in the 2017-2019 annual monitoring periods.

Reasons for the unexpected increase in average annual EMCs at Church Creek may include the following and could confound efforts to determine the cumulative benefits of restoration projects in the Church Creek watershed:

- Natural variability in pollutant deposition on impervious surfaces and other phenomena, such as frequency of rain (which would keep surfaces relatively cleaner or allow buildup of pollutants depending on frequency); or
- Disintegration of stormwater infrastructure at Parole Plaza and possibly elsewhere due to age, which would promote leaching of metals from metal pipes (via storms at Parole Plaza outfalls, which form 42.7% of the impervious surface in the Church Creek watershed) and transport of suspended solids and other stored material from BMPs.

Although the stream channel has been stabilized along several reaches, the positive effects on biota are yet to be seen from these efforts. 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 will be used to evaluate the effects of this restoration.

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APPENDIX A

STORM EVENT HYDROGRAPHS, NARRATIVES AND COMPOSITE SAMPLING METHOD TECHNICAL MEMORANDUM

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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
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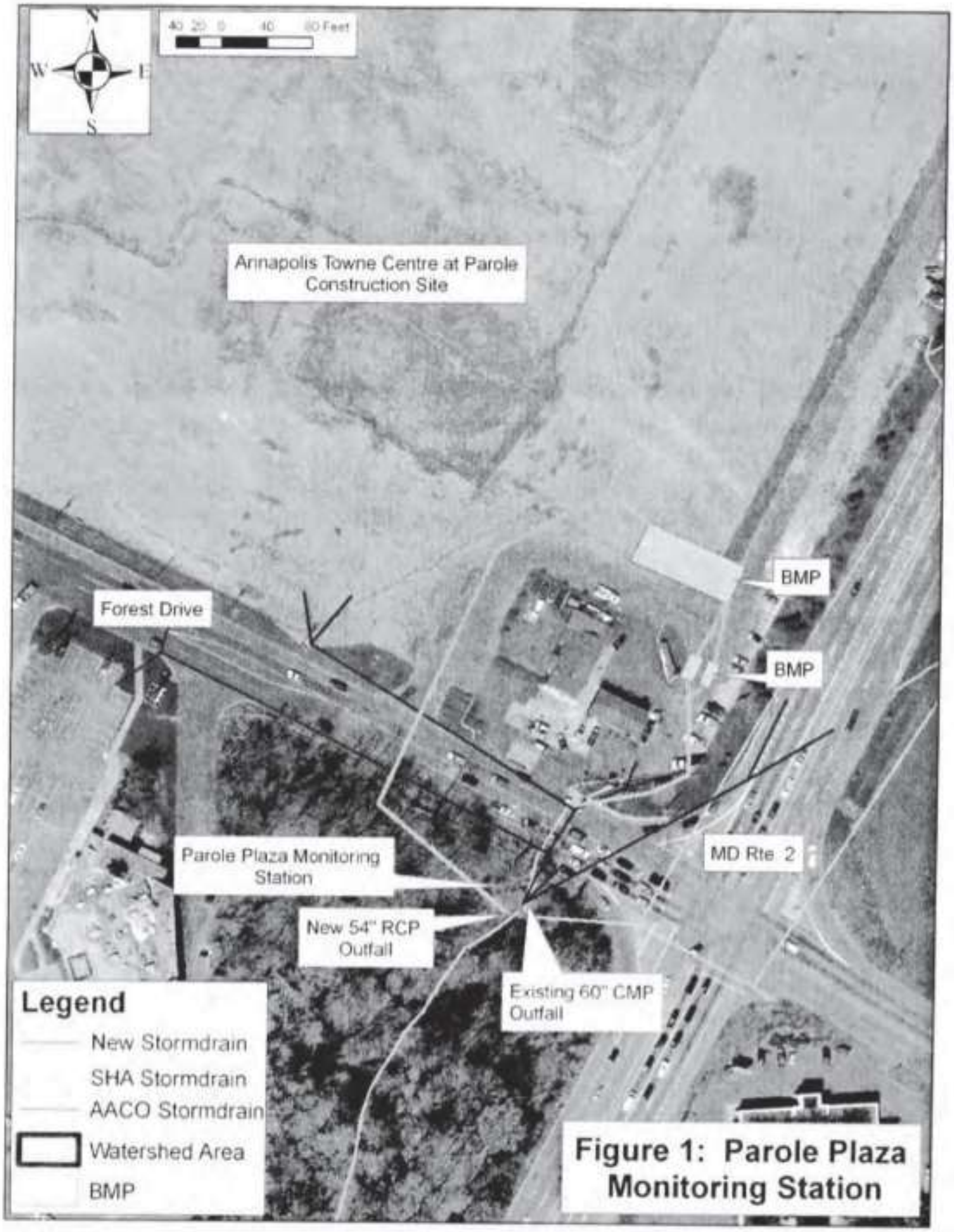

Figure 1: Parole Plaza Monitoring Station

Proposed Modifications to Sampling Procedures
Church Creek/Parole Plaza NPDES Monitoring 2008
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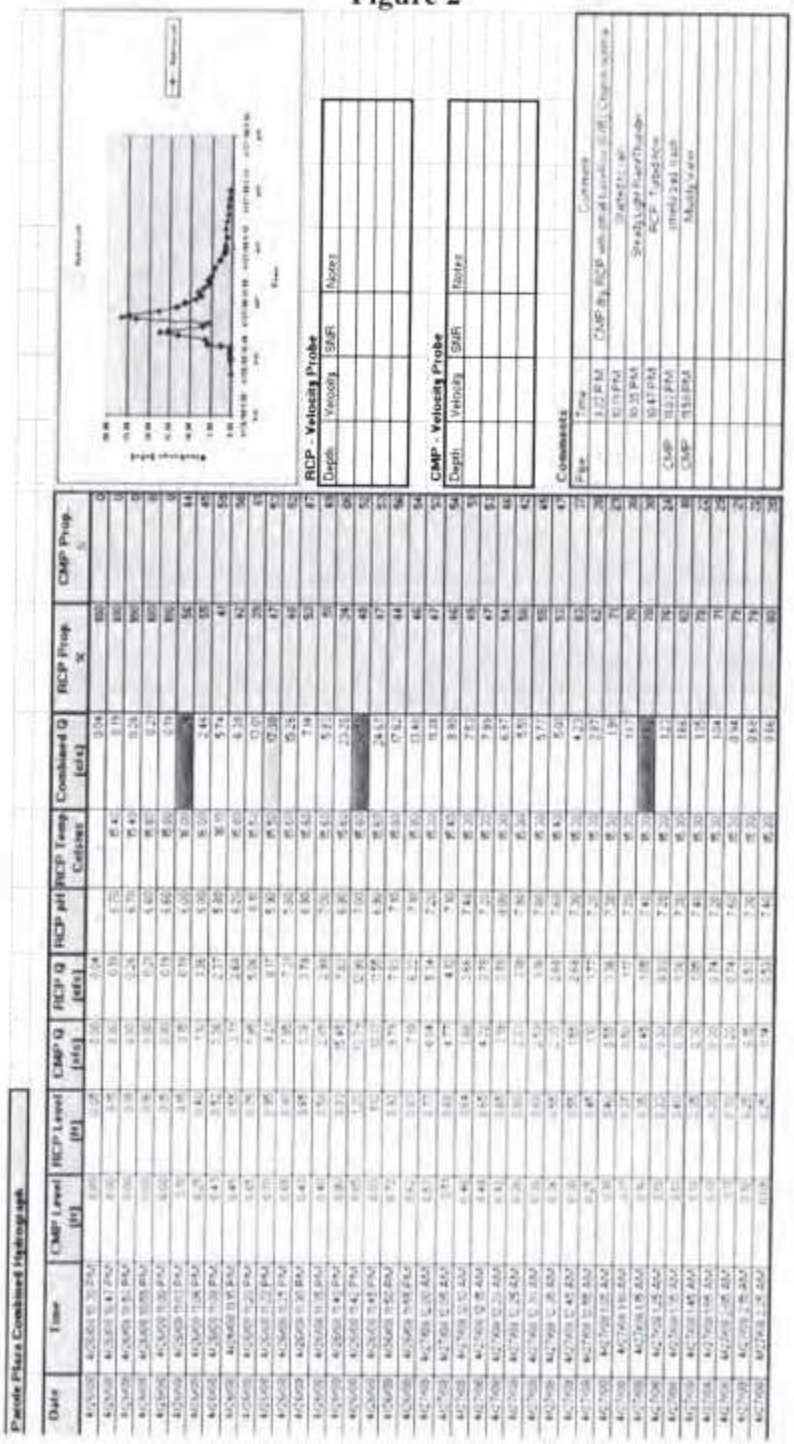
Figure 2



Storm Event Narratives

Storm: July 11, 2019

The total rainfall for this event was 1.28 inches. The storm lasted approximately six hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, four of the parameter event mean concentrations (EMCs) were greater than their respective long-term average concentrations measured during storms monitored for the program (i.e., since December 12, 2012). The EMC for total suspended solids (TSS) exceeded the average by 78%. The concentrations for TSS were 140 mg/L (rising), 120 mg/L (peak), and 27 mg/L (falling) during the storm event. The lead concentrations for the storm measured 14.5 µg/L (rising), 15.6 µg/L (peak), and 4.48 µg/L (falling); the EMC exceeded the average by 124%. The EMC for *Escherichia coli* (*E. coli*) was slightly higher than the average, by 5%. The *E.* coli concentrations were 638 MPN (rising), 4,352 MPN (peak), and 8,664 MPN (falling). Total Phosphorus exceeded the average by 25%. Phosphorus concentrations were 0.39 mg/L (rising), 0.26 mg/L (peak), and 0.14 mg/L (falling). Total petroleum hydrocarbons (TPH) were detected during the peak limb at Church Creek.

None of the pollutants exceeded their respective long-term event mean concentrations.

Storm: October 16, 2019

The total rainfall for this event was 1.14 inches. The storm lasted approximately six hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, three 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 24.5%. The concentrations for TP were 0.66 mg/L (rising), 0.22 mg/L (peak), and 0.17 mg/L (falling) during the storm event. The higher concentrations of TP may be due to wash off of fertilizer products applied to lawns in the watershed. The lead concentrations for the storm measured 17.5 µg/L (rising), 5.97 µg/L (peak), and 3.07 µg/L (falling); the EMC exceeded the average by 7.6%. The EMC for *Escherichia coli* (*E. coli*) exceeded the long-term average EMC by 44.8%. The *E. coli* concentrations were 2,046 MPN/100 ml (rising), 9,804 MPN/100 ml (peak), and 6,867 MPN/100 ml (falling).

At Parole Plaza, *E. coli* exceeded the long-term average EMC by 107.6%. The measured concentrations in the Corrugated Metal Pipe (CMP) were 3,076 MPN/100 mL (rising), 5,794 MPN/100 mL, and > 24,196 MPN/100 mL (falling). At the Reinforced Concrete Pipe (RCP), the measured concentrations were 160 MPN/100 mL (rising), > 24,196 MPN/100 mL (peak), and > 24,196 MPN/100 mL (falling). The limbs with results greater than 24,196 MPN/100 mL contained *E. coli* concentrations that exceeded the limits of the test. The laboratory applied a 10:1 dilution, as requested by Versar field staff, for samples from this storm, which is typical for fall storms; however, dry conditions in the preceding months may have led to increased concentrations of *E. coli* on impervious surfaces. In the future, staff will consider antecedent dry conditions when determining which dilution to request from the lab. For the purpose of calculating the EMC and load, staff will set the *E. coli* value to 24,196 MPN/100 mL for limb results that exceeded the limits of the test. Additionally, pH values at Parole Plaza were elevated with the CMP showing values between 9 and 10, and the RCP showing values between 8 and 9. These readings may be attributable to mobilization of residue in the storm drain system and on upland impervious surfaces from washing activity in the catchment. Further investigation is needed to determine the cause of the elevated pH values.

Storm: November 24, 2019

The total rainfall for this event was 0.61 inches. The storm lasted approximately eight and a half hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, the only pollutant that exceeded its long-term average EMC was *E. coli*, by 82.1%. Measured concentrations were 228 MPN/100 ml (rising), 15,665 MPN/100 ml (peak), and 1,223 MPN/100 ml (falling).

At Parole Plaza, none of the pollutants exceeded their respective long-term average EMCs. During this storm event, pH values at Parole Plaza were elevated with the CMP showing values between 10 and 11, and the RCP showing values between 8 and 9, probably due to ongoing conditions in the contributing catchment and storm drain system.

Storm: December 29, 2019

The total rainfall for this event was 0.52 inches. The storm lasted approximately nine hours. These measurements were based on data from the Church Creek rain gauge.

The only pollutant at either site that exceeded its long-term EMC was total petroleum hydrocarbons (TPH) at Parole Plaza, which exceeded the long-term average by 503%. TPH was below the detection limit for the rising and falling limbs of the storm but was measured at 6 mg/L at the peak flow for this storm. Note that because detections of TPH are rare due to concentrations that are below the reportable detection limit of 5 mg/L, the EMC resulting from a detectible concentration, compared against a history of mostly non-detects (when they set to 0 mg/L for calculation purposes), results in a high percent difference.

During this storm event, pH values at Parole Plaza were elevated, with the CMP showing values between 10 and 11, and the RCP showing values between 8 and 9, probably due to ongoing conditions in the contributing catchment and storm drain system.

Storm: January 25, 2020

The total rainfall for this event was 1.32 inches and lasted approximately eight hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, five 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 15%. The concentrations for TP were 0.35 mg/L (rising), 0.26 mg/L (peak), and 0.10 mg/L (falling) during the storm event. The lead concentrations for the storm measured 5.8 µg/L (rising), 13.9 µg/L (peak), and 3.2 µg/L (falling); the EMC exceeded the average by 95%. The EMC for zinc exceeded the long-term average EMC by 12%. The zinc concentrations were 77.2 mg/L (rising), 125 mg/L (peak), and 51.9 mg/L (falling). Total suspended solids (TSS) exceeded its long-term EMC by 100% with concentrations of 100 mg/L (rising), 140 mg/L (peak), and 19 mg/L (falling). Hardness exceeded its long-term EMC by just 4%. The high rainfall in a relatively short period of time, resulting in a high volume of discharge, may have been the cause of the elevated concentrations of TSS. 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.

At Parole Plaza, three of the parameter EMCs were greater than their respective long-term EMCs. TSS exceeded its long-term EMC by 28% with concentrations of 25 mg/L (rising), 50 mg/L (peak), and 11 mg/L (falling). Lead was not detected in the rising or falling limb samples but had a concentration of 2.6 µg/L at peak flow, causing the EMC to exceed the long-term average EMC by 13%. Hardness exceeded its long-term EMC by 15% with concentrations of 80 mg/L (rising), 48 mg/L (peak), and 52 mg/L (falling). Additionally, pH values at Parole Plaza were elevated with the CMP showing values between 8 and 10, and the RCP showing values between 8 and 11. These readings may be attributable to mobilization of residue in the storm drain system and on upland impervious surfaces from washing activity in the catchment. Further investigation is needed to determine the cause of the elevated pH values.

Storm: March 13, 2020

The total rainfall for this event was 0.25 inches. The storm lasted approximately four and one half hours. These measurements were based on data from the Church Creek rain gauge.

At Church Creek, three parameters exceeded their long-term average EMCs. Nitrate-nitrite concentrations, possibly present from fertilizer applications but not taken up and metabolized by plants, were 1.2 mg/L (rising), 0.73 mg/L (peak), and 0.54 mg/L (falling); exceeding the long-term EMC by 54%. TSS exceeded the long-term EMC by 46% with concentrations of 160 mg/L (rising), 120 mg/L (peak), and 15 mg/L (falling). Hardness exceeded the long-term EMC by just 10% with concentrations of 120 mg/L for the rising limb and 48 mg/L for both the peak and falling limbs.

At Parole Plaza, three of the parameters exceeded their respective long-term average EMCs. Nitrate-nitrite exceeded its long-term EMC by 13% with concentrations of 1.3 mg/L (rising), 0.42 mg/L (peak), and 0.61 mg/L (falling). The zinc concentrations during this event were 346 µg/L (rising), 171 µg/L (peak), and 100 µg/L (falling), resulting in an EMC that was slightly above (8%) the long-term average. Hardness exceeded its long-term EMC by 25% with concentrations of 92 mg/L (rising), 56 mg/L (peak), 48 mg/L (falling). The total petroleum hydrocarbon EMC did not exceed its respective long-term average EMC; however, note that the rising limb result was 14 mg/L, which was unusually high. During this storm event, pH values at Parole Plaza were elevated with the CMP showing values between 9 and 10, and the RCP showing values between 8 and 9, probably due to ongoing conditions in the contributing catchment and storm drain system.

Note that the concentrations of each of the parameters discussed above at both stations were highest during the rising limb which may be due to runoff in the catchment rapidly initiating at the beginning of this storm event and mobilizing stored residue on impervious surfaces.

Storm: March 25, 2020

The total rainfall for this event was 0.22 inches. The storm lasted approximately four and one half hours. These measurements were based on data from the Church Creek rain gauge.

None of the pollutants exceeded their respective long-term EMCs at either site. These results may be due to the passage of three rain events between the event on March 13, 2020 and this event that may have kept impervious surfaces relatively free of pollutants.

During this storm event, pH values at Parole Plaza continued to be elevated, with the CMP showing values between 10 and 11, and the RCP showing values between 8 and 9, probably due to ongoing conditions in the contributing catchment and storm drain system.

Also, during this storm, staff discovered that the water quality sonde at Church Creek was not recording data. Versar staff was able to remedy the issue by tightening the connection between the cable and the automated sampler to restore communication.

Storm: April 12, 2020

The storm delivered 1.37 inches of total rainfall and lasted approximately 13 hours. These measurements were based on data from the Church Creek rain gauge.

At the Church Creek station, the following pollutants exceeded their long-term average EMC values: total Kjeldahl nitrogen (45%), total phosphorus (99%), TSS (78%), copper (46%), and lead (95%). Maximum lead (23.9 µg/L), copper (27.4 µg/L), and zinc (178 µg/L) concentrations occurred during the peak limb, following the peak TSS concentration (210 mg/L). Nutrients were highest during the rising limb, indicating a buildup of fertilizers and fecal matter in the catchment. *E. coli* concentrations, however, were lower than the long-term average. The rainfall rate peaked at 0.35 in./5 min., which may have helped mobilize TSS and attached metals, while diluting nutrients.

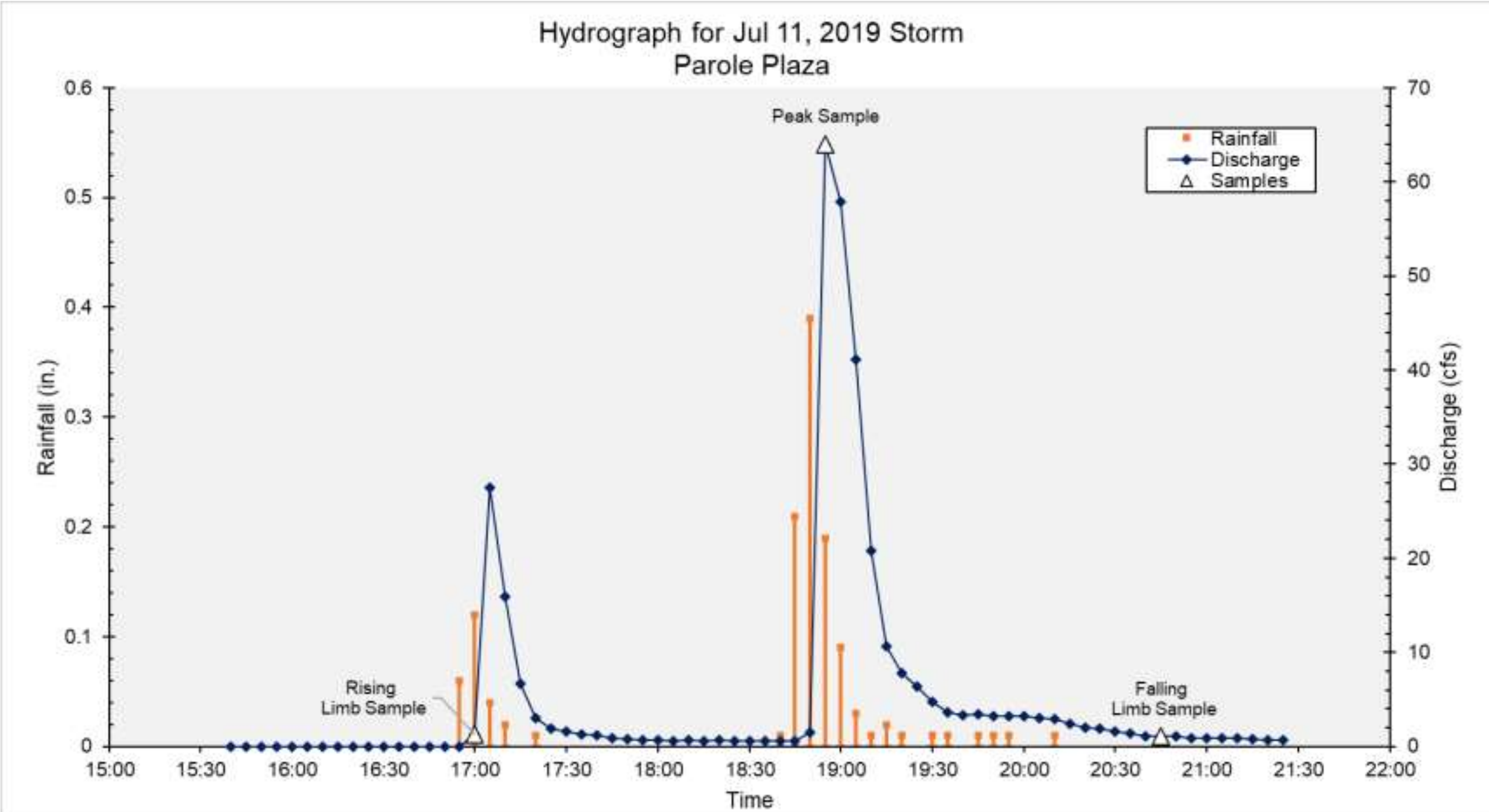
At the Parole Plaza station, the following pollutants exceeded their long-term average EMC values: total Kjeldahl nitrogen (43%), total phosphorus (19%), nitrate and nitrite (37%), copper (117%), lead (263%), zinc (92%), and hardness (68%). As was the case at Church Creek, maximum concentrations of metals occurred during the peak limb: lead (15.9 µg/L), copper (83.1 µg/L), and zinc (451 µg/L). Nutrient concentrations were highest during the rising limb at Parole. *E. coli* was also highest during the peak limb, but the EMC was lower than the long-term average. The presence of high concentrations of metals may be due to a) the prevalence of impervious surfaces and vehicular traffic, b) may be related to the hypothetical dissolution of the cladding in the CMP due to deposition of highly basic material, or c) the vigorousness of the discharge from the peak intensity of the storm. Note that peak copper and zinc concentrations were higher in proportion to TSS, which may indicate that leaching of material from the CMP may be more of a factor than presence of metal-labelled suspended solids. During the event, pH values at the CMP rose from approximately 9.0 to approximately 9.5 during the peak limb, and then gradually fell toward the conclusion of the storm. The In-situ sonde failed to log at the RCP due to technician error, so those data are not available and are not incorporated into the flow-weighted values presented in Appendix G.

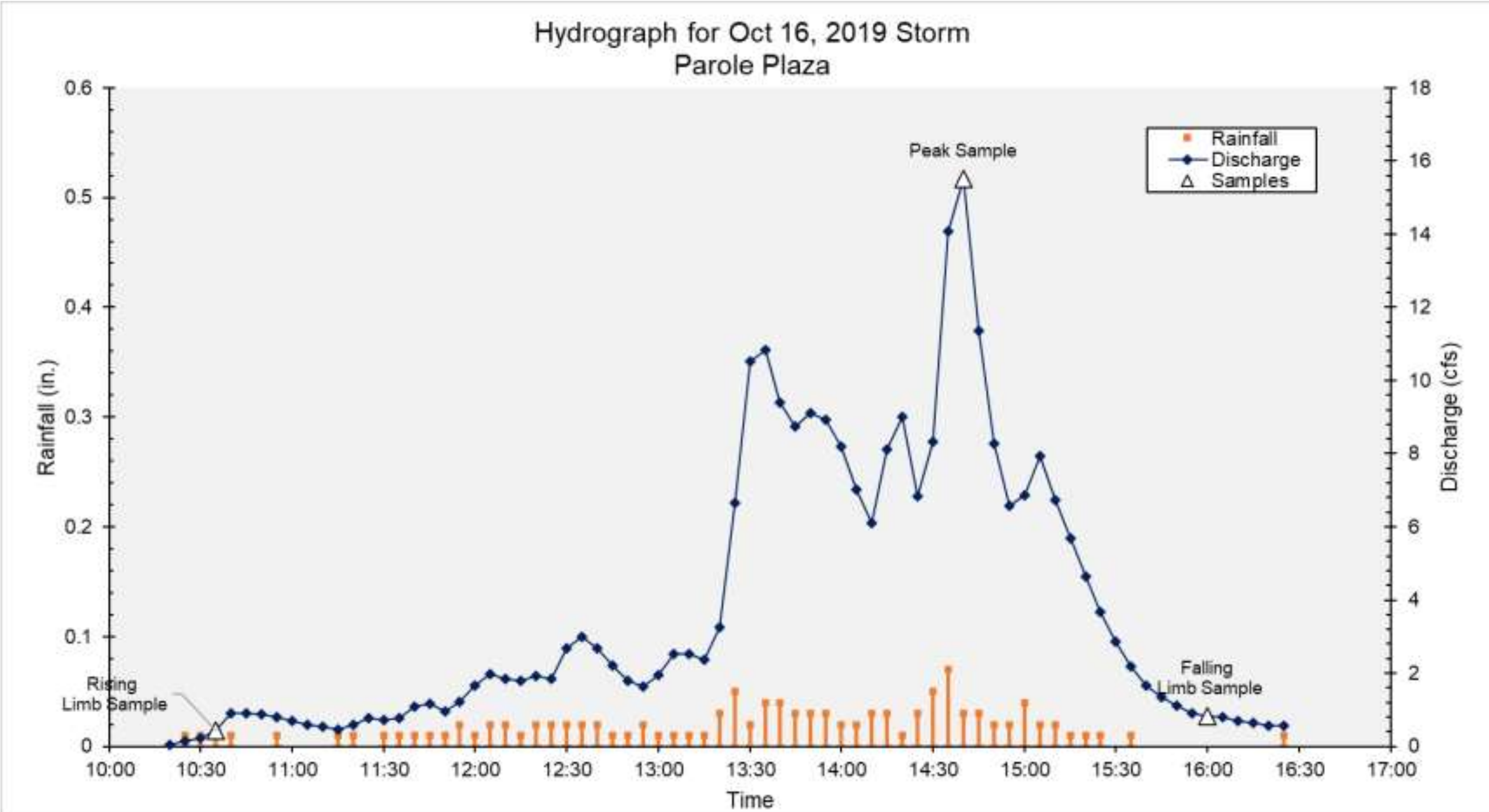
Storm: June 11, 2020

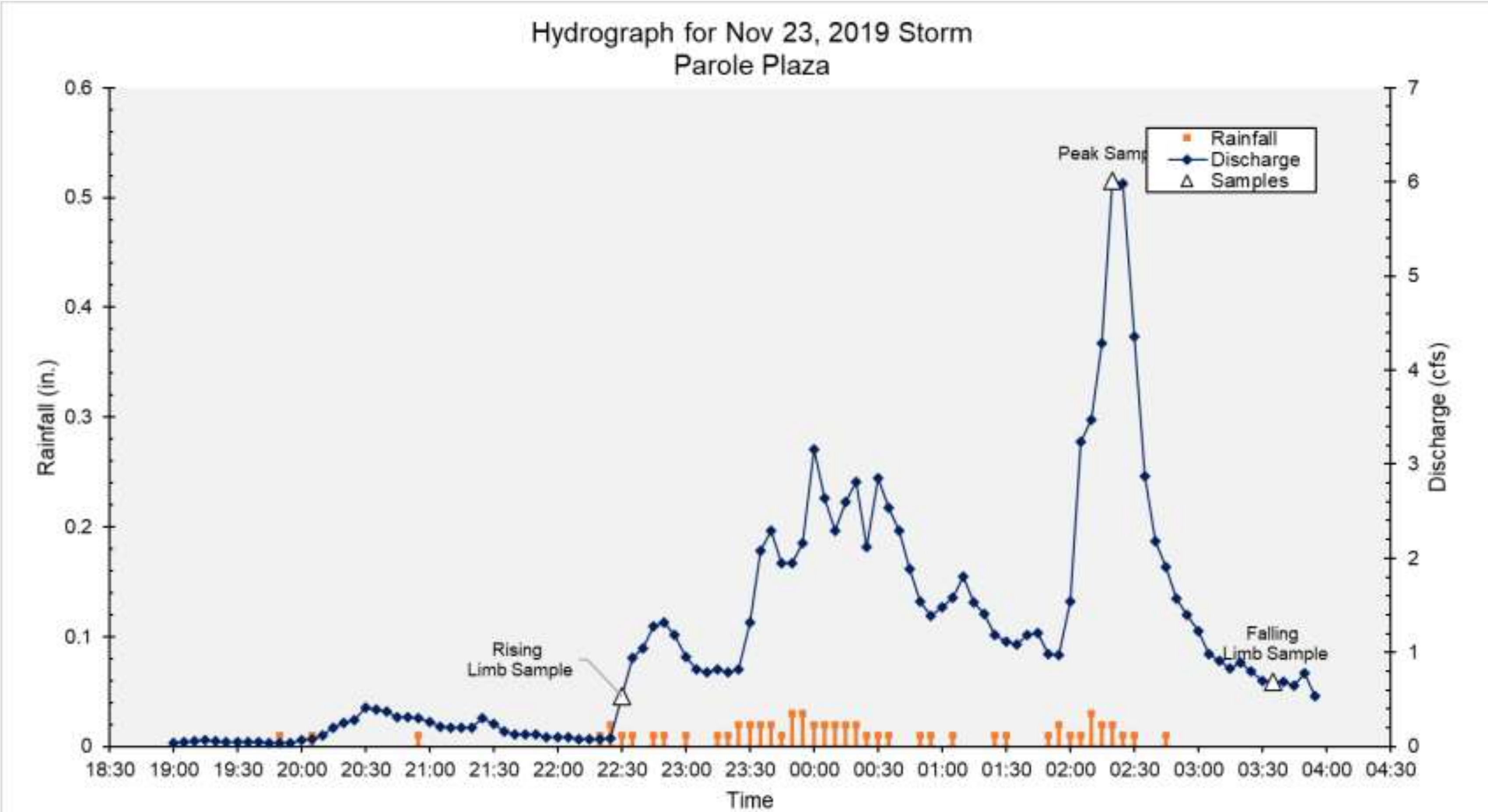
The total rainfall for this event was 0.41 inches; the storm lasted approximately four hours. These measurements were based on data from the Church Creek rain gauge.

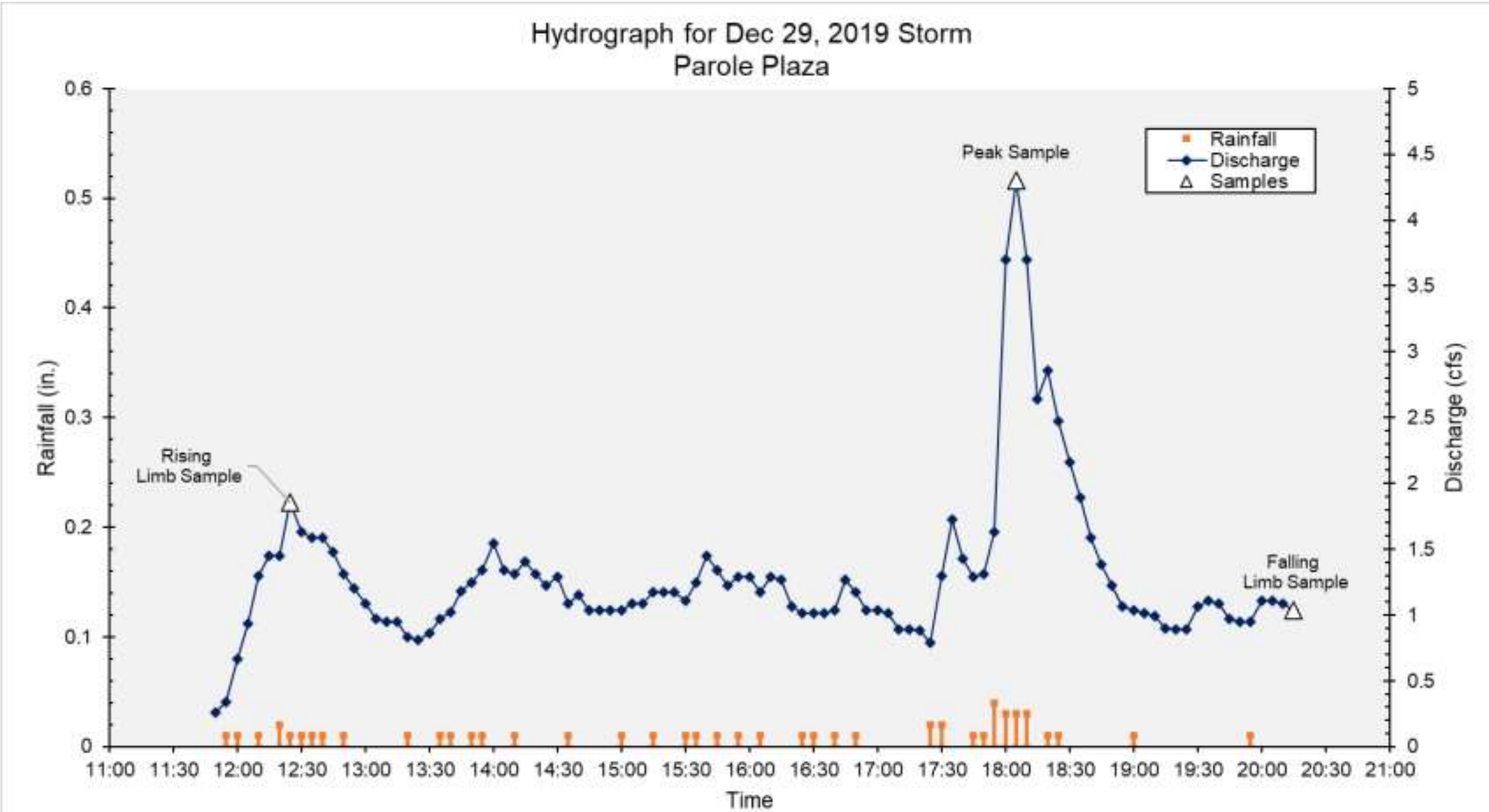
At both stations, only the EMCs for *E. coli* exceeded the corresponding long-term average concentrations. Maximum composite concentrations of *E. coli* during the event were 17,329 MPN/100 ml (peak limb) and 13,568 MPN/100 ml (falling limb), respectively, at the Church Creek and Parole Plaza stations. The high *E. coli* values may be due to deposition of fecal matter in the catchments by local fauna over the five days since the previous rainfall event. *E. coli* levels are typically higher during the warmer months of the year.

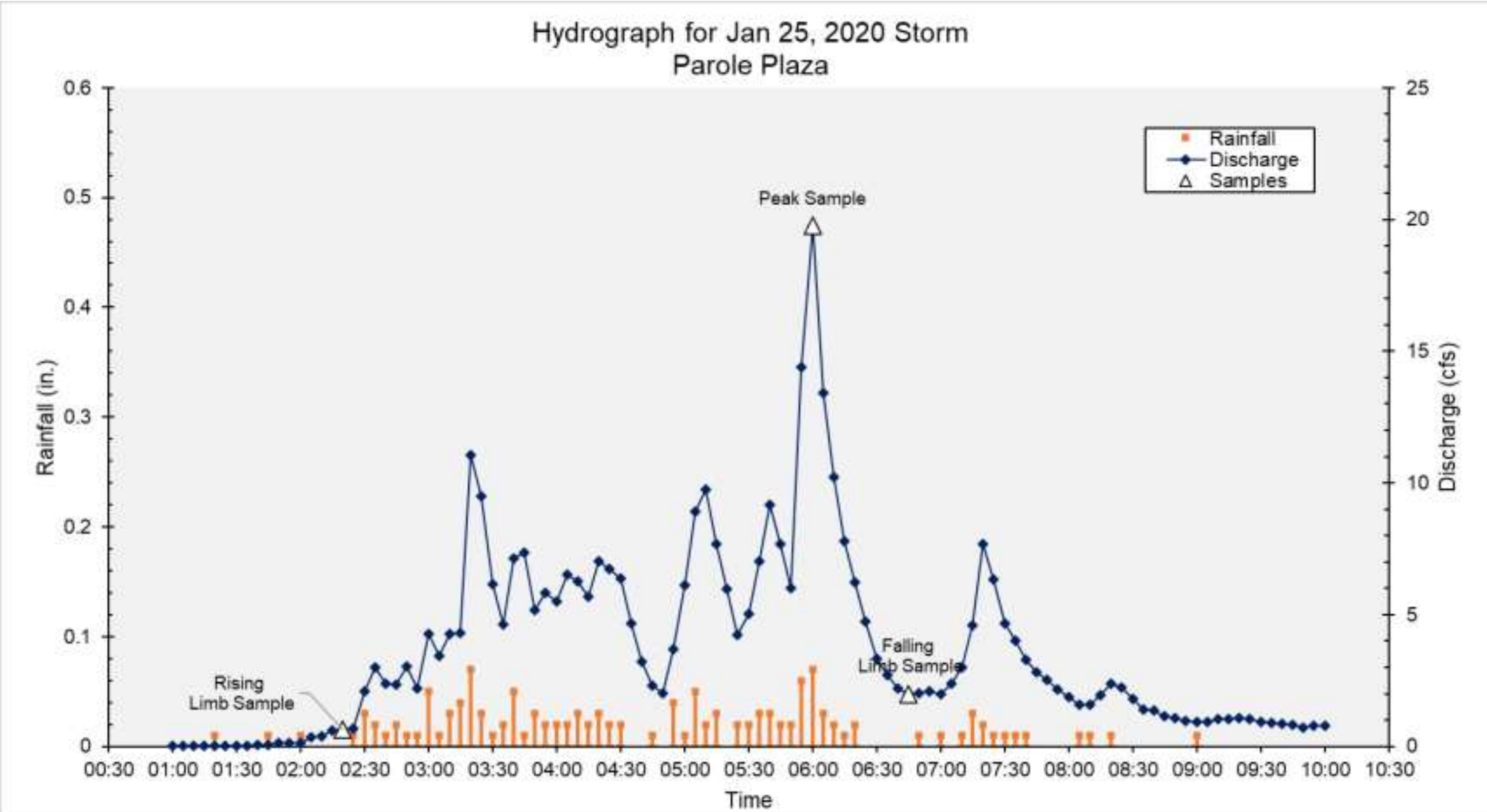
At the Parole Plaza station, pH at the RCP ranged from approximately 10 during the peak limb to approximately 9.0 near the conclusion of the storm. The pH value was 10.5 during the rising limb, up from the baseflow value of 8.8 five minutes before. At the CMP, pH increased from 10.2 to 10.8 during the rising limb, then increased to 10.9 during the peak flow, and then gradually decreased to below 9 during the falling limb. Both behaviors may indicate the dissolving and mobilization of material deposited in the storm drain system or the BMPs.

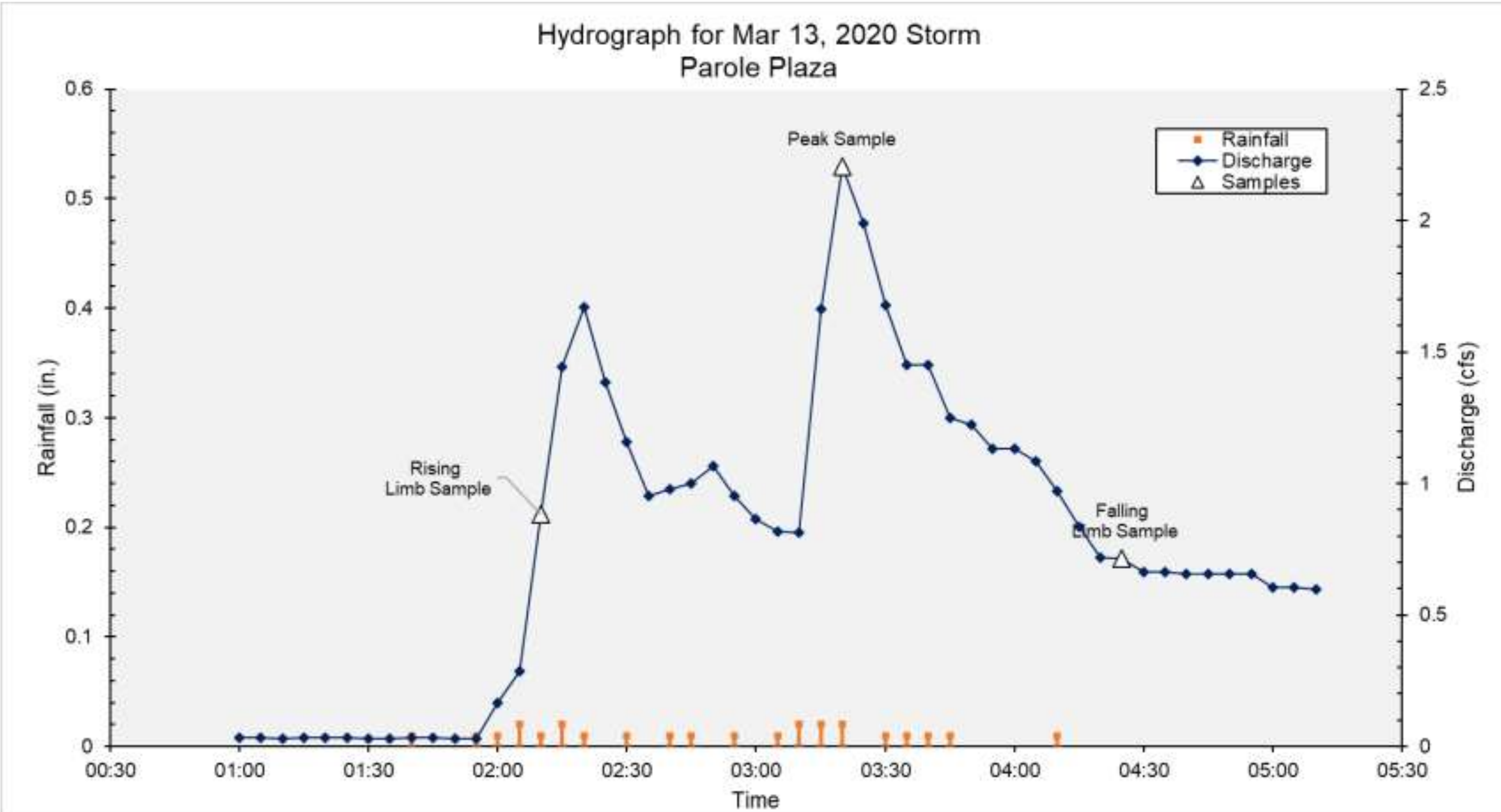

Hydrograph for Jul 11, 2019 Storm
Parole Plaza
Peak Sample
Rainfall
Discharge
Samples
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
70
60
50
40
30
20
10
0
15:00
15:30
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30
20:00
20:30
21:00
21:30
22:00

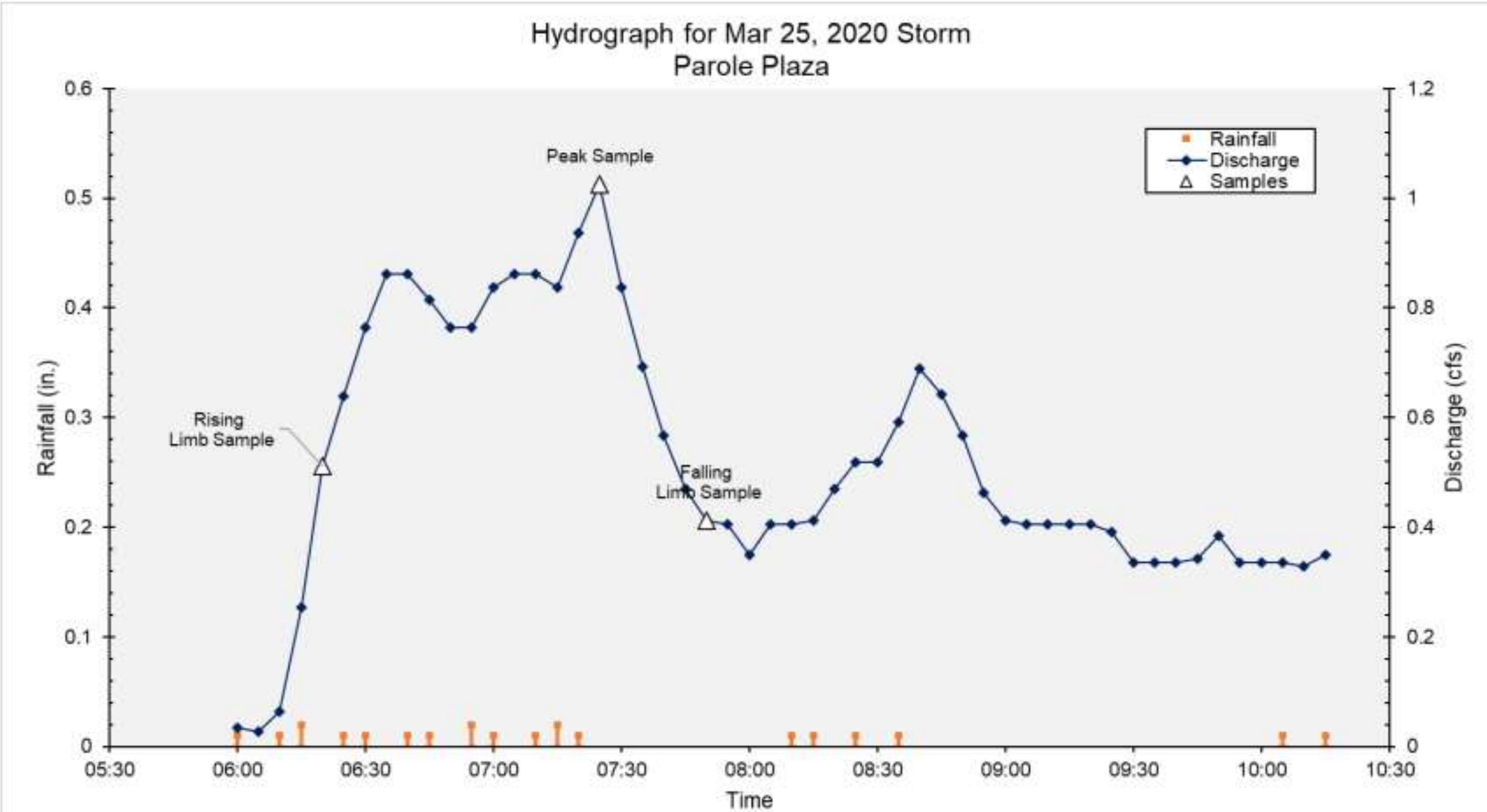

Hydrograph for Oct 16, 2019 Storm
Parole Plaza
Rainfall (in.)
Discharge (cfs)
Time
Rainfall
Discharge
Samples
Peak Sample
Rising Limb Sample
Falling Limb Sample
0.6
0.5
0.4
0.3
0.2
0.1
0
18
16
14
12
10
8
6
4
2
0
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00


Hydrograph for Nov 23, 2019 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Samp
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
7
6
5
4
3
2
1
0
18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 00:00 00:30 01:00 01:30 02:00 02:30 03:00 03:30 04:00 04:30

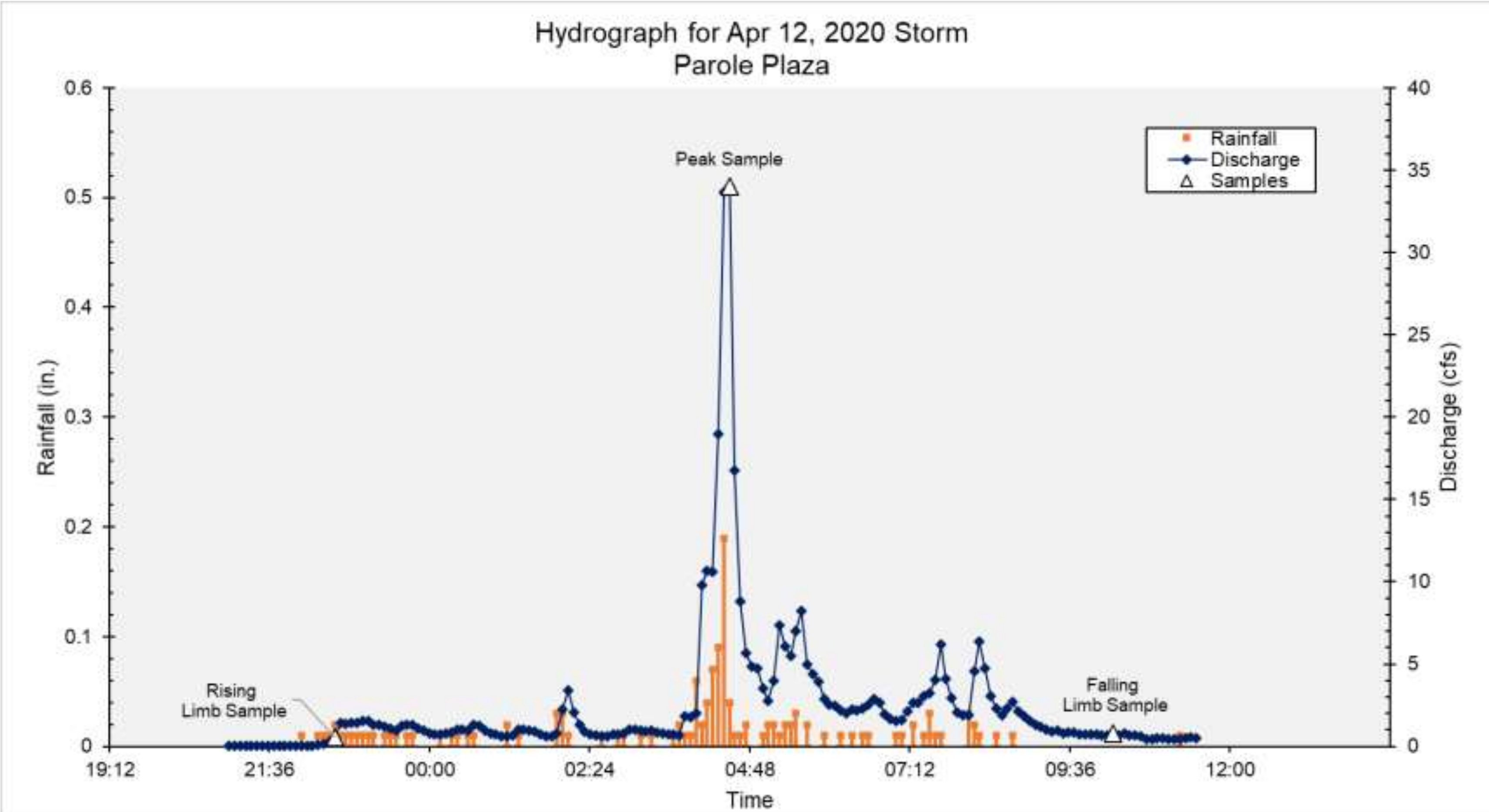

Hydrograph for Dec 29, 2019 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00

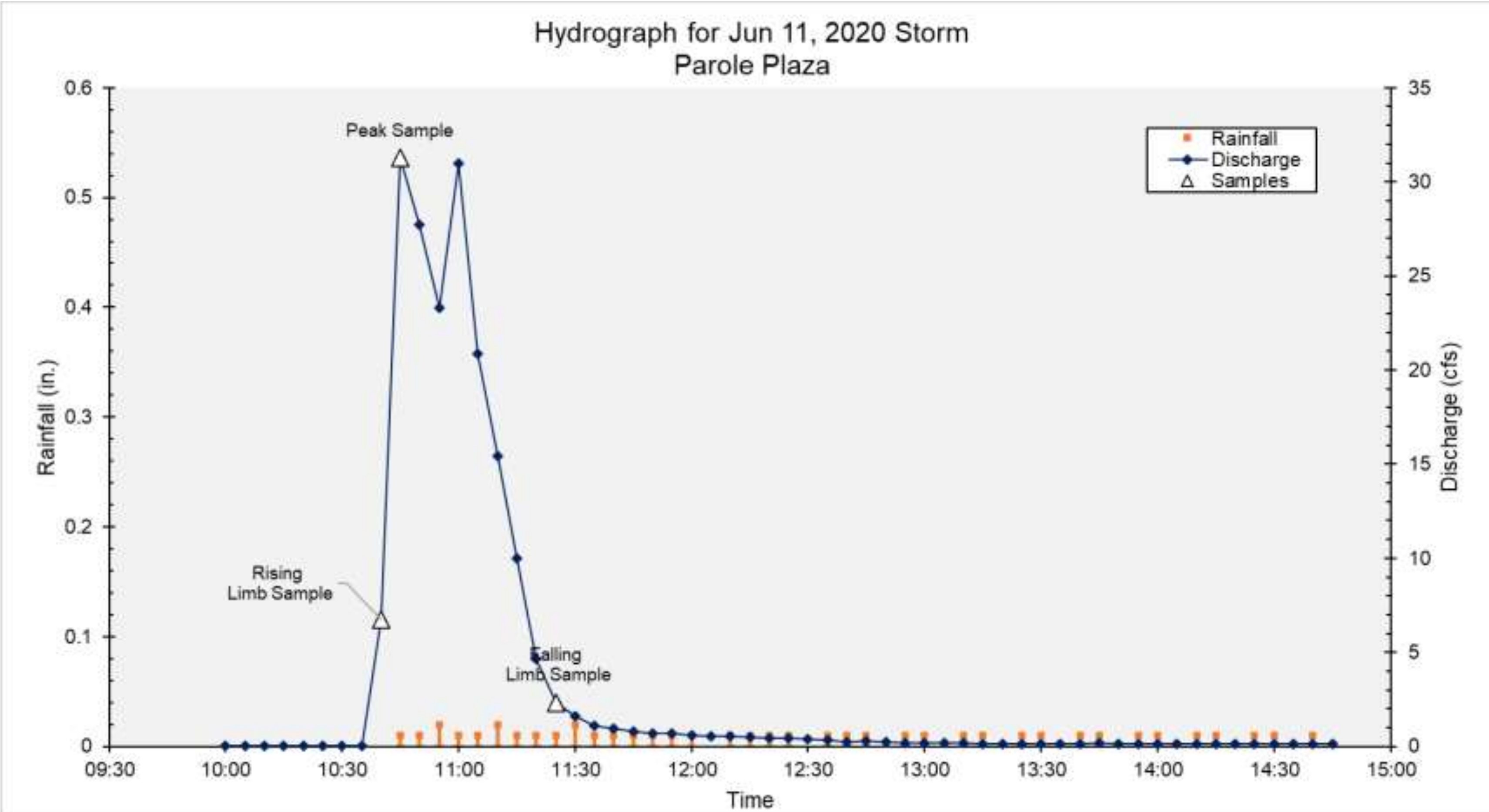

Hydrograph for Jan 25, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
25
20
15
10
5
0
00:30 01:00 01:30 02:00 02:30 03:00 03:30 04:00 04:30 05:00 05:30 06:00 06:30 07:00 07:30 08:00 08:30 09:00 09:30 10:00 10:30


Hydrograph for Mar 13, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.5
1
1.5
2
2.5
00:30
01:00
01:30
02:00
02:30
03:00
03:30
04:00
04:30
05:00
05:30



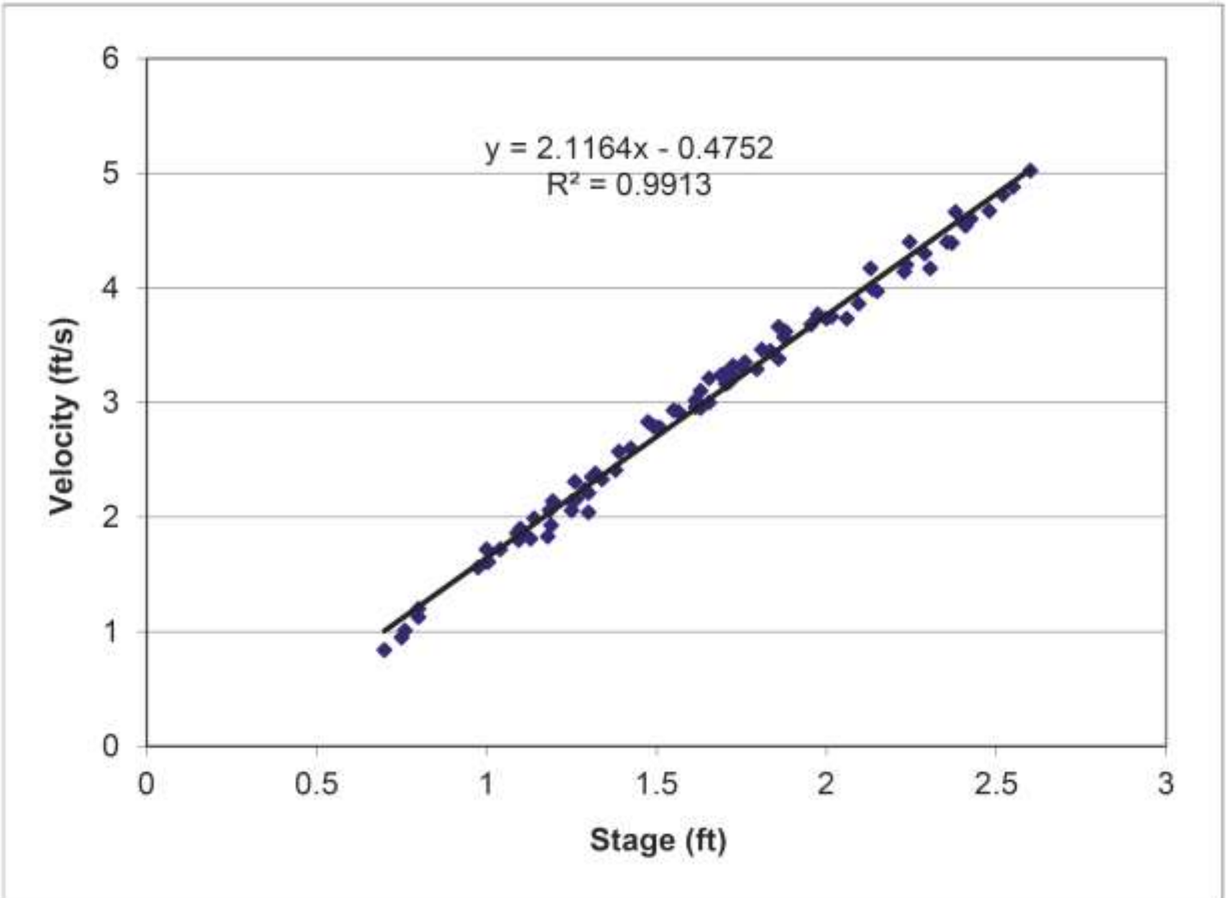
Hydrograph for Mar 25, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising Limb Sample
Falling Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.2
0.4
0.6
0.8
1
1.2
05:30
06:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30

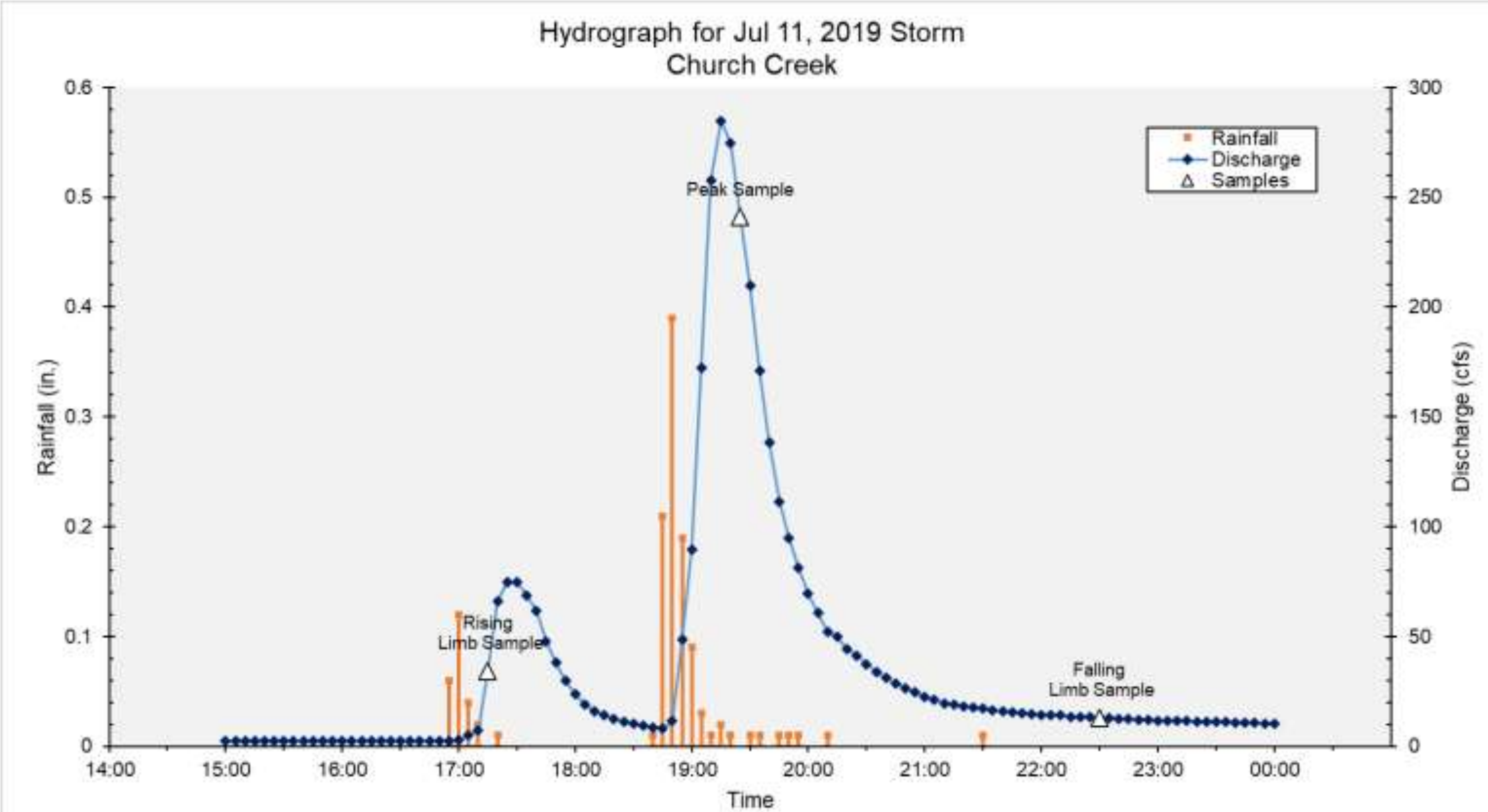

Hydrograph for Apr 12, 2020 Storm
Parole Plaza
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
40
35
30
25
20
15
10
5
0
19:12
21:36
00:00
02:24
04:48
07:12
09:36
12:00

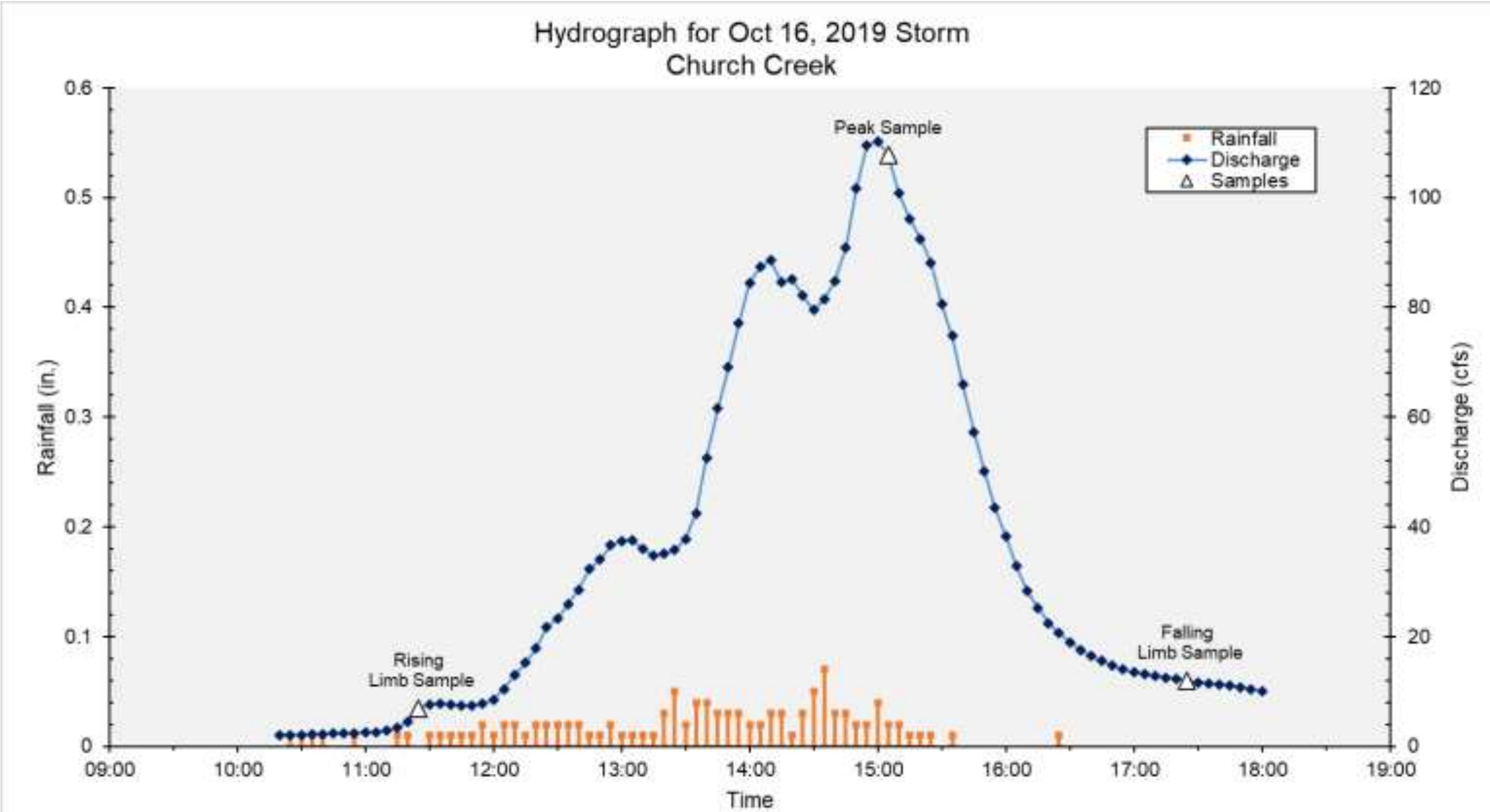

Hydrograph for Jun 11, 2020 Storm
Parole Plaza
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
Rainfall
Discharge
Samples
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
35
30
25
20
15
10
5
0
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00

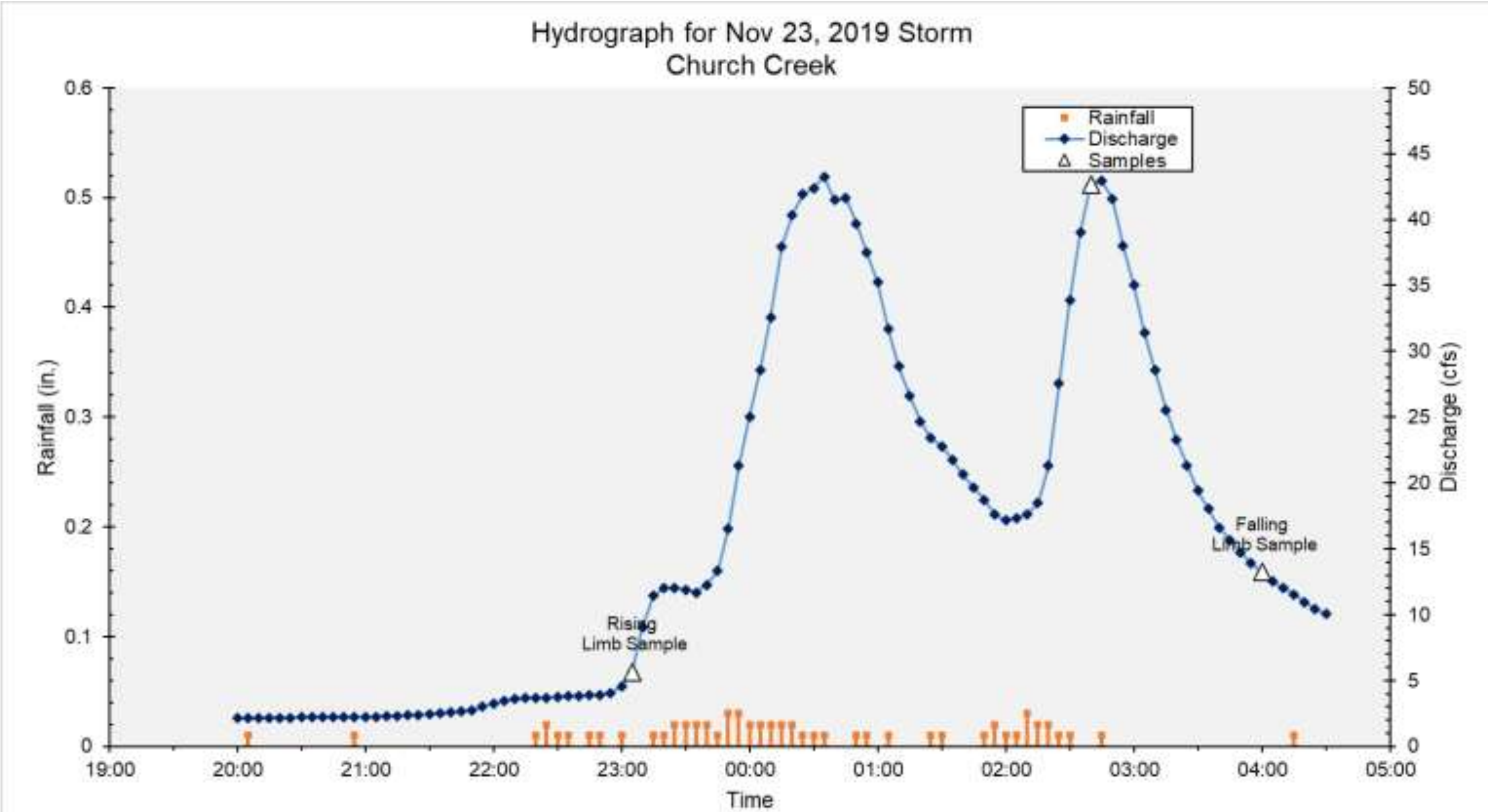
Church Creek Discharge Rating Table

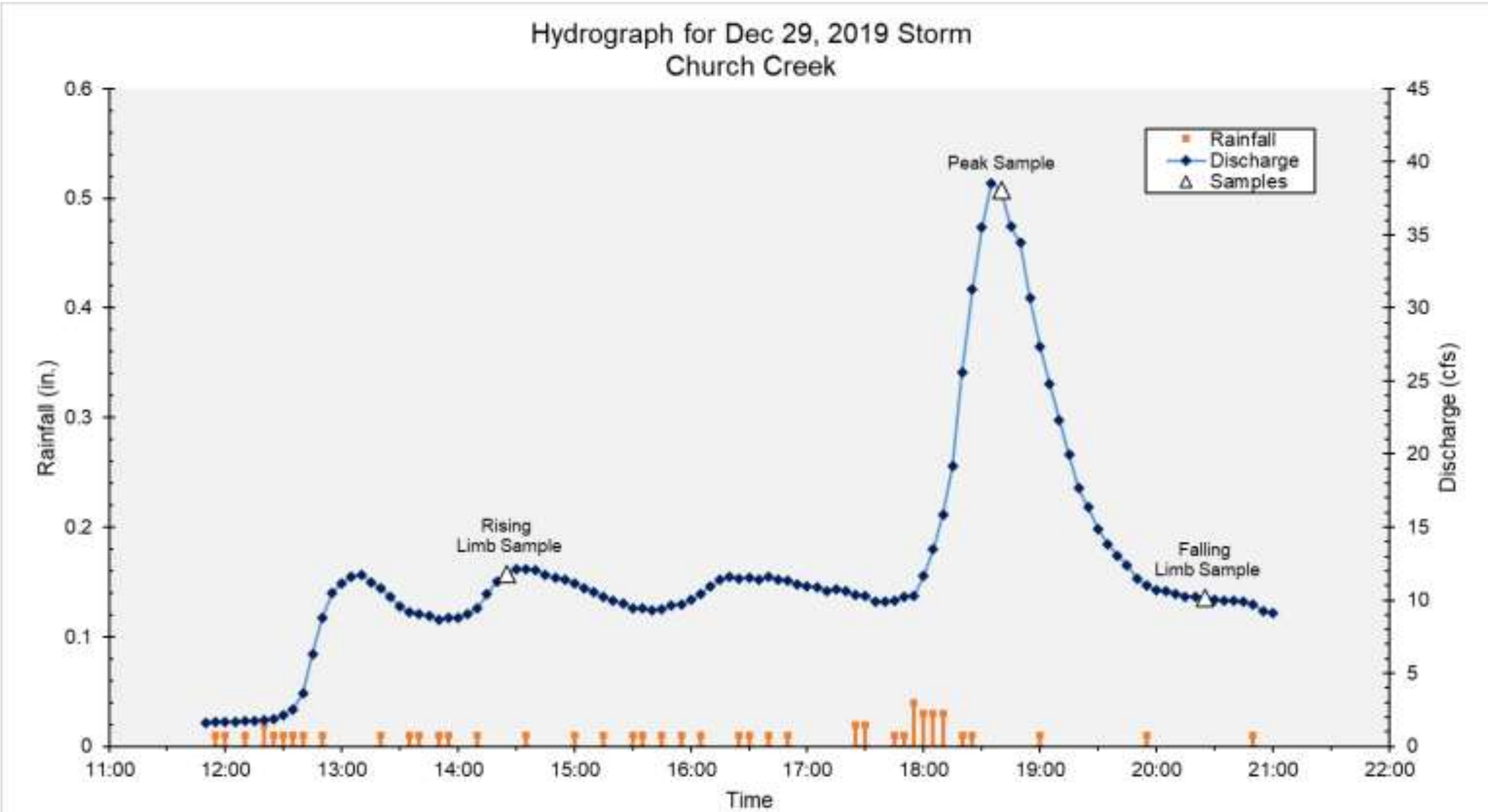
Stage (ft)	Flow Area (ft^2)	Wetted Perimeter (ft)	Top Width (ft)	Velocity, (ft/s)	Discharge (cfs)
0.0	0	0	0	0.00	0.00
0.1	0.21	2.77	2.75	0.00	0.00
0.2	0.53	3.62	3.57	0.00	0.00
0.3	0.91	4.03	3.93	0.16	0.15
0.4	1.31	4.36	4.19	0.37	0.49
0.5	1.75	4.83	4.58	0.58	1.02
0.6	2.22	5.09	4.73	0.79	1.76
0.7	2.70	5.34	4.88	1.01	2.72
0.8	3.20	5.73	5.20	1.22	3.90
0.9	3.74	6.14	5.54	1.43	5.35
1.0	4.31	6.48	5.81	1.64	7.07
1.1	4.90	6.75	5.98	1.85	9.08
1.2	5.50	7.01	6.16	2.06	11.35
1.3	6.13	7.28	6.33	2.28	13.95
1.4	6.77	7.53	6.49	2.49	16.84
1.5	7.43	7.80	6.66	2.70	20.06
1.6	8.10	8.08	6.86	2.91	23.58
1.7	8.80	8.37	7.06	3.12	27.48
1.8	9.51	8.65	7.26	3.33	31.71
1.9	10.25	8.93	7.44	3.55	36.35
2.0	11.00	9.15	7.52	3.76	41.33
2.1	11.75	9.35	7.54	3.97	46.64
2.2	12.51	9.55	7.57	4.18	52.30
2.3	13.26	9.75	7.60	4.39	58.24
2.4	14.03	9.96	7.63	4.60	64.60
2.5	14.79	10.16	7.65	4.82	71.23
2.6	15.56	10.36	7.68	5.03	78.23
2.7	16.33	10.56	7.71	5.24	85.55
2.8	17.10	10.76	7.73	5.45	93.21
2.9	17.87	10.96	7.76	5.66	101.19
3.0	18.65	11.17	7.79	5.87	109.55
3.1	19.43	11.37	7.81	6.09	118.24
3.2	20.21	11.57	7.84	6.30	127.27
3.3	21.00	11.77	7.87	6.51	136.69
3.4	21.79	11.97	7.89	6.72	146.44
3.5	22.58	12.18	7.92	6.93	156.53
3.6	23.37	12.38	7.95	7.14	166.95
3.7	24.17	12.58	7.98	7.36	177.78

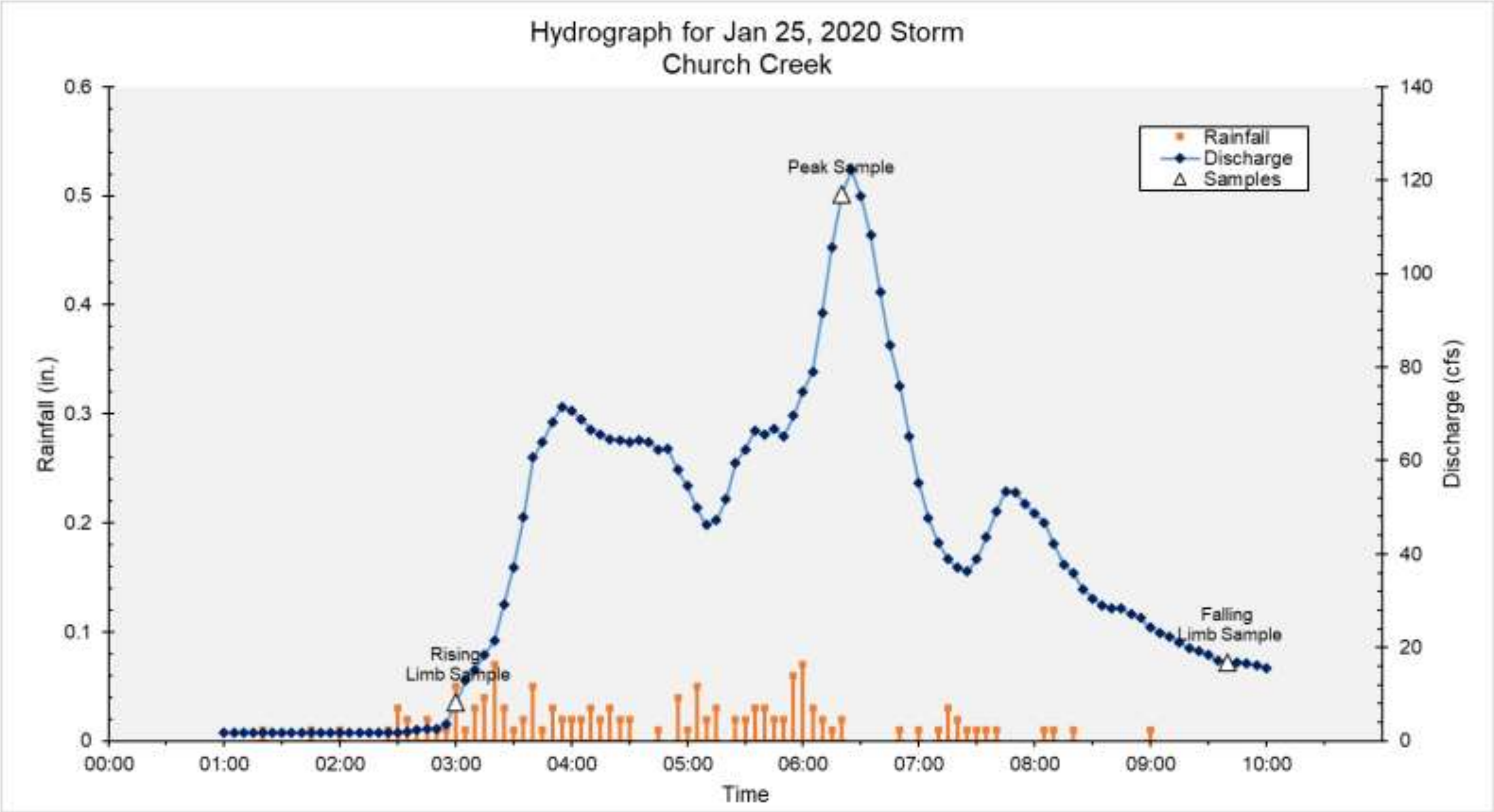

y = 2.1164x - 0.4752
R² = 0.9913
Velocity (ft/s)
Stage (ft)
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3


Hydrograph for Jul 11, 2019 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
300
250
200
150
100
50
0
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00

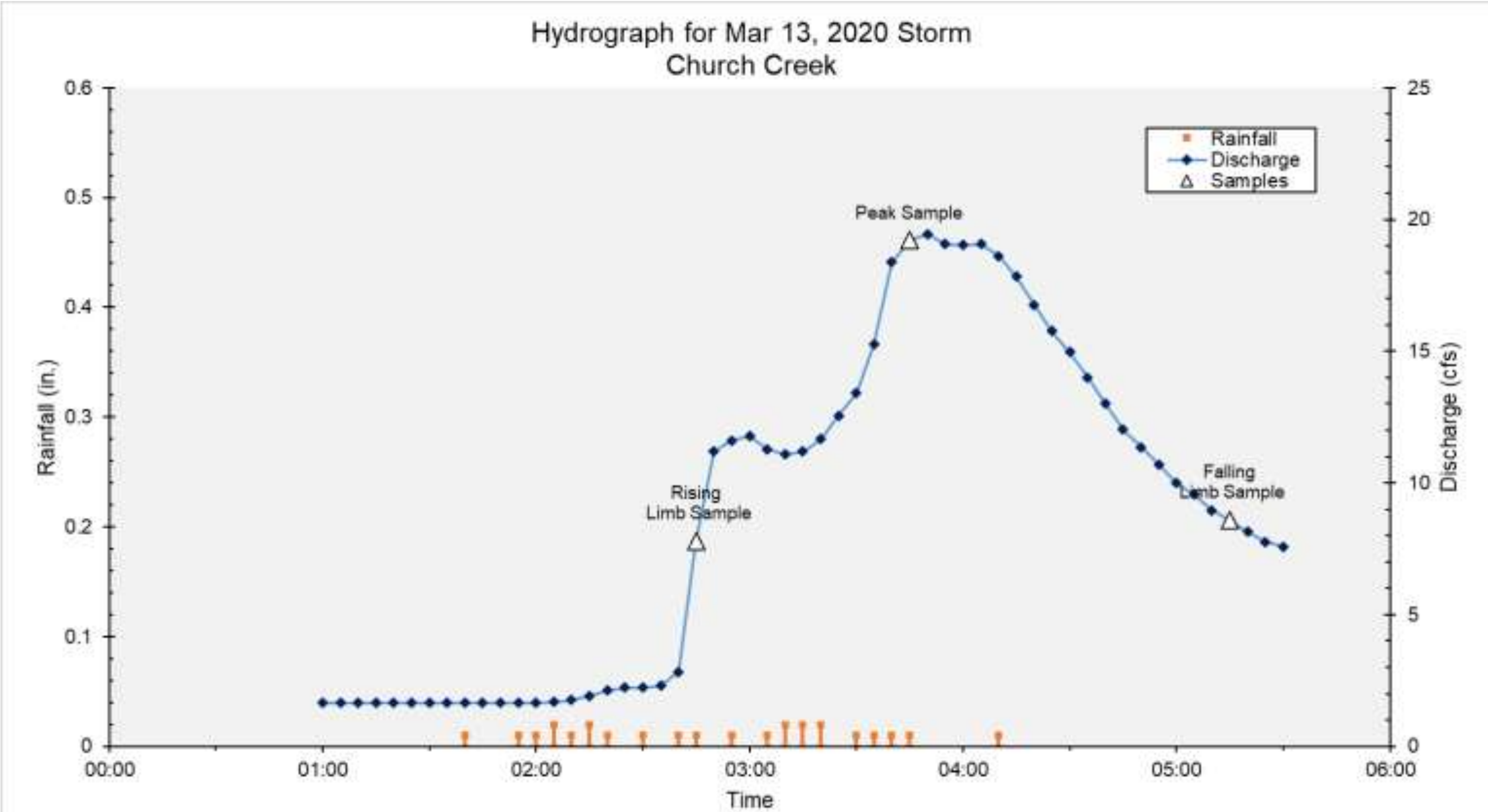

Hydrograph for Oct 16, 2019 Storm
Church Creek
Rainfall (in.)
Discharge (cfs)
Time
Rainfall
Discharge
Samples
Peak Sample
Rising
Limb Sample
Falling
Limb Sample
0.6
0.5
0.4
0.3
0.2
0.1
0
120
100
80
60
40
20
0
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00

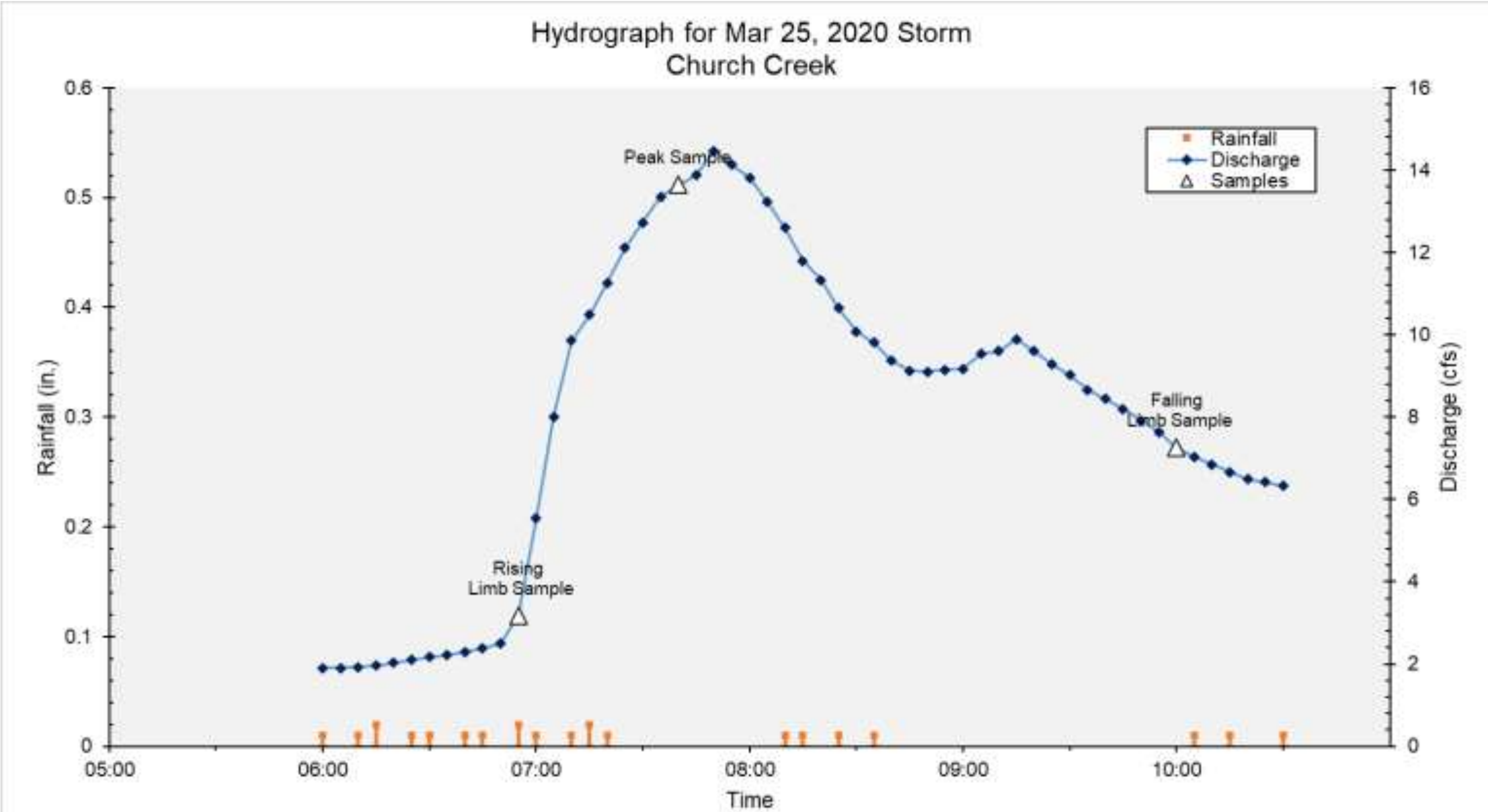

Hydrograph for Nov 23, 2019 Storm
Church Creek
Rainfall
Discharge
Samples
Rising
Limb Sample
Falling
Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
5
10
15
20
25
30
35
40
45
50
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00

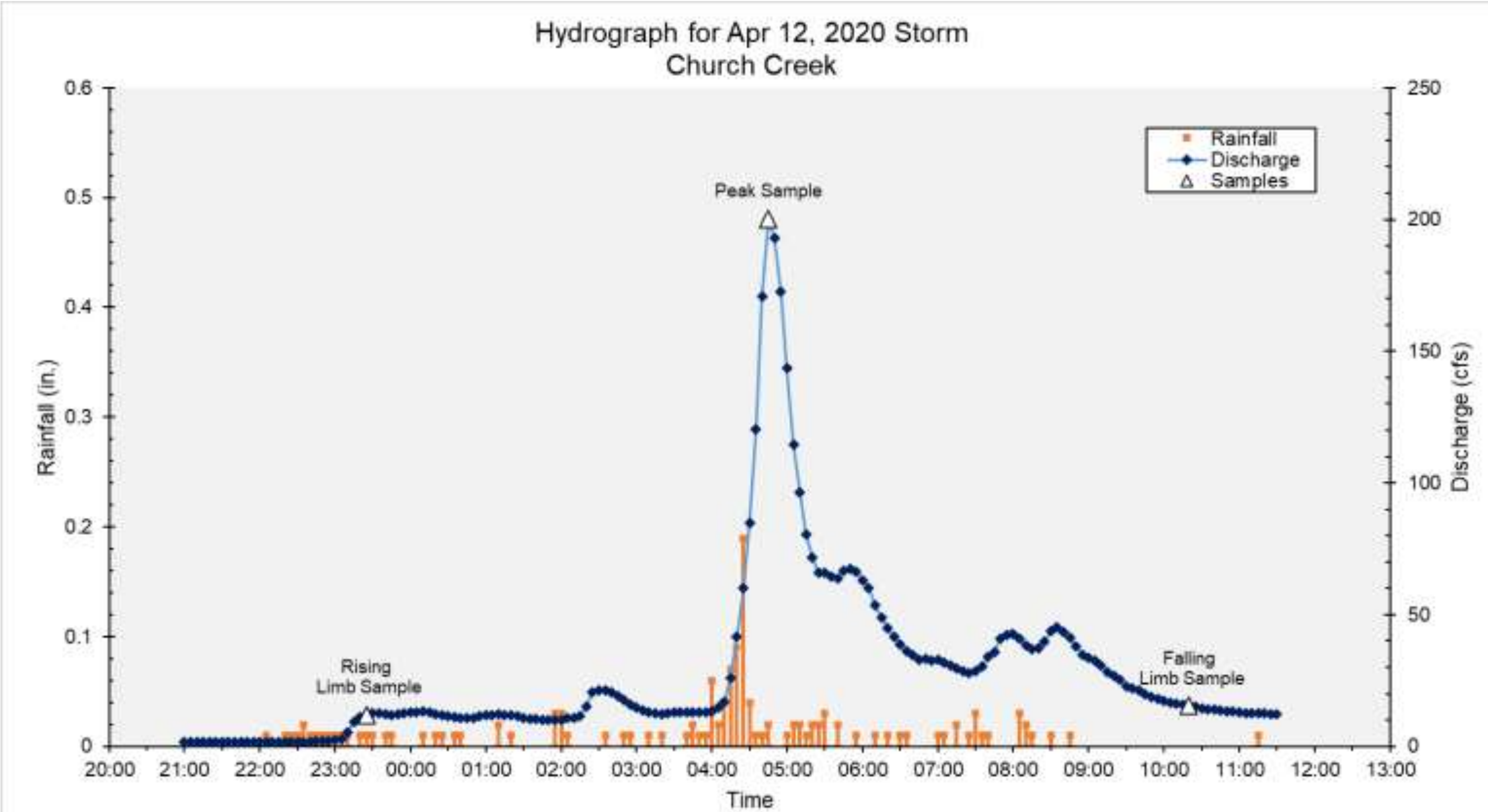

Hydrograph for Dec 29, 2019 Storm
Church Creek
Rainfall
Discharge
Samples
Peak Sample
Rising Limb Sample
Falling Limb Sample
Rainfall (in.)
Discharge (cfs)
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
45
40
35
30
25
20
15
10
5
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00



Hydrograph for Jan 25, 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
140
120
100
80
60
40
20
0
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 13, 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
25
20
15
10
5
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00


Hydrograph for Mar 25, 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
16
14
12
10
8
6
4
2
0
05:00
06:00
07:00
08:00
09:00
10:00



Hydrograph for Apr 12, 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
250
200
150
100
50
0
20:00
21:00
22:00
23:00
00:00
01:00
02:00
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05:00
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09:00
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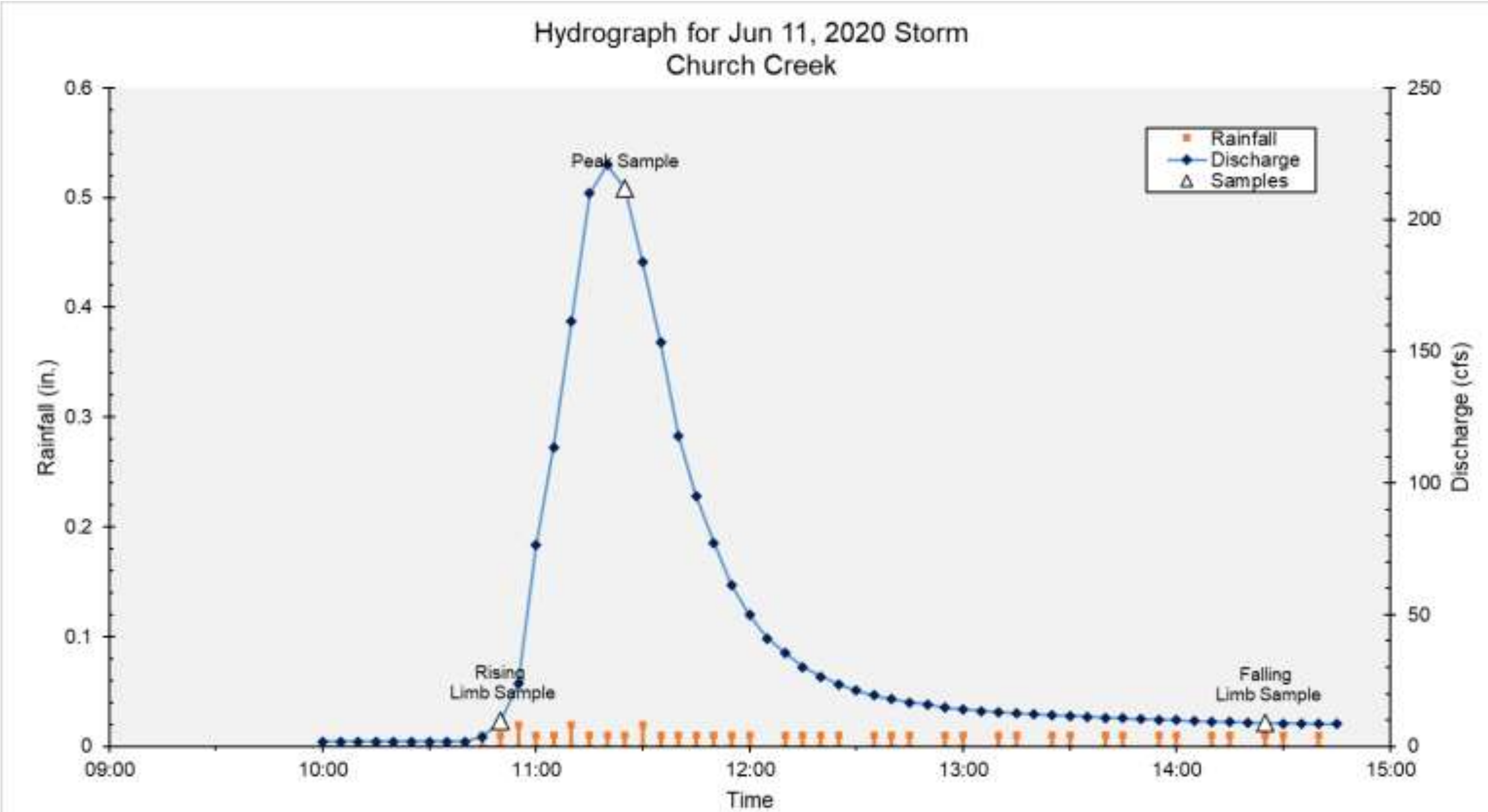
11:00
12:00
13:00


Hydrograph for Jun 11, 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
250
200
150
100
50
0
09:00
10:00
11:00
12:00
13:00
14:00
15:00

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APPENDIX B

MASTER TAXA LIST

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Order	Family	Genus	Taxon	FFG[a]	Habit[b]	Tolerance Value[c]
Amphipoda	Crangonyctidae	Crangonyx	Crangonyx	Collector	sp	6.7
Amphipoda	Gammaridae	Gammarus	Gammarus	Shredder	sp	6.7
Basommatophora	Ancylidae	Ferrissia	Ferrissia	Scraper	cb	7
Basommatophora	Lymnaeidae	Fossaria	Fossaria	Scraper	cb	6.9
Basommatophora	Physidae	Physa	Physa	Scraper	cb	7
Basommatophora	Planorbidae	Menetus	Menetus	Scraper	cb	7.6
Coleoptera	Dytiscidae	Copelatus	Copelatus	Predator	sw	5
Diptera			Diptera			6
Diptera	Chironomidae	Chironomini	Chironomini			5.9
Diptera	Chironomidae	Cricotopus	Cricotopus	Shredder	cn, bu	9.6
Diptera	Chironomidae	Cryptochironomus	Cryptochironomus	Predator	sp, bu	7.6
Diptera	Chironomidae	Dicrotendipes	Dicrotendipes	Collector	bu	9
Diptera	Chironomidae	Eukiefferiella	Eukiefferiella	Collector	sp	6.1
Diptera	Chironomidae	Orthocladius	Orthocladius	Collector	sp, bu	9.2
Diptera	Chironomidae	Polypedilum	Polypedilum	Shredder	cb, cn	6.3
Diptera	Chironomidae	Rheotanytarsus	Rheotanytarsus	Filterer	cn	7.2
Diptera	Chironomidae	Thienemannimyia group	Thienemannimyia group	Predator	sp	8.2
Diptera	Empididae	Hemerodromia	Hemerodromia	Predator	sp, bu	7.9
Diptera	Simuliidae	Simulium	Simulium	Filterer	cn	5.7
Haplotaxida	Enchytraeidae		Enchytraeidae	Collector	bu	9.1
Haplotaxida	Naididae		Naididae	Collector	bu	8.5
Hemiptera	Veliidae	Microvelia	Microvelia	Predator	sk	6
Hoplonemertea	Tetrastemmatidae	Prostoma	Prostoma	Predator		7.3
Isopoda	Asellidae	Caecidotea	Caecidotea	Collector	sp	2.6
Lumbricida	Lumbricidae		Lumbricidae	Collector		10
Odonata	Aeshnidae	Boyeria	Boyeria	Predator	cb, sp	6.3
Odonata	Coenagrionidae	Argia	Argia	Predator	cn, cb, sp	9.3
Odonata	Coenagrionidae	Ischnura	Ischnura	Predator	cb	9
Odonata	Libellulidae		Libellulidae	Predator		9
Odonata	Libellulidae	Pachydiplax	Pachydiplax	Predator		8
Odonata	Libellulidae	Plathemis	Plathemis	Predator		3
Rhynchobdellida	Glossiphoniidae		Glossiphoniidae	Predator	sp	6
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche	Filterer	cn	6.5
Tricladida	Dugesiidae	Girardia	Girardia	Predator	sp	9.3
Tubificida	Tubificidae		Tubificidae	Collector	cn	8.4
Veneroida	Pisidiidae		Pisidiidae	Filterer		6.5
Veneroida	Pisidiidae	Pisidium	Pisidium	Filterer	bu	5.7

[a] Functional Feeding Group

[b] Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer
Some information for the particular taxa was not available.

[c] Tolerance Values, based on Hilsenhoff, modified for Maryland

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APPENDIX C

BIOLOGICAL ASSESSMENT RESULTS

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Church Creek Site CC-01

Sampled: 4/6/2020

Biological Condition

Benthic Macroinvertebrate IBI

Narrative Rating	Very Poor
BIBI Score	1.86

Metric	Value	Score
Total Taxa	12	1
EPT Taxa	0	1
Number Ephemeroptera	0	1
% Intolerant to Urban	0	1
% Ephemeroptera	0	1
Scraper Taxa	1	3
% Climbers	52.63	5

Benthic Macroinvertebrate Taxa List

Taxa	Count
Naididae	9
Tubificidae	36
Lumbricidae	1
Physa	64
Pisidium	5
Argia	5
Ischnura	1
Gammarus	3
Pachydiplax	2
Microvelia	1
Copelatus	1
Prostoma	3

Physical Habitat

Maryland Biological Stream Survey PHI

Narrative Rating	Degraded
PHI Score	64.30

Metric	Score
Drainage area (acres)	108.96
Remoteness	23.05
Percent Shading	73.32
Epifaunal Substrate	54.70
Instream Habitat	82.62
Instream Woody Debris	100.00
Bank Stability	52.14

Rapid Bioassessment Protocol

Narrative Rating	Non-supporting
RBP Score	58

Metric	Score
Epifaunal Substrate / Cover	6
Embeddedness	6
Velocity / Depth Regime	9
Sediment Deposition	8
Channel Flow Status	12
Channel Alteration	19
Frequency of Riffles	10
Bank Stability	2(Left)/3(Right)
Vegetative Protection	5(Left)/5(Right)
Riparian Veg Zone Width	6(Left)/7(Right)

Water Chemistry

Dissolved Oxygen (mg/L)	9.66
pH	6.72
Specific Conductance (µS/cm)	1147
Temperature (°C)	17.8
Turbidity (NTUs)	12.9

Church Creek Site CC-02

Sampled: 4/6/2020

Biological Condition

Benthic Macroinvertebrate IBI

Narrative Rating	Poor
BIBI Score	2.43

Metric	Value	Score
Total Taxa	17	3
EPT Taxa	1	1
Number Ephemeroptera	0	1
% Intolerant to Urban	2	1
% Ephemeroptera	0	1
Scraper Taxa	2	5
% Climbers	13.14	5

Benthic Macroinvertebrate Taxa List

Taxa	Count
Girardia	10
Naididae	21
Tubificidae	22
Glossiphoniidae	1
Physa	3
Menetus	1
Pisidium	4
Gammarus	39
Caecidotea	1
Argia	2
Plathemis	2
Cheumatopsyche	1
Polypedilum	12
Cricotopus	7
Orthocladius	3
Thienemannimyia group	3
Hemerodromia	1

Physical Habitat

Maryland Biological Stream Survey PHI

Narrative Rating	Degraded
PHI Score	60.45

Metric	Score
Drainage area (acres)	292.45
Remoteness	20.96
Percent Shading	68.32
Epifaunal Substrate	54.08
Instream Habitat	61.42
Instream Woody Debris	100.00
Bank Stability	57.95

Rapid Bioassessment Protocol

Narrative Rating	Partially Supporting
RBP Score	67

Metric	Score
Epifaunal Substrate / Cover	10
Embeddedness	9
Velocity / Depth Regime	10
Sediment Deposition	12
Channel Flow Status	13
Channel Alteration	13
Frequency of Riffles	8
Bank Stability	2(Left)/5(Right)
Vegetative Protection	6(Left)/5(Right)
Riparian Veg Zone Width	10(Left)/9(Right)

Water Chemistry

Dissolved Oxygen (mg/L)	8.17
pH	6.64
Specific Conductance (µS/cm)	583
Temperature (°C)	12.9
Turbidity (NTUs)	12.4

Church Creek Site CC-03

Sampled: 4/6/2020

Biological Condition

Benthic Macroinvertebrate IBI

Narrative Rating	Poor
BIBI Score	2.43

Metric	Value	Score
Total Taxa	18	3
EPT Taxa	0	1
Number Ephemeroptera	0	1
% Intolerant to Urban	0.78	1
% Ephemeroptera	0	1
Scraper Taxa	2	5
% Climbers	21.09	5

Benthic Macroinvertebrate Taxa List

Taxa	Count
Girardia	7
Enchytraeidae	2
Naididae	44
Fossaria	1
Menetus	3
Pisidium	3
Caecidotea	1
Boyeria	1
Argia	2
Libellulidae	1
Dicrotendipes	1
Polypedilum	20
Rheotanytarsus	3
Cricotopus	8
Eukiefferiella	2
Orthocladius	24
Thienemannimyia group	4
Simulium	1

Physical Habitat

Maryland Biological Stream Survey PHI

Narrative Rating	Partially Degraded
PHI Score	72.44

Metric	Score
Drainage area (acres)	271.67
Remoteness	18.60
Percent Shading	58.94
Epifaunal Substrate	95.22
Instream Habitat	100.00
Instream Woody Debris	100.00
Bank Stability	61.90

Rapid Bioassessment Protocol

Narrative Rating	Supporting
RBP Score	80

Metric	Score
Epifaunal Substrate / Cover	15
Embeddedness	12
Velocity / Depth Regime	13
Sediment Deposition	15
Channel Flow Status	16
Channel Alteration	18
Frequency of Riffles	8
Bank Stability	7(Left)/6(Right)
Vegetative Protection	6(Left)/6(Right)
Riparian Veg Zone Width	7(Left)/6(Right)

Water Chemistry

Dissolved Oxygen (mg/L)	8.47
pH	7.17
Specific Conductance (µS/cm)	584
Temperature (°C)	15.7
Turbidity (NTUs)	15.5

Church Creek Site CC-04

Sampled: 4/6/2020

Biological Condition

Benthic Macroinvertebrate IBI

Narrative Rating	Poor
BIBI Score	2.71

Metric	Value	Score
Total Taxa	17	3
EPT Taxa	1	1
Number Ephemeroptera	0	1
% Intolerant to Urban	16.67	3
% Ephemeroptera	0	1
Scraper Taxa	2	5
% Climbers	34.85	5

Benthic Macroinvertebrate Taxa List

Taxa	Count
Naididae	13
Tubificidae	10
Glossiphoniidae	2
Ferrissia	1
Menetus	6
Pisidium	14
Crangonyx	1
Gammarus	1
Caecidotea	22
Cheumatopsyche	1
Cryptochironomus	1
Polypedilum	39
Cricotopus	1
Orthocladius	4
Thienemannimyia group	10
Simulium	1
Diptera	1

Physical Habitat

Maryland Biological Stream Survey PHI

Narrative Rating	Degraded
PHI Score	63.70

Metric	Score
Drainage area (acres)	118.19
Remoteness	24.93
Percent Shading	49.95
Epifaunal Substrate	48.36
Instream Habitat	87.33
Instream Woody Debris	100.00
Bank Stability	71.63

Rapid Bioassessment Protocol

Narrative Rating	Supporting
RBP Score	77

Metric	Score
Epifaunal Substrate / Cover	6
Embeddedness	8
Velocity / Depth Regime	5
Sediment Deposition	11
Channel Flow Status	15
Channel Alteration	20
Frequency of Riffles	16
Bank Stability	8(Left)/8(Right)
Vegetative Protection	7(Left)/7(Right)
Riparian Veg Zone Width	10(Left)/8(Right)

Water Chemistry

Dissolved Oxygen (mg/L)	7.12
pH	6.92
Specific Conductance (µS/cm)	508
Temperature (°C)	19.3
Turbidity (NTUs)	16.2

Select physical habitat parameters (raw scores) 2020			
Site	**Epifaunal Substrate (0 – 20)**	**Instream Habitat (0-20)**	**Embeddedness (0 – 100%)**
CC-01	5	9	90
CC-02	6	7	85
CC-03	13	14	40
CC-04	4	10	80

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APPENDIX D

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.

Biological and Geomorphological Field Sampling and Assessments

Initial QA/QC procedures for benthic macroinvertebrate field sampling included formal training for field crew leaders in MBSS Sampling Protocols. All field crew members have attended at least one MBSS Spring Index Period Training. At least one crew member extensively trained and certified in MBSS sampling protocols was present for each field sampling day. Also, during field sampling, each data sheet was double checked for completeness and sample bottle labels were double checked for accuracy. 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.

For biological monitoring, water quality QA/QC procedures include calibration of the YSI multiprobe meter daily during the sampling season. Dissolved oxygen probe membranes were inspected regularly and replaced when dirty or damaged.

Laboratory Sorting and Subsampling

Sorting QA/QC was conducted on one sample since only seven samples were collected for this survey (The four samples from Church Creek are analyzed concurrently with three samples taken in Picture Spring Branch). This check consisted of entirely resorting the sorted grid cells of one randomly selected sample. This QC met the sorting efficiency criterion of 90%, so no further action was required. As a taxonomic QC, one sample was re-identified completely by another Versar SFS-certified taxonomist following the same identification methods stated above. The Percent Difference in Enumeration (PDE) and the Percent Taxonomic Disagreement (PTD) were calculated, and no further action was required since both the PDE and PTD met MBSS and County MQO requirements.

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.

Metric and IBI Calculations

Ten percent of metric and IBI calculations were checked by hand using a calculator to ensure correct calculation by the Access database. Any discrepancies were addressed at that time.

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.

APPENDIX E

ROSGEN CLASSIFICATION SCHEME

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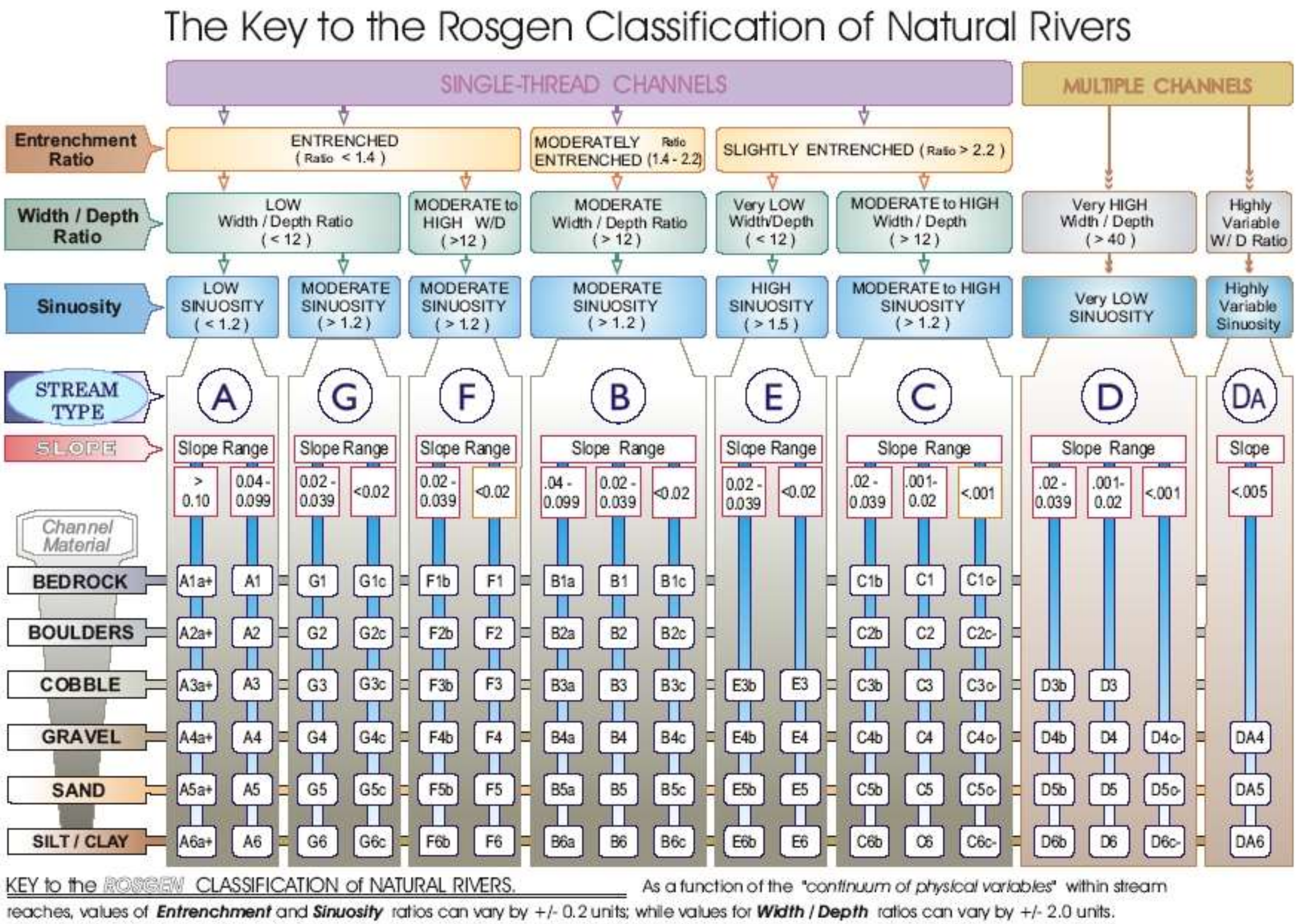

Source: Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

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APPENDIX F

GEOMORPHOLOGICAL DATA

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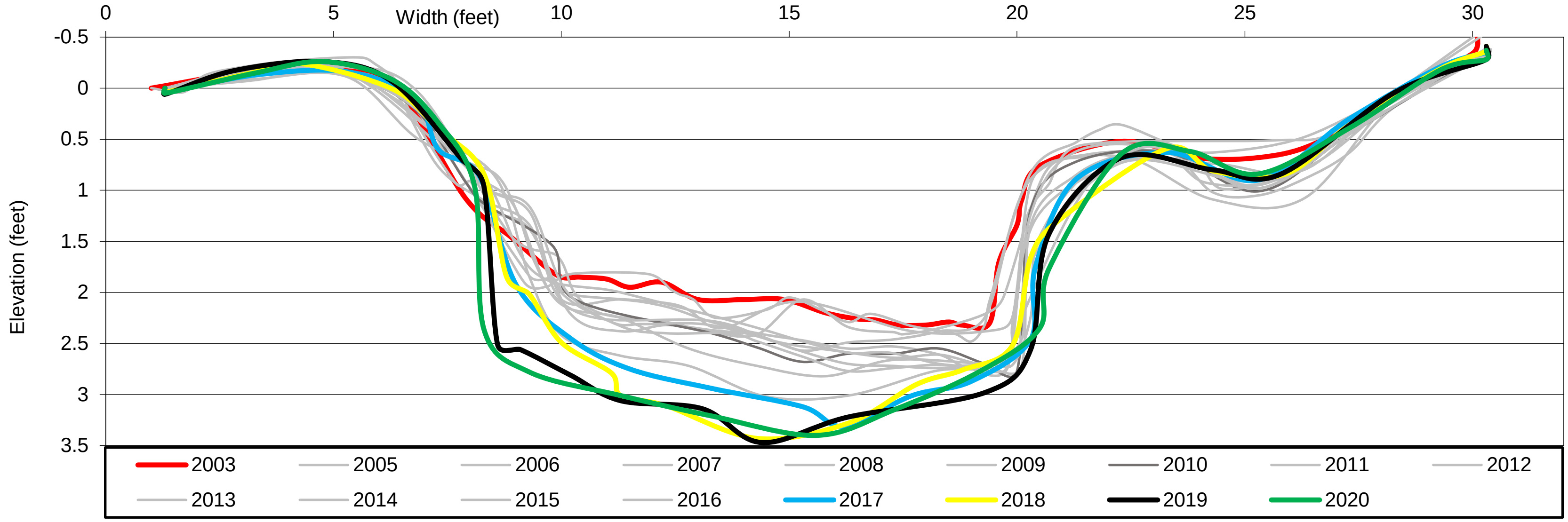
Church Creek
2020 Geomorphic Assessment Results Summary

Assessment Parameter	Cross-section					
	XS-1 Pool @ sta 3+70.5	XS-1D Riffle @ sta 5+24.8	XS-2 Riffle @ sta 6+82	XS-3 Pool @ sta 11+00	XS-4 Pool @ sta 13+53	XS-5 Glide @ sta 17+10
Classification	F5	C4	G4c	G4c	E4	F4
Bankfull Width (ft)	12.4	9.0	7.2	6.7	8.4	10.8
Mean Depth (ft)	1.0	0.7	0.8	0.8	1.4	0.7
Bankfull X-Sec Area (sq ft)	11.8	6.8	5.7	5.4	12.1	7.1
Width:Depth Ratio	12.9	12.0	9.1	8.3	5.9	16.3
Flood-Prone Width (ft)	13.5	17.8	9.7	8.2	12.8	15.8
Entrenchment Ratio	1.1	2.0	1.3	1.2	1.5	1.5
D50(mm)	1.1	N/A	19.0	15.0	14.0	56.0
Water Surface Slope (ft/ft)	0.0002	0.0059	0.013	0.011	0.0096	0.013
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 ↑	Sin ↑, ER ↑	Sin ↑	Sin ↑	Sin ↑, ER ↑	Sin ↑, ER ↓

CROSS SECTION 1



Upstream View

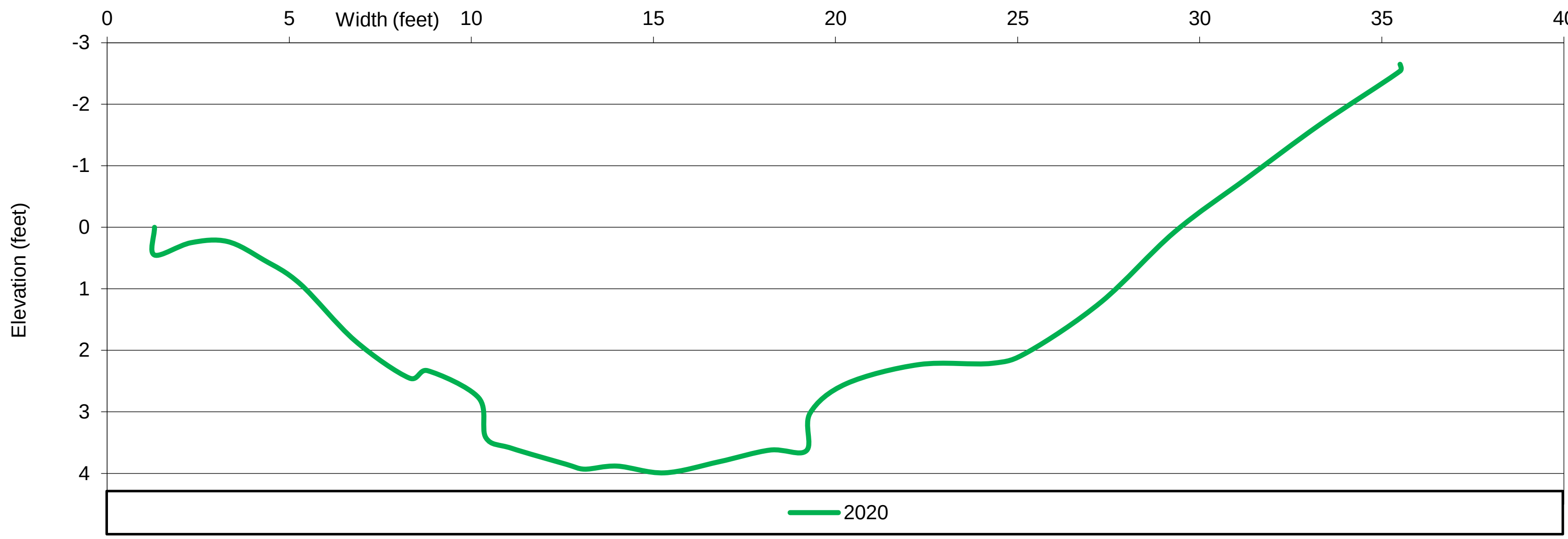
Downstream View

Left Bank View

Right Bank View

2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	12.4
Mean Depth (d_{bkf}) (feet)	1.0
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	11.8
Width/Depth Ratio (W_{bkf}/d_{bkf})	12.9
Width of Flood-prone Area (W_{fpa}) (feet)	13.5
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 ↑
STREAM TYPE	**F5**

CROSS SECTION 1D



Upstream View

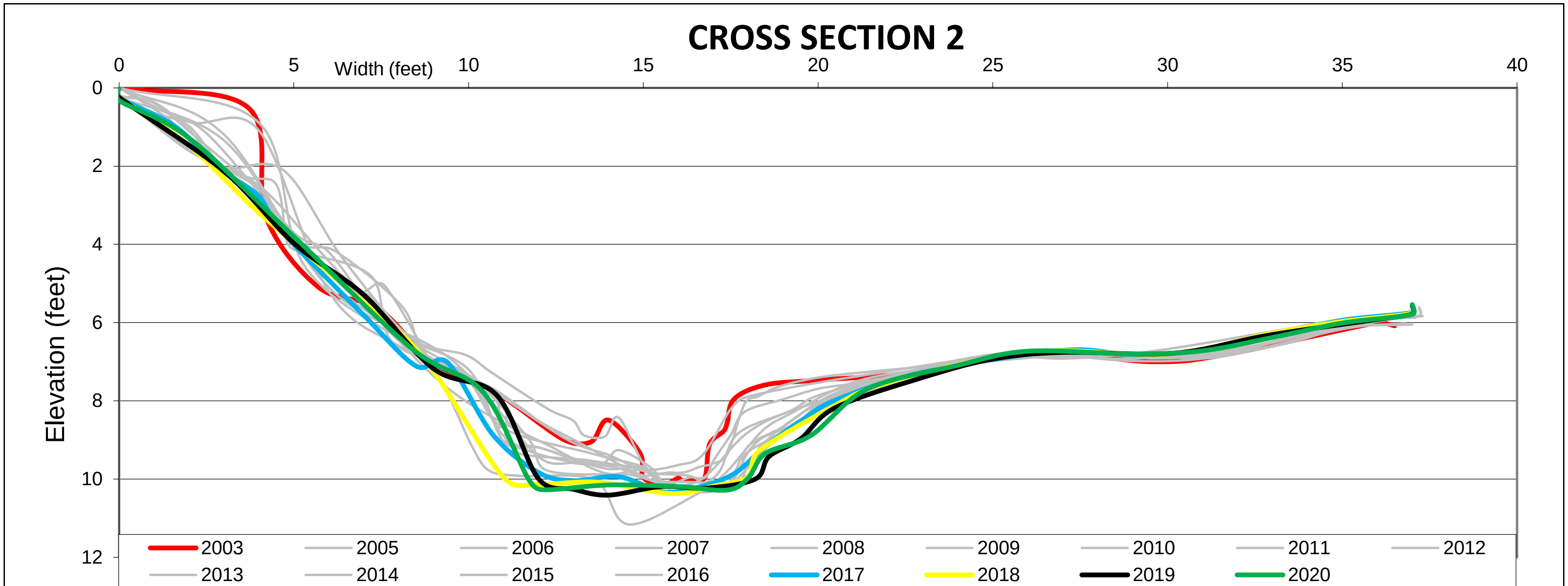
Downstream View

Left Bank View

Right Bank View

2020 Geomorphic Assessment Results

Bankfull Width (W_{bkf}) (feet)	9.0
Mean Depth (d_{bkf}) (feet)	0.7
Bankfull Cross-sectional Area (A_{bkf}) ($feet^2$)	6.8
Width/Depth Ratio (W_{bkf}/d_{bkf})	12.0
Width of Flood-prone Area (W_{fpa}) (feet)	17.8
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	2.0
Channel Materials D_{50} (millimeters)	N/A
Water Surface Slope (S)	0.0059
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, ER ↓
STREAM TYPE	**C4**



Upstream View

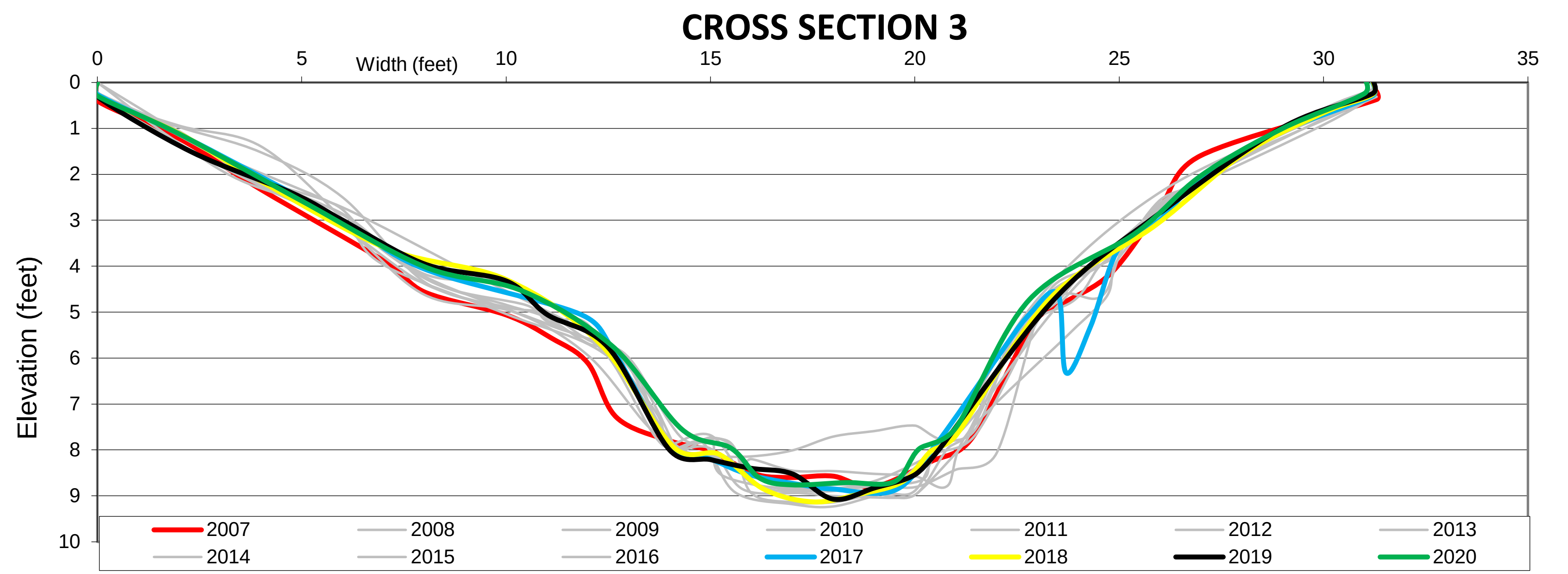
Downstream View

Left Bank View

Right Bank View

2020 Geomorphic Assessment Results

Bankfull Width (W_{bkf}) (feet)	7.2
Mean Depth (d_{bkf}) (feet)	0.8
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	5.7
Width/Depth Ratio (W_{bkf}/d_{bkf})	9.1
Width of Flood-prone Area (W_{fpa}) (feet)	9.7
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.3
Channel Materials D_{50} (millimeters)	19.0
Water Surface Slope (S)	0.013
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, ER ↓
STREAM TYPE	**G4c**



Upstream View

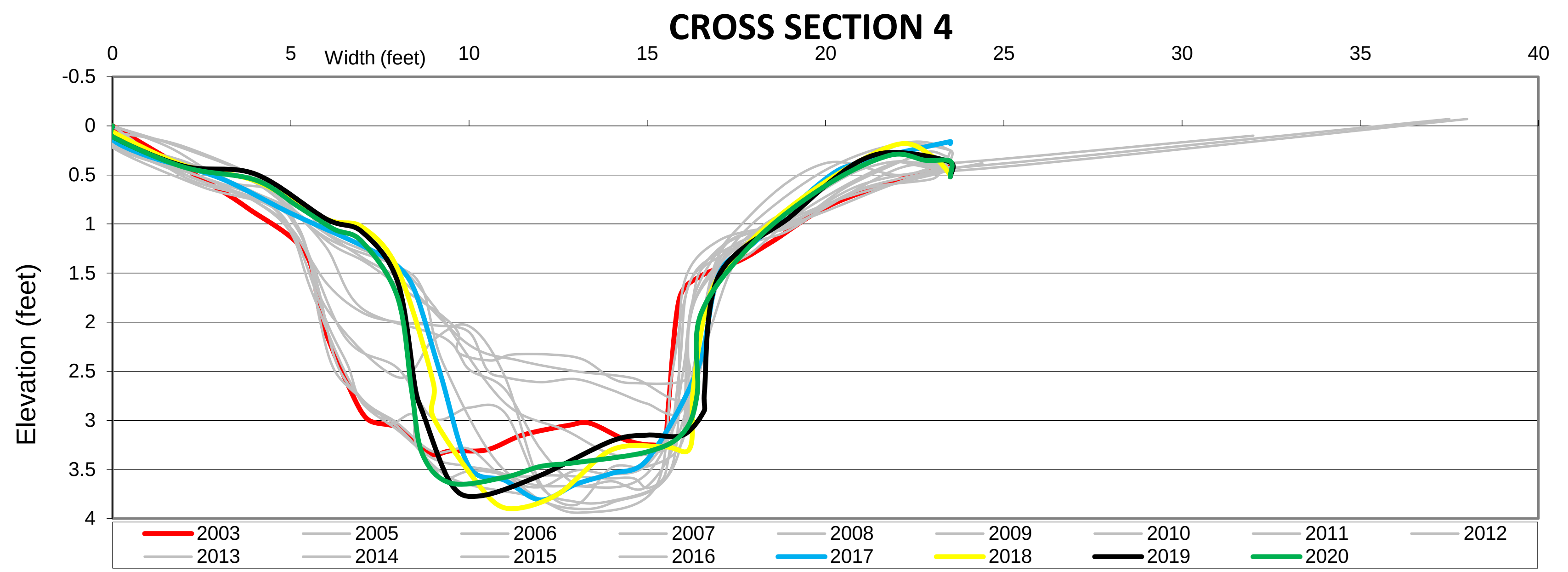
Downstream View

Left Bank View

Right Bank View

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)	5.4
Width/Depth Ratio (W_{bkf}/d_{bkf})	8.3
Width of Flood-prone Area (W_{fpa}) (feet)	8.2
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.2
Channel Materials D_{50} (millimeters)	15.0
Water Surface Slope (S)	0.011
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, W/D ↓
STREAM TYPE	**G4c**



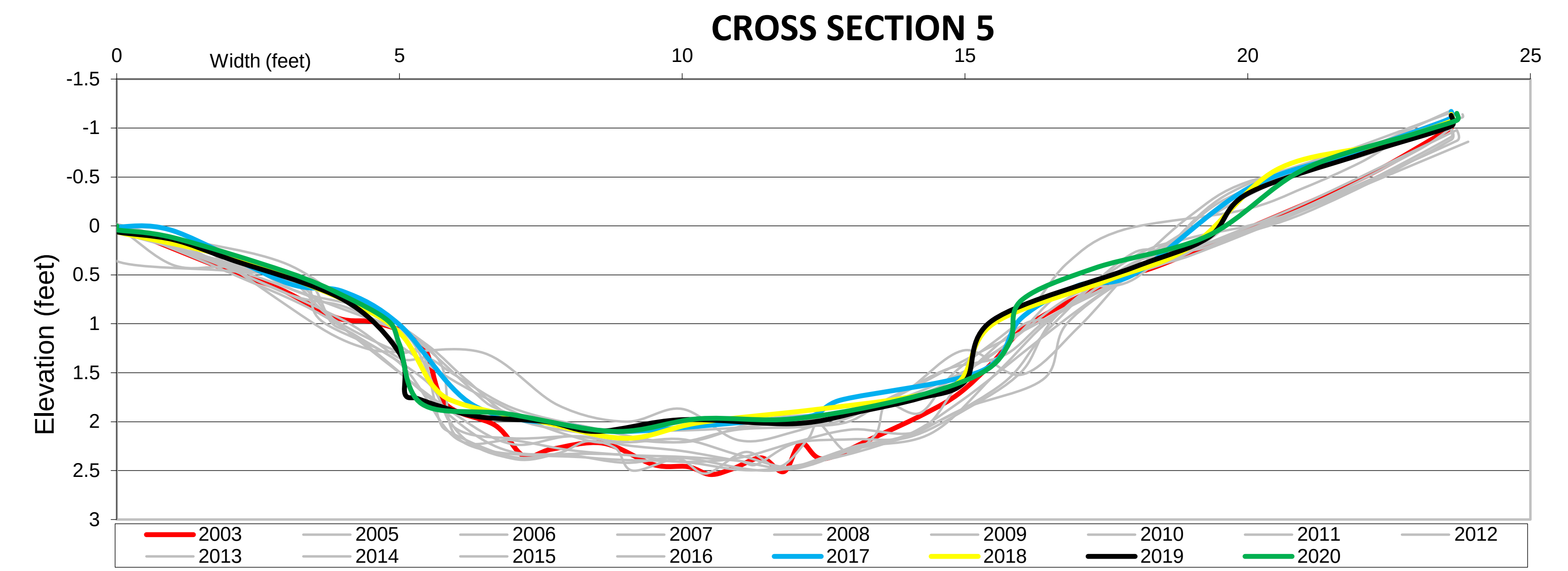
Upstream View

Downstream View

Left Bank View

Right Bank View

2020 Geomorphic Assessment Results	
Bankfull Width (W_{bkf}) (feet)	8.4
Mean Depth (d_{bkf}) (feet)	1.4
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	12.1
Width/Depth Ratio (W_{bkf}/d_{bkf})	5.9
Width of Flood-prone Area (W_{fpa}) (feet)	12.8
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.5
Channel Materials D_{50} (millimeters)	14.0
Water Surface Slope (S)	0.0096
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑
STREAM TYPE	**E4**



Upstream View

Downstream View

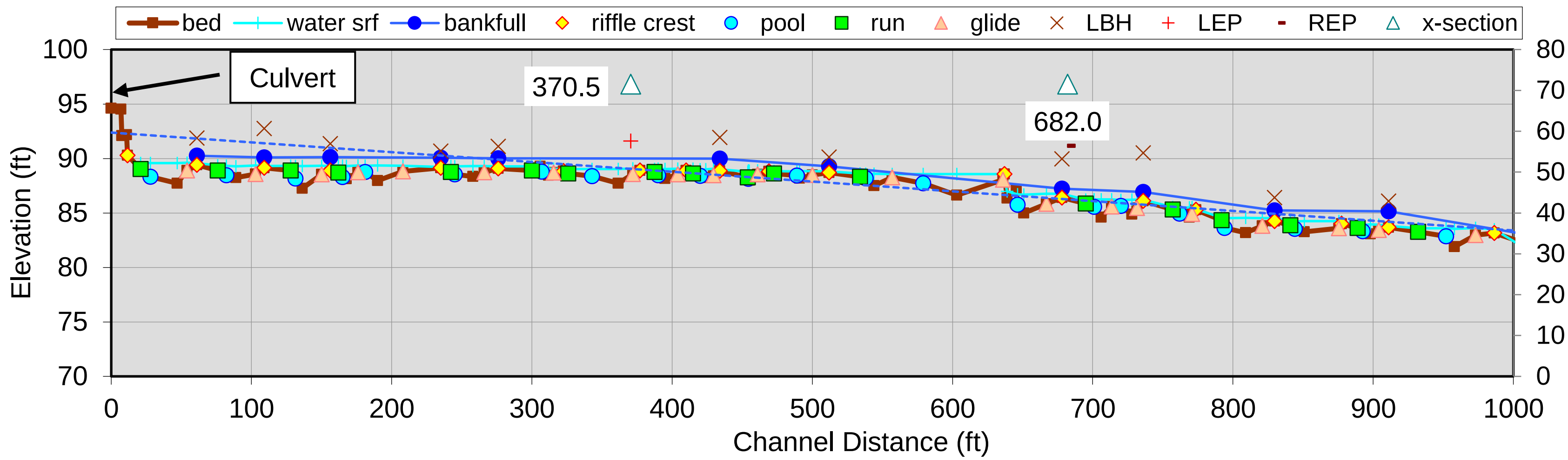
Left Bank View

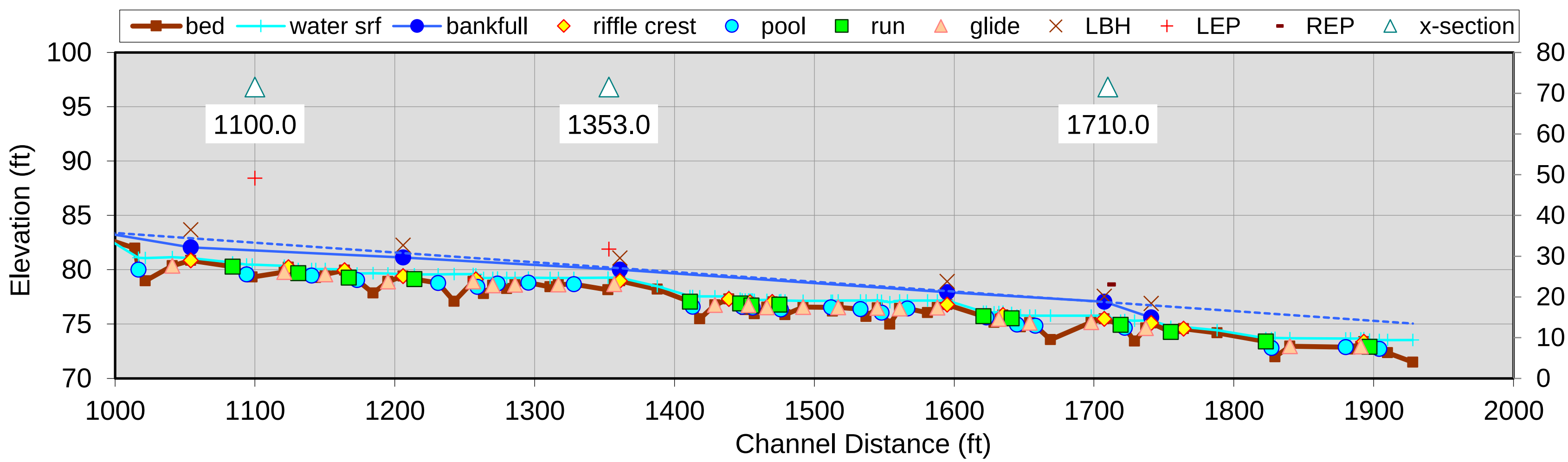
Right Bank View

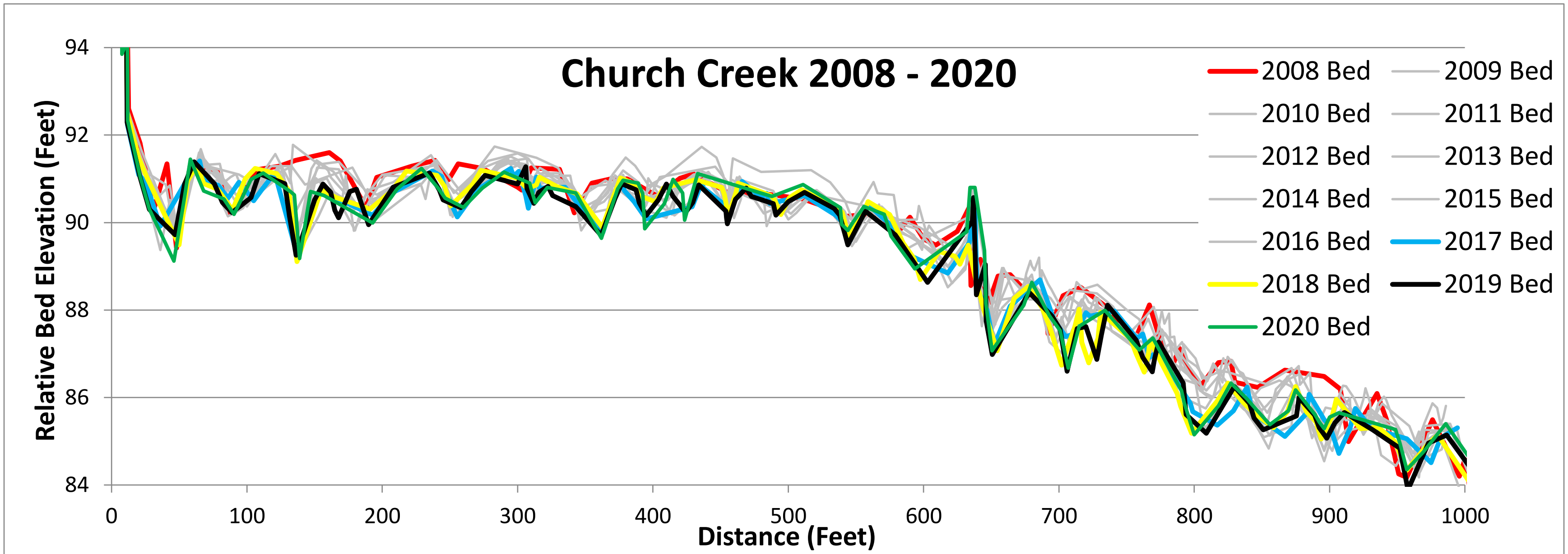
2020 Geomorphic Assessment Results

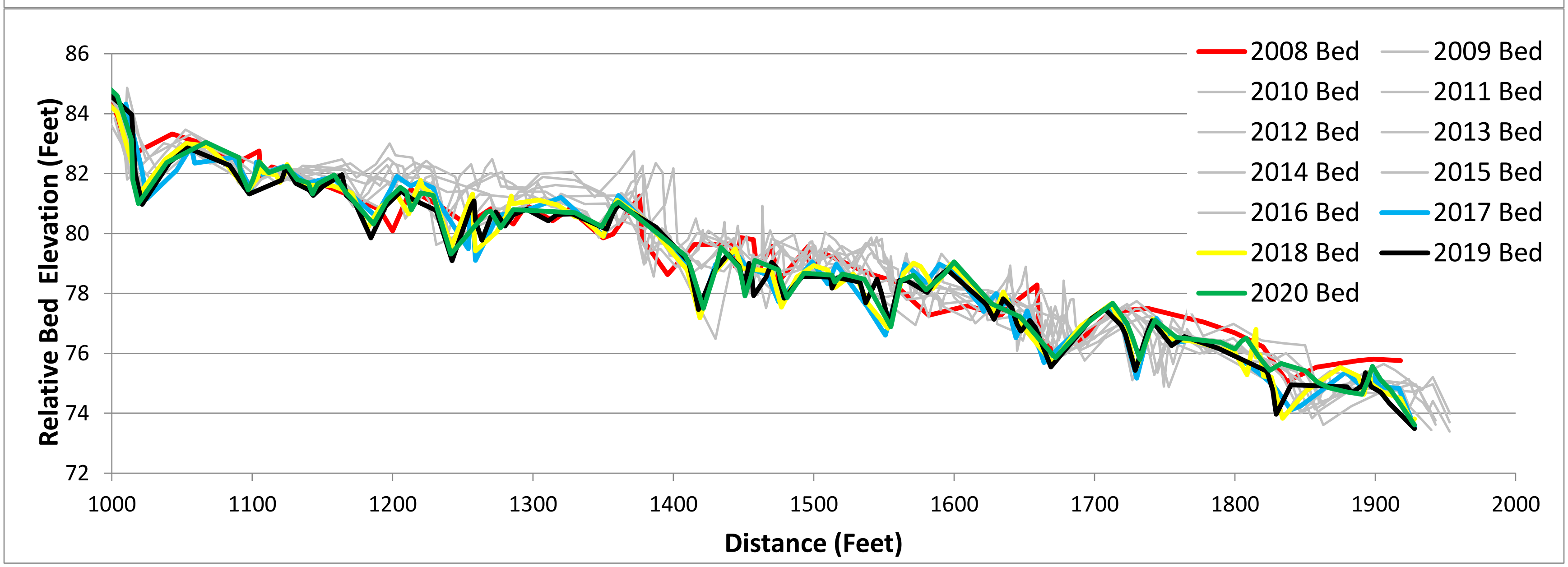
Bankfull Width (W_{bkf}) (feet)	10.8
Mean Depth (d_{bkf}) (feet)	0.7
Bankfull Cross-sectional Area (A_{bkf}) (feet^2)	7.1
Width/Depth Ratio (W_{bkf}/d_{bkf})	16.3
Width of Flood-prone Area (W_{fpa}) (feet)	15.8
Entrenchment Ratio (ER) = W_{fpa}/W_{bkf}	1.5
Channel Materials D_{50} (millimeters)	56.0
Water Surface Slope (S)	0.013
Sinuosity (K) = stream length/valley length	<1.2
Adjustments?	Sin ↑, ER ↓
STREAM TYPE	**F4**

Church Creek Longitudinal Profile






Church Creek 2008 - 2020
Relative Bed Elevation (Feet)
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


Relative Bed Elevation (Feet)
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

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APPENDIX G

CHEMICAL MONITORING RESULTS

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Anne Arundel County NPDES
Sampling Data – 2020 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	7/11/2019	17:00	2019Q3	ST1	Storm	1.28	6	0.21	81.80	261	8.8	12	1.3	0.57	0.2	200	38.7	5.9	391	<5	84	298
AP	7/11/2019	18:55	2019Q3	ST2	Storm				77.05	30,481	8.7	3	1.1	0.18	0.12	67	30.3	4.7	144	<5	30	725
AP	7/11/2019	20:45	2019Q3	ST3	Storm				76.49	65,454	8.8	<2	<0.5	0.61	0.09	13	12.7	<2	81	<5	30	5,081
AP	9/17/2019	17:00	2019Q3	MM	Baseflow				65.10	10	5.8	<2	<0.5	4.1	<0.01	1	3.7	<2	129	<5	340	20
AP	9/26/2019	14:03	2019Q3	MM	Baseflow				66.02	8	6.0	<2	0.7	4.8	<0.01	2	2.7	<2	116	<5	300	52
AP	10/16/2019	10:25	2019Q4	ST1	Storm	1.14	6	0.19	65.69	185	9.0	12	1.7	1.1	0.22	44	33.3	3.8	374	<5	80	974
AP	10/16/2019	14:40	2019Q4	ST2	Storm				62.92	57,184	9.2	<2	0.6	0.17	0.08	34	17.5	2.2	123	<5	23	18,993
AP	10/16/2019	16:05	2019Q4	ST3	Storm				65.03	23,997	9.4	<2	<0.5	0.74	0.09	9	13.9	<2	131	<5	34	24,196
AP	11/23/2019	22:30	2019Q4	ST1	Storm	0.61	8.5	0.07	48.52	2,006	10.1	11	1.1	0.61	0.18	72	25.0	3.2	336	<5	54	2,289
AP	11/24/2019	2:20	2019Q4	ST2	Storm				45.02	24,575	9.9	<2	<0.5	0.14	0.04	9	6.1	<2	108	<5	18	893
AP	11/24/2019	3:35	2019Q4	ST3	Storm				47.32	8,989	10.6	<2	<0.5	0.39	0.05	3	6.5	<2	82	<5	24	1,320
AP	12/27/2019	9:20	2019Q4	MM	Baseflow				56.66	17	6.1	<2	<0.5	5.6	0	2	3.3	<2	158	<5	290	<10
AP	12/29/2019	12:25	2019Q4	ST1	Storm	0.52	9	0.06	51.74	2,158	10.2	6	1.6	0.87	0.17	63	40.5	3.3	313	<5	36	59
AP	12/29/2019	18:05	2019Q4	ST2	Storm				50.23	25,444	10.5	<2	<0.5	0.16	0.07	24	14.2	<2	124	6	0	144
AP	12/29/2019	20:15	2019Q4	ST3	Storm				51.11	11,644	10.6	<2	<0.5	0.41	0.05	2	9.1	<2	107	<5	0	671
AP	1/25/2020	2:20	2020Q1	ST1	Storm	1.32	8	0.17	49.42	698	8.8	<2	1.2	1.5	0.38	21	50.5	<2	235	<5	80	10
AP	1/25/2020	6:00	2020Q1	ST2	Storm				46.89	75,313	10.7	<2	<0.5	0.12	0.09	55	16.0	2.7	120	<5	48	406
AP	1/25/2020	6:45	2020Q1	ST3	Storm				47.00	18,454	10.0	<2	<0.5	0.35	0.08	11	7.5	<2	63	<5	52	1,430
AP	3/13/2020	3:10	2020Q1	ST1	Storm	0.25	4.5	0.06	52.61	378	9.6	6	1.6	1.3	0.23	81	25.6	4.3	346	14	92	137
AP	3/13/2020	4:20	2020Q1	ST2	Storm				52.49	4,895	9.8	<2	<0.5	0.42	0.07	48	14.4	2.5	171	<5	56	66
AP	3/13/2020	5:25	2020Q1	ST3	Storm				52.26	4,915	9.7	<2	<0.5	0.61	0.04	5	12.0	<2	100	<5	48	267
AP	3/25/2020	7:20	2020Q1	ST1	Storm	0.22	4.5	0.05	48.67	185	9.8	7	<0.5	0.64	0.11	46	18.4	2.6	231	<5	76	777
AP	3/25/2020	8:25	2020Q1	ST2	Storm				48.04	3,172	10.0	<2	<0.5	0.2	0.04	12	9.3	<2	109	<5	32	201
AP	3/25/2020	8:50	2020Q1	ST3	Storm				48.57	986	9.9	<2	<0.5	0.33	0.04	5	8.9	<2	103	<5	28	642
AP	4/13/2020	23:35	2020Q2	ST1	Storm	1.37	14.5	0.09	30.36	406	9.1	16	2.4	0.88	0.25	41	19.7	<2	221	<5	76	36
AP	4/13/2020	5:30	2020Q2	ST2	Storm				15.56	51,415	9.4	<2	1.7	0.19	0.23	45	83.1	15.9	451	<5	88	1,213
AP	4/13/2020	11:15	2020Q2	ST3	Storm				55.48	69,662	9.2	<2	<0.5	0.99	0.06	6	11.9	<2	107	<5	60	890
AP	6/11/2020	11:40	2020Q2	ST1	Storm	0.41	4.75	0.09	76.51	1,040	10.6	14	1.6	0.59	0.32	220	47.5	10.3	450	<5	76	1,667
AP	6/11/2020	11:45	2020Q2	ST2	Storm				75.59	5,714	10.4	4	<0.5	0.19	0.12	59	20.9	3.5	134	<5	52	9,562
AP	6/11/2020	12:25	2020Q2	ST3	Storm				73.85	44,898	9.4	<2	<0.5	0.53	0.06	11	13.2	<2	83	<5	17	13,568
AP	6/25/2020	10:15	2020Q2	MM	Baseflow				65.12	5	7.4	<2	<0.5	4.7	<0.01	<1	2.9	<2	125	<5	330	120

Anne Arundel County NPDES
Sampling Data – 2020 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	7/11/2019	17:15	2019Q3	ST1	Storm	1.28	6	0.21	79.88	25,812	6.8	13	1.3	0.88	0.39	140	28.9	14.5	196	<5	28	638
AC	7/11/2019	19:25	2019Q3	ST2	Storm				77.00	561,441	6.7	4	0.8	0.28	0.26	120	15.4	15.6	108	5	23	4,352
AC	7/11/2019	22:30	2019Q3	ST3	Storm				77.72	518,871	6.6	2	<0.5	0.32	0.14	27	5.9	4.5	41	<5	36	8,664
AC	9/17/2019	15:45	2019Q3	MM	Baseflow				70.90	635	6.6	<2	<0.5	0.59	0.04	3	<2	<2	22	<5	220	109
AC	9/26/2019	14:28	2019Q3	MM	Baseflow				68.70	604	6.2	3	0.8	0.78	0.05	2	4.4	<2	32	<5	150	201
AC	10/16/2019	11:25	2019Q4	ST1	Storm	1.14	6	0.15	61.52	10,803	6.2	<2	1.3	0.91	0.66	160	26.4	17.5	169	<5	160	2,046
AC	10/16/2019	15:05	2019Q4	ST2	Storm				63.32	629,240	6.4	3	<0.5	0.31	0.22	30	11.4	6.0	85	<5	27	9,804
AC	10/16/2019	17:25	2019Q4	ST3	Storm				63.32	341,764	6.3	3	<0.5	0.51	0.17	24	9.8	3.1	60	<5	51	6,867
AC	11/23/2019	23:05	2019Q4	ST1	Storm	0.61	8.5	0.07	46.22	31,999	6.3	5	0.7	0.87	0.22	58	10.2	8.3	100	<5	100	228
AC	11/24/2019	2:40	2019Q4	ST2	Storm				45.50	327,543	6.5	3	<0.5	0.29	0.14	43	9.5	5.4	77	<5	24	15,665
AC	11/24/2019	4:00	2019Q4	ST3	Storm				45.50	124,173	6.5	2	<0.5	0.28	0.08	12	5.0	<2	40	<5	26	1,223
AC	12/27/2019	8:45	2019Q4	MM	Baseflow				43.20	581	6.3	<2	<0.5	0.85	0.06	10	0.0	<2	54	<5	120	<10
AC	12/29/2019	14:25	2019Q4	ST1	Storm	0.52	9	0.06	49.64	66,878	6.2	2	0.7	0.59	0.11	44	10.4	3.9	75	<5	56	1,236
AC	12/29/2019	18:40	2019Q4	ST2	Storm				49.64	199,639	6.2	<2	<0.5	0.31	0.11	47	8.3	4.0	54	<5	44	3,255
AC	12/29/2019	20:25	2019Q4	ST3	Storm				48.92	114,627	6.3	<2	<0.5	0.28	0.06	10	5.5	<2	51	<5	20	2,909
AC	1/25/2020	3:00	2020Q1	ST1	Storm	1.32	8	0.17	43.70	8,660	6.1	<2	1.5	1.3	0.35	100	6.2	5.9	77	<5	120	52
AC	1/25/2020	6:25	2020Q1	ST2	Storm				45.86	702,170	6.4	<2	<0.5	0.24	0.26	140	16.5	13.9	125	<5	60	1,071
AC	1/25/2020	9:40	2020Q1	ST3	Storm				45.32	558,319	6.3	<2	<0.5	0.36	0.1	19	6.3	3.3	52	<5	40	573
AC	3/13/2020	3:45	2020Q1	ST1	Storm	0.25	4.5	0.06		12,464		5	<0.5	1.2	0.31	160	11.7	8.7	112	<5	120	158
AC	3/13/2020	4:45	2020Q1	ST2	Storm					45,874		4	<0.5	0.73	0.27	120	15.1	8.3	105	<5	48	3,076
AC	3/13/2020	6:15	2020Q1	ST3	Storm					79,214		<2	<0.5	0.54	0.08	15	6.1	<2	48	<5	48	1,674
AC	3/25/2020	7:55	2020Q1	ST1	Storm	0.22	4.5	0.05		7,211	6.8	3	<0.5	0.47	0.06	10	5.5	<2	47	<5	72	203
AC	3/25/2020	8:40	2020Q1	ST2	Storm					27,527	6.6	3	<0.5	0.76	0.15	43	9.7	5.1	92	<5	86	546
AC	3/25/2020	11:00	2020Q1	ST3	Storm				49.46	86,980	6.5	<2	<0.5	0.27	0.07	12	6.5	<2	44	<5	36	465
AC	4/13/2020	0:25	2020Q2	ST1	Storm	1.37	14.5	0.09	57.56	22,692	5.9	4	2.6	1.3	0.55	190	13.7	10.6	117	<5	140	288
AC	4/13/2020	5:45	2020Q2	ST2	Storm				58.46	406,116	6.1	3	1.3	0.33	0.5	210	27.4	23.9	178	<5	60	933
AC	4/13/2020	11:20	2020Q2	ST3	Storm				59.54	960,735	6.1	<2	0.6	0.34	0.25	20	13.3	2.9	46	<5	48	565
AC	6/11/2020	11:50	2020Q2	ST1	Storm	0.41	4.75	0.09	71.06	6,919	6.7	4	1.2	0.71	0.63	210	116.0	16.2	224	<5	72	1,935
AC	6/11/2020	12:25	2020Q2	ST2	Storm				73.04	275,057	6.5	3	<0.5	0.33	0.2	75	13.1	7.9	77	<5	24	17,329
AC	6/11/2020	14:25	2020Q2	ST3	Storm				67.46	389,986	6.6	4	<0.5	0.36	0.1	23	10.4	<2	35	<5	30	9,804
AC	6/25/2020	9:15	2020Q2	MM	Baseflow				66.02	478	6.6	<2	<0.5	0.75	0.05	4	4.8	<2	<20	<5	120	173

Anne Arundel County NPDES
Quarterly EMC and Load Data – 2020 Reporting Year

Quarterly Average EMCs															
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	2019Q3	1,107,362	77.40	6.7	3	0.6	0.31	0.21	77	11.2	10.3	79	4	29	6,281
AC	2019Q4	1,847,246	55.78	6.4	3	0.3	0.36	0.16	32	9.7	4.5	71	3	35	8,063
AC	2020Q1	1,528,419	45.95	6.4	1	0.3	0.34	0.18	79	11.3	8.1	88	3	52	919
AC	2020Q2	2,061,983	62.64	6.2	2	0.6	0.35	0.27	68	15.8	7.4	76	3	45	4,623
Parole Plaza															
AP	2019Q3	96,215	76.68	8.8	2	0.5	0.47	0.10	31	18.3	2.2	102	3	30	3,687
AP	2019Q4	156,198	56.25	9.8	1	0.4	0.30	0.07	21	13.8	1.5	124	3	19	10,992
AP	2020Q1	108,997	47.49	10.5	1	0.3	0.21	0.09	43	14.3	2.2	113	3	49	551
AP	2020Q2	173,141	49.12	7.1	1	0.7	0.60	0.11	22	33.9	5.6	206	3	57	4,562

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	2019Q3	1,107,362	226	38	22	14	5,305	0.8	0.7	5	260	2,031
AC	2019Q4	1,847,246	297	32	42	19	3,727	1.1	0.5	8	288	4,078
AC	2020Q1	1,528,419	109	25	32	17	7,538	1.1	0.8	8	238	4,932
AC	2020Q2	2,061,983	292	83	45	35	8,730	2.0	1.0	10	322	5,774
Parole Plaza												
AP	2019Q3	96,215	10	3	3	0.6	184	0.1	0.01	0.6	15	181
AP	2019Q4	156,198	12	4	3	0.7	208	0.1	0.01	1	30	187
AP	2020Q1	108,997	7	2	1	0.6	293	0.1	0.02	0.8	17	332
AP	2020Q2	173,141	13	7	7	1	238	0.4	0.1	2	27	616

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	2019Q3	18,674,269	3,812	645	365	241	89,467	13.1	12.1	92	4,391	34,256
AC	2019Q4	28,160,557	4,533	492	638	288	56,820	17.0	7.9	125	4,394	62,161
AC	2020Q1	23,928,604	1,706	384	508	268	118,007	17.0	12.2	131	3,734	77,216
AC	2020Q2	25,881,204	3,669	1,048	569	434	109,573	25.6	12.0	122	4,038	72,479
Parole Plaza												
AP	2019Q3	556,515	58	18	16	3	1,063	0.6	0.08	4	87	1,049
AP	2019Q4	1,232,485	93	32	23	6	1,640	1.1	0.1	10	236	1,475
AP	2020Q1	1,019,363	63	17	14	5	2,744	0.9	0.1	7	162	3,105
AP	2020Q2	978,074	74	42	37	7	1,343	2.1	0.3	13	153	3,482

Anne Arundel County NPDES
Annual EMC and Load Data – 2020 Reporting Year

Annual Average EMCs															
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	2020	6,545,010	59.30	6.4	2	0.4	0.35	0.21	62	12.3	7.3	78	3	41	5,009
Parole Plaza															
AP	2020	534,550	55.83	8.9	1	0.5	0.41	0.09	28	21.2	3.1	144	3	39	5,466

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	2020	6,545,010	925	179	141	85	25,300	5.0	3.0	32	1,109	16,815
Parole Plaza												
AP	2020	534,550	42	16	14	3	923	0.7	0.1	5	89	1,317

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	2020	96,644,634	13,720	2,569	2,081	1,231	373,867	72.6	44.2	469	16,558	246,112
Parole Plaza												
AP	2020	3,786,437	287	109	90	21	6791	4.7	0.7	33	637	9,111