

First Flush and Total Storm Event Pollutant Distribution at Ferry Terminal and Rest Area Facilities

WA-RD 951.1

Brandon Slone

June 2025



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WSDOT Research Report

Research Report
Agreement K0012, Task 69
WA-RD 951.1

First Flush and Total Storm Event Pollutant Distribution at Ferry Terminal and Rest Area Facilities

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Prepared for
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Department of Transportation
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June 2025

1. Report No. WA-RD 951.1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle First Flush and Total Storm Event Pollutant Distribution at Ferry Terminal and Rest Area Facilities				5. Report Date June 13, 2025	
				6. Performing Organization Code	
7. Author(s) Brandon Slone				8. Performing Organization Report No.	
9. Performing Organization Name and Address Washington State Department of Transportation Stormwater Branch P.O. Box 47332 Olympia, WA 98504-7332				10. Work Unit No.	
				11. Contract or Grant No. Agreement # K0012, Task 69	
12. Sponsoring Agency Name and Address Washington State Department of Transportation Research Office, MS 47372 Olympia, Washington 98504-7372 Project Manager: Jon Peterson, 360-705-7499				13. Type of Report and Period Covered Final Report (December 2011 - May 2024)	
				14. Sponsoring Agency Code	
5. Supplementary Notes This project was done in cooperation with the Federal Highway Administration.					
16. Abstract This Study characterized select stormwater pollutants, and their changing concentrations, throughout the entirety of storm durations at a Washington State Department of Transportation (WSDOT) Ferry Terminal and Rest Area facilities. Emphasis was placed on demarcating First Flush phases (initial 10%-40% of storm events), where higher pollutant concentrations generally occur, from later lower pollutant phases. Site analysis confirmed and delineated a clear pollutant phase change at both sites, with a consistent trend of highest pollutant concentrations during the first 0-0.06/0.08 inches of rainfall depth (RD), followed by a sharp, steep reduction (~60%) by 0.012/0.23 RD. This was further followed by a relative leveling out of concentrations at lower values for the remainder of storm durations. This "L-curve" was observed for all pollutants. Implications of this L-curve are significant, indicating numerous potential Best Management Practice (BMP) design opportunities such as lower volumetric requirements for intensive BMPs, reductions in certain treatment amendments (i.e. compost), and enhanced treatment train designs. Findings are expected to impact subsequent BMP development at Ferry Terminal and Rest Area facilities.					
17. Key Words Stormwater, First Flush, Rainfall Depth, Total Storm Pollutant Distribution			18. Distribution Statement NA		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 59	22. Price NA

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EXECUTIVE SUMMARY

Objectives

This Study aimed to characterize stormwater pollutants, and their changing concentrations, throughout the entirety of storm durations at a WSDOT Ferry Terminal and Rest Area facilities. Emphasis was placed on demarcating First Flush phases (initial 10%-40% of storm events), where higher pollutant concentrations generally occur, from later lower pollutant phases.

Background

WSDOT is required to manage or treat stormwater runoff pollutants from its Ferry Terminals and Rest Areas. However, detailed understanding of these pollutants is limited. Particularly, pollutant changes throughout storm events are unknown, with most studies either focusing on early storm grab/short duration sampling or total storm composite sampling. The problem with this separation is that early storm “first flush” pollutant concentrations are generally elevated and later event composite concentrations are lower. Management approaches that target only the higher, acute concentrations may be unnecessarily conservative, devoting excess space or treatment technologies; however, approaches that only factor average composite pollutant levels may miss acute toxicity impacts as well as be unnecessarily conservative for late storm low pollution concentrations. Instead, BMPs that account for pollutant phase changes, notably when higher acute concentrations switch to lower concentrations and at what conditions, may allow more effective, efficient, space optimized approaches.

Research Activities

WSDOT collected discrete stormwater samples, throughout the entire duration of select storm events, at Point Defiance Ferry Terminal (Tacoma) and Scatter Creek Northbound Rest Area (Rochester). Staff collected eight to nine storm events between 2022 through 2024 for each Site, in various seasons and storm precipitation depths. Number of samples for each storm varied but ranged 7-18, median 11 per event for Point Defiance; and ranged 8-22, median 14 for Scatter Creek. Targeted pollutants were total suspended solids, dissolved copper, and dissolved zinc, collectively referred to as “pollutants”. Pt. Defiance had supplemental samples for total phosphorus and nitrate-nitrite during two storm events, and fecal coliform, gasoline, diesel and heavy oil grab samples at the beginning of one event. Scatter Creek sample collection was flow-weighted, with increased sample collection during first flush phases. Point Defiance sampling, due to site constraints, was time-weighted but incorporated manual grab samples periodically to generate greater resolution during first flush periods.

Conclusions

Site analysis confirmed and demarcated a clear pollutant phase change at both sites, with a consistent trend of highest pollutant concentrations during the first 0-0.06/0.08 inches of rainfall depth (RD), followed by a sharp, steep reduction (~60%) by 0.012/0.23 RD. This was further followed by a relative leveling out of concentrations at lower values for the remainder of storm durations. This “L-curve” was observed for all pollutants.

Implications of this L-curve are significant, indicating numerous potential BMP design opportunities such as lower volumetric requirements for intensive BMPs, reductions in certain treatment amendments (i.e. compost), and enhanced treatment train designs. Findings are expected to impact subsequent BMP development at Ferry Terminal and Rest Area facilities.

1.0 Introduction

Effective stormwater runoff (runoff) characterization is essential in developing best management practices (BMPs) to treat and manage runoff pollutants and volumes. The Washington State Dept. of Transportation (WSDOT) is required to manage runoff from its surfaces and activities, specifically its highways/roads and facilities.

This paper examines stormwater runoff at two WSDOT facility types, ferry terminals and rest areas, represented by research at Pt. Defiance Ferry Terminal (Pt. Defiance) and the Scatter Creek I-5 Northbound Rest Area (Scatter Cr.). These sites are not intended to represent all ferry terminals/rest areas but are characteristic enough to demonstrate many broad patterns for these facility types.

This Study collected discrete pollutant samples throughout all phases of storm events. The goal was to understand:

- Pollutant concentration amounts and changes throughout storm events, from beginning to end
- Relevant environmental factors affecting pollutants, such as rainfall amount/depth and storm intensity
- Application of Study findings to future BMP development

2.0 Review of Previous Work

WSDOT conducted previous characterization on its Facilities in the *WSDOT NPDES Municipal Stormwater Permit Rest Areas, Maintenance Facilities, and Ferry Terminals Stormwater Monitoring Report (S7.D) Water Years 2012 and 2013* report (WSDOT, 2014). This study examined stormwater runoff during the first hour of storm events, finding elevated pollutant concentrations. Additional research has been conducted during WSDOTs Facilities BMP research, detailed in the *Quality Assurance Project Plan WSDOT Facility Stormwater Treatment Evaluation: Best Management Practices* (2021). This study focuses on BMP treatment efficacy but does collect influent facilities stormwater runoff, informing characterization data.

Greater pollutant concentrations in initial stormwater runoff is a long-recognized phenomenon (Bertrand-Krajewski et al. 1998). Regarding total storm event pollutant studies, they generally support the pattern of higher initial pollutant concentrations followed by lower concentrations (Stenstrom and Masoud, 2005). However, some studies demonstrate that many pollutants don't follow the first flush pattern, displaying peaks in concentration later in storm events, particularly those that are transport-limited rather than mass-limited (Peter et. al. 2020).

This variation in pollutant mobilization suggests the need for identifying WSDOT specific pollutant patterns for compliance targets and facilities. Clarifying which pollutants, and under what conditions, is imperative for designing effective BMPs to

manage facility stormwater.

3.0 Research Approach

3.1 Site Selection

Ferry Terminal

WSDOT assessed multiple ferry terminals for monitoring. Of these, Pt. Defiance (Tacoma) offered the best location. Figures 1-2 display Pt. Defiance layout and rough drainage areas.



Figure 1 – Pt. Defiance Location, Adjacent Highways/Infrastructure, and Monitoring Site



Figure 2 - Eastward Lanes Stormwater Runoff and Receiving Catchbasin

Staff assessed sampling locations at Pt. Defiance, which was complicated by lack of a non-tidally influenced stormwater outfall pipe. To address, Staff decided to utilize the entrance of a stormwater catch basin, collecting runoff running down the ramp towards the ferry. This location was one of the final catchbasins before discharge to Puget Sound piping and collected much of the stormwater running down the ramp from multiple traffic lanes, aided by a slight east-wards gradient slope directing stormwater along the curb. A mortar softpatch was installed to further direct runoff into the catchbasin. Figure 3 details site setup.



Figure 3 - (left) Sampled Catchbasin and Piping; (right) Sampling Equipment (Autosampler, Datalogger, Battery, etc)

Staff installed a stainless-steel collection box under the lid of the sampled catchbasin (Figure 4), capturing runoff as it entered the catchbasin but before comingling with the tidally influenced piping/conveyance system at the bottom of the catchbasin.



Figure 4 - Sampled Catchbasin with Tubing Connecting to Autosampler (Cleaned Prior to Storm Events)

Rest Area

Scatter Cr NB (Rochester) was found ideal for monitoring. The drainage area for this stormwater was from the truck parking area. Drainage from the car parking area did not support sampling infrastructure. Figure 5 details.



Figure 5 - Scatter Cr Rest Area Northbound Truck Parking/Stormwater Drainage Area

Stormwater went through multiple commingled conveyance pipes before final discharge to detention basins. Runoff was collected from this outfall, which had a flume/sample collection box attached to end, prior to entrance into the BMPs (Figure 6).



Figure 6 - (Left) Scatter Cr Monitoring Station; (Right) Pipe Outfall to Flume

3.2 Site Infrastructure

Each Site consisted of a:

- Steel containment box that housed sampling equipment
- Forest Technology Services (FTS) DataLogger, which directed sampling and hydrological/meteorological monitoring
- ISCO Avalanche Autosampler(s) which collected and refrigerated samples
- 950 mL carousel sample bottles installed inside the ISCOs. These bottles were cleaned by AmTest and reused for multiple events

- FTS rain gage, which collected rainfall data and radar stage monitor
- FTS GOES satellite antenna and telemetry system, used to transmit and monitor the sites via transmission to the NOAA GOES system
- Miscellaneous support items (tubing, batteries, shelving, etc)
- Flume for flow monitoring (Scatter Cr)

Sites were constructed in 2022 and received routine maintenance (3-week cycle) and calibration. Figure 7 displays a typical setup.



Figure 7 - Monitoring Station Setup

3.3 Storm Targeting and Rainfall Monitoring

Storm events were targeted to meet portions of Washington State Dept. of Ecology (Ecology) Technology Assessment Protocol – Ecology (TAPE) criteria, specifically:

- Rainfall depth of 0.15 inches or greater
- Ending storm events when 6 hours or less than 0.04 inches of rain
- Capturing at least 75% of storm hydrographs

One exception was that WSDOT started sampling at 0.02 inches of rainfall, as opposed to TAPE's 0.04 requirement. This was done to ensure WSDOT captured and had greater resolution for the first flush runoff generated by the 0.02 of rainfall, rather than waiting until 0.04 when some of the first flush had already passed.

Note: meeting TAPE criteria was a goal but not a determinate in accepting sampling results.

Staff monitored for potential storm events via multiple weather forecast services,

primarily: National Oceanic and Atmospheric Administration (NOAA) – National Weather Service, Accuweather, and WeatherUnderground.

Intra-storm rainfall was measured by site rain gages.

3.4 Sampled Pollutants and Criteria

Primary sampled pollutants were total suspended solids (TSS), dissolved copper (Diss Cu), and dissolved zinc (Diss Zn). These samples were chosen for the following reasons:

- 1) TSS is the major target of TAPE Basic Treatment BMP studies, and TSS, Diss Cu, and Diss Zn are the major targets of TAPE Enhanced Treatment BMP studies. Basic and Enhanced Treatment BMPs make up the majority of WSDOT BMPs and BMP studies.
- 2) TSS, Diss Cu, and Diss Zn often correlate with certain other pollutants and can act of proxies.
- 3) TSS, Diss Cu, and Diss Zn are inexpensive to analyze via laboratory costs. This low cost allowed the large number of samples required for this Study.

Pt. Defiance had supplemental samples for total phosphorus (TP), nitrate-nitrite (N+N), fecal coliform (FC), gasoline (Gx), diesel (Dx) and heavy oil (HO) at select storm events. These samples were chosen via discussions and characterization goals with the WA State Ferries Office.

Staff aimed to sample eight storms for each site. This number was based on balancing sufficient events for baseline characterization with available Study budget. Staff aimed to collect between 10-28 samples per storm, with increased sample collection during the first flush period for greater resolution during that higher pollutant phase.

3.5 Site Preparation for Individual Storm Events

Before every sampled storm, sites were prepared to ensure accurate monitoring and sample collection. These steps included:

- Cleaning and removal of debris/residue from sample collection boxes and flume (Scatter Cr)
- Ensuring all sensors and systems were reading accurately and in order
- Programming sample collection thresholds and sampling activation

3.6 Sample Collection Thresholds

Scatter Creek sample collection was flow-weighted, with increased sample collection during first flush phases. This was accomplished by utilization of two

ISCO autosamplers (Figure 8).



Figure 8 - Autosamplers ISCO 1 (left) and ISCO 2 (right)

ISCO 1 was programmed to capture the First Flush period, usually set with volume collection thresholds that were divisible into the thresholds used by ISCO 2, for comparison.

ISCO 2 was programmed to collect samples throughout the entire duration of the storm event, based on predicted runoff amounts.

Pt. Defiance sampling was time-weighted due to inability to safely install a flume/flow-measuring device at the sample collection area. Instead, Staff used predicted meteorological patterns and on-going site data to determine ideal time thresholds. These thresholds were based on dividing the duration of the storm event by the number of samples the single site ISCO could collect (14). 50 minutes was the most common threshold, as most storm events concluded within a 12-hour period. Samples collected during no rain periods were discarded.

3.7 Submittal to Laboratory and Field Filtering

Samples were delivered to AmTest laboratory within 24 hours of collection to meet laboratory holding times for Diss Cu/Diss Zn. When samples couldn't be delivered in 24 hours, Staff manually homogenized and filtered sample water, via lab supplied syringes/filters, and put in nitric acid rinsed sample bottles for Diss Cu/Diss Zn analysis. The remaining sample water was put into non-preservative lab supplied sample bottles for TSS analysis.

3.8 Laboratory Analytical Reports

Data results, and analysis methodology, were delivered in the form of laboratory analytical reports.

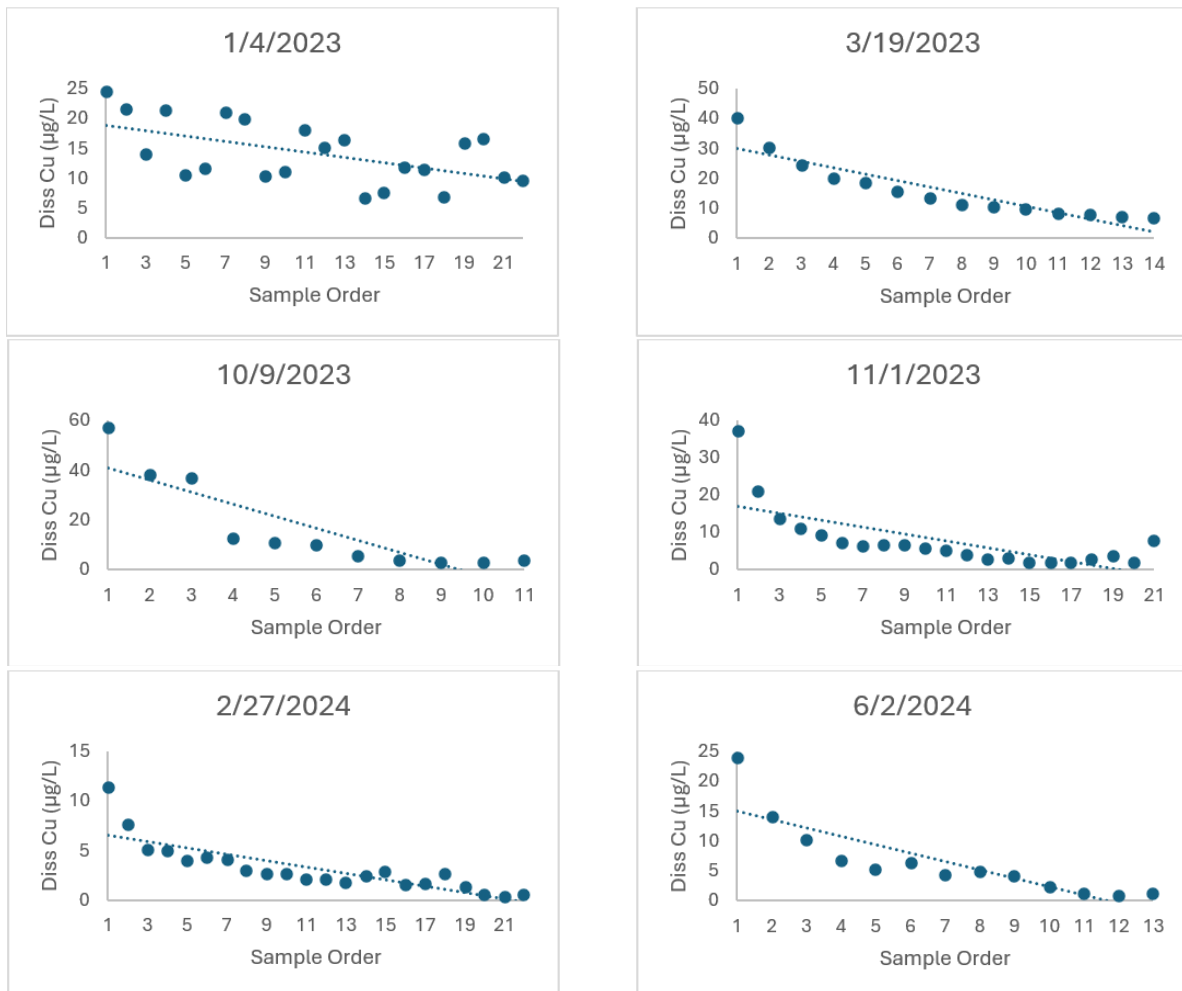
4.0 Scatter Creek Rest Area Results

Staff collected eight storm events at Scatter Cr, between 1/4/23 to 10/30/24, meeting Study goals. Staff collected an additional storm event on 10/9/23 but this event was very small (0.04 in), and immediately adjacent to another event (10/10/23), so WSDOT paired the two together as one event.

Tables in Appendix A detail pollutant data for each storm and paired hydrological/meteorological data.

4.1 Pollutant Concentrations Over Storm Durations

Figures 9-11 below demonstrate sequential changing pollutant concentrations throughout storm events for Diss Cu, Diss Zn, and TSS.



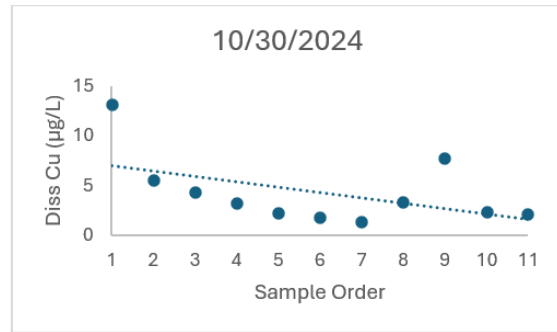
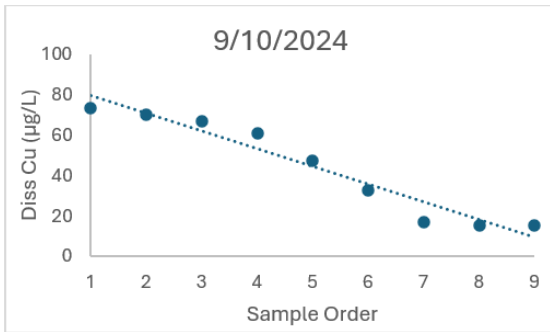
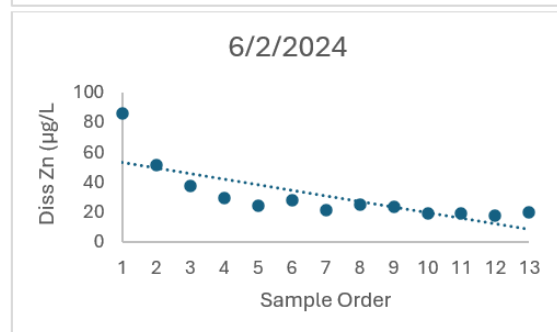
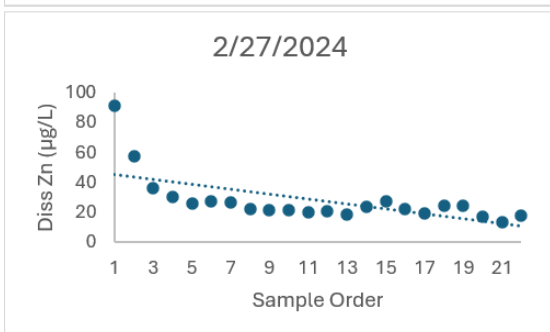
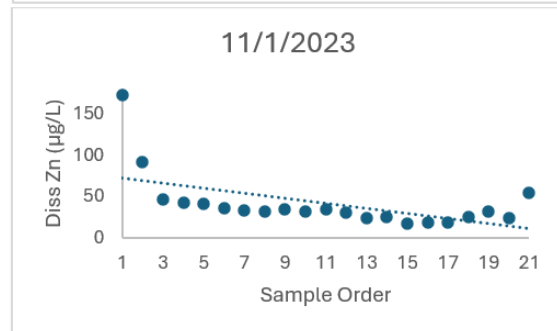
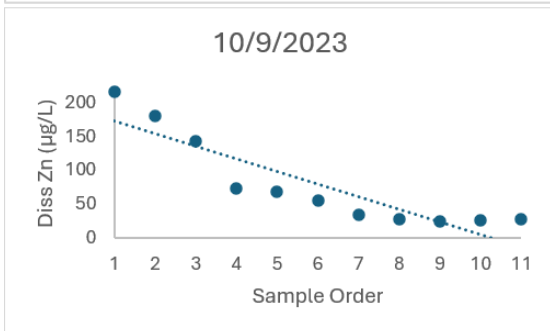
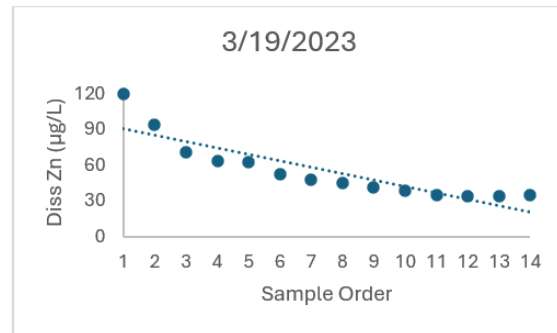
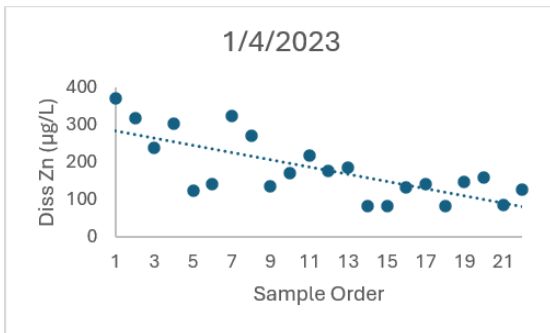


Figure 9 - Scatter Cr Dissolved Copper Concentrations vs Sample Order for Individual Storm Events

Diss Cu, in all eight storm events, displayed a clear trend of highest values near the beginning of storm events followed by a mostly consistent drop, with occasional upward bounces. Diss Cu concentrations didn't level out, possibly due to the short duration of most events but displayed moderating of concentrations at lower levels later in events.



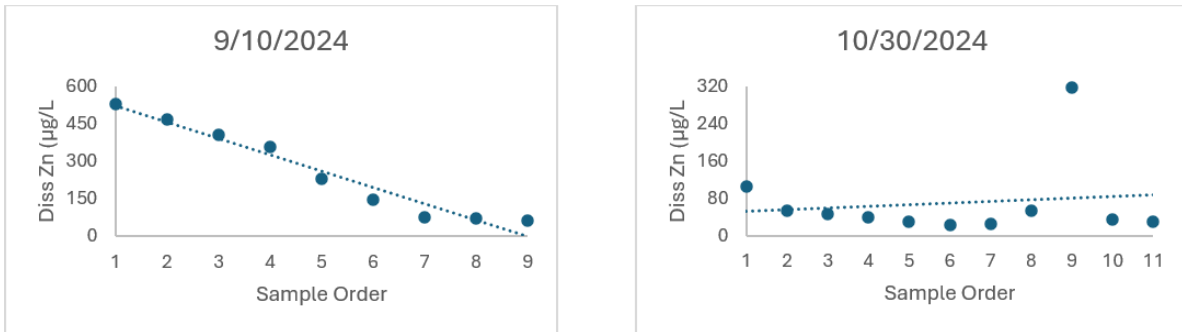
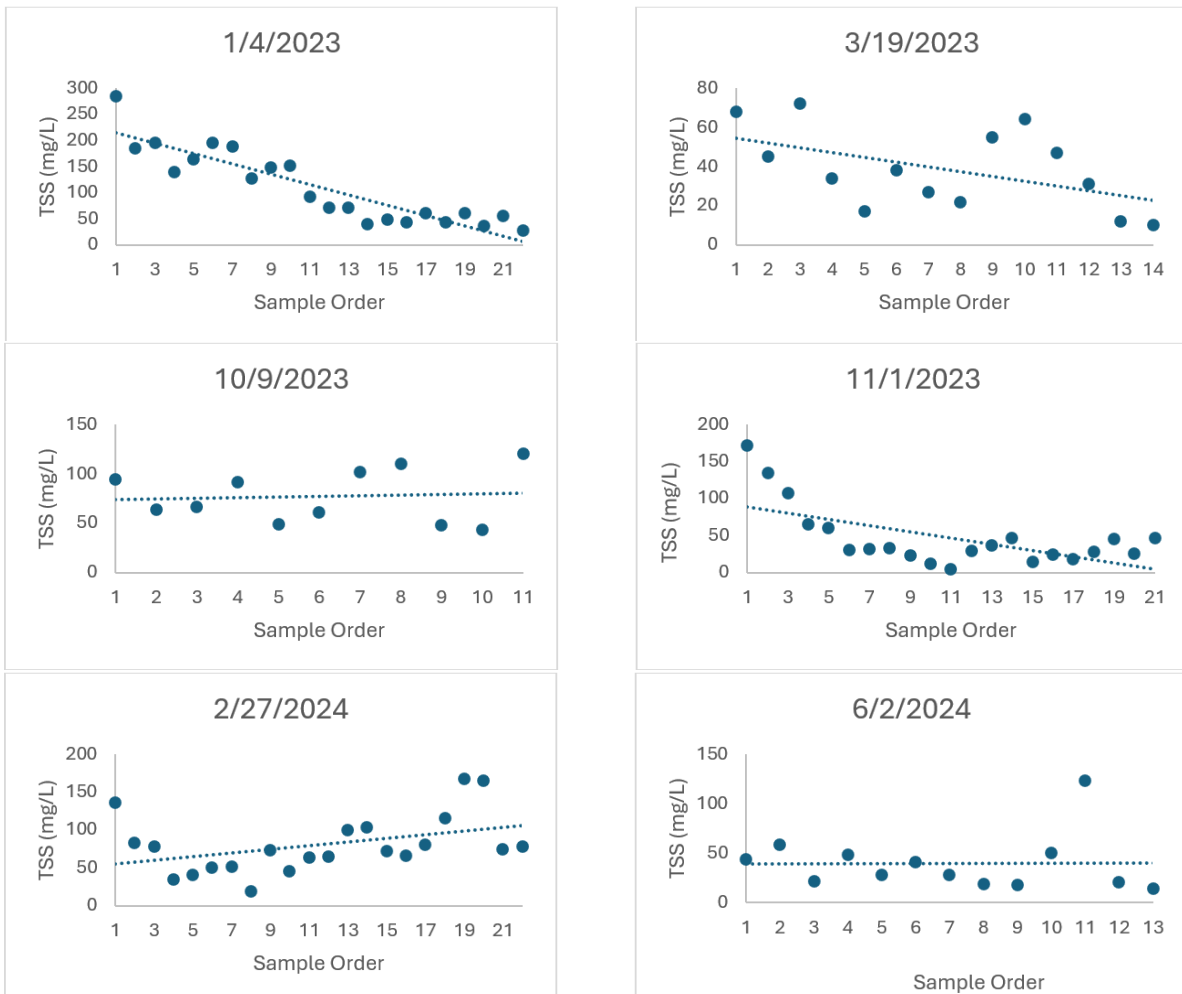


Figure 10 - Scatter Cr Dissolved Zinc Concentrations vs Sample Order for Individual Storm Events

Diss Zn, in seven of eight events, displayed a clear trend of highest values near the beginning of storm events followed by a consistent drop. Event 10/30/24, which didn't display this trend had a single outlier value later in the storm event, followed by a return to lower Diss Zn concentrations. Concentrations, in contrast to Diss Cu, demonstrated greater leveling out at lower levels.



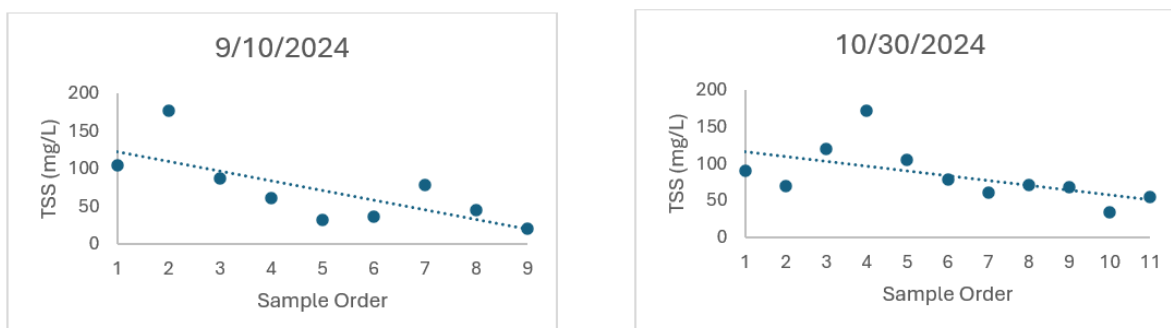


Figure 11 - Scatter Cr TSS Concentrations vs Sample Order for Individual Storm Events

TSS displayed a slight trend of higher values near the beginning of storm events followed by decreasing values over storm duration, but was much bouncier than Diss Cu/Zn, demonstrating spikes in concentration later in storm events and a less consistent pattern.

4.2 Pollutant Concentrations in Response to Meteorological/Hydrological Variables

WSDOT conducted further analysis into hydrological or meteorological variables affecting concentrations.

The variables examined were:

- Rainfall Depth (RD)
- Runoff Volume (runoff)
- Flow Intensity
- Antecedent Dry Period (ADP)

These variables were assessed at the cumulative storm events level, rather than the individual storm event level, to increase n values and assess larger overall patterns.

RD and runoff demonstrated consistent patterns or plot trends. ADP displayed a trend with Diss Cu, and partially with Diss Zn, but not TSS.

Flow intensity displayed no trend. However, this Study was not designed to assess flow intensity vs pollutant concentrations, with potential confounding variables.

Because ADP only displayed an intermittent trend, not replicated at the other monitoring site Pt. Defiance (Section 5.0), and flow intensity demonstrated no trend, scatter plots and analysis for these variables are relegated to Appendices D and F, for reference. Neither of these variables are considered important considerations for this Study.

Regarding runoff volume, it's primarily a function of RD, particularly at Scatter Cr where all known contributing drainage areas consisted of impervious surface. This

was confirmed by plotting RD vs runoff (Figure 12), which showed a mostly linear trend.

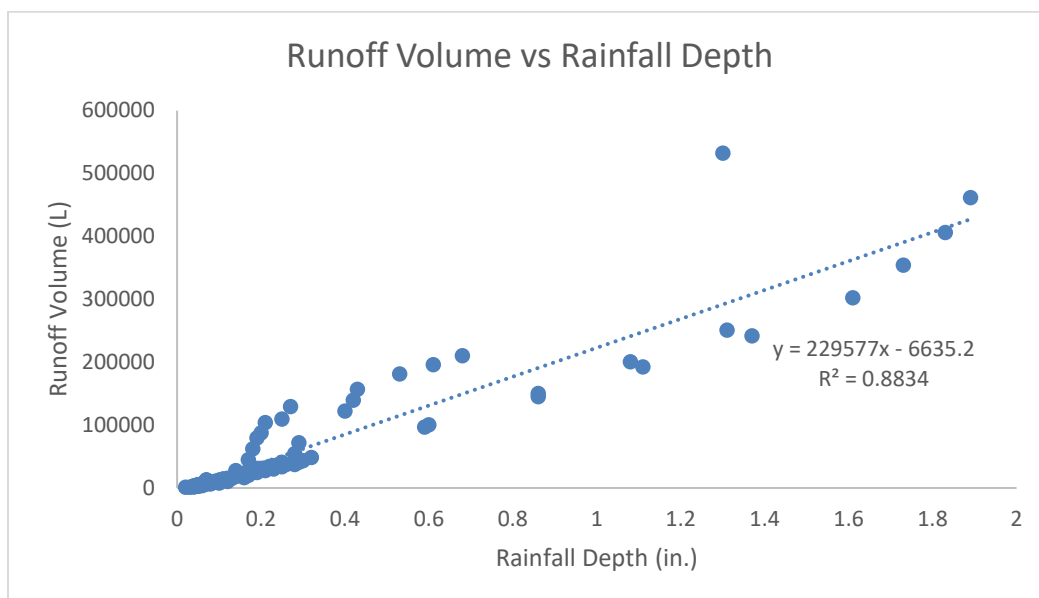


Figure 12 - Stormwater Runoff Volume vs Rainfall Depth

Runoff is a site-specific variable, dependent on drainage size, and not broadly applicable to other sites in the way that RD performs. As such, runoff volume is not discussed here as a significant variable in assessing intra-storm event pollutant concentrations. Scatter plots and analysis relating to runoff are presented in Appendix H.

4.3 Rainfall Depth

Figures 13-15 display consolidated storm events pollutant values corresponding to the RD, separated out by pollutant type. Tables 1-3 further assign summary statistics to RD subsets, denoted by quartile percentages. Note: the quartile percentage separations are not strict quarters but rather 0-20%, 21-50%, 51-75%, and 76-100%. This was done due to a disproportionately higher n (41) value in the original 0-25% category, compared to a lower n value (22) in the original 25-50% category. “Tweaking” the boundaries to 0-20% and 21-50% created more balanced n values (27 and 36 respectively) for statistical comparison.

Utilized statistical tests, the Kruskal-Wallis and Wilcoxon Rank Sum (Wilcoxon), were conducted using the R statistical program. R outputs and code are presented in Appendix I.

WSDOT also examined pollutant differences on the RD categories of first sample (FS)/0-5%/decile (decile) percentages. Examination at these levels, via the Kruskal-Wallis and Wilcoxon tests, found similar patterns validating quartile separations and results. To avoid redundancy of results and discussion, decile tables are in Appendix C.

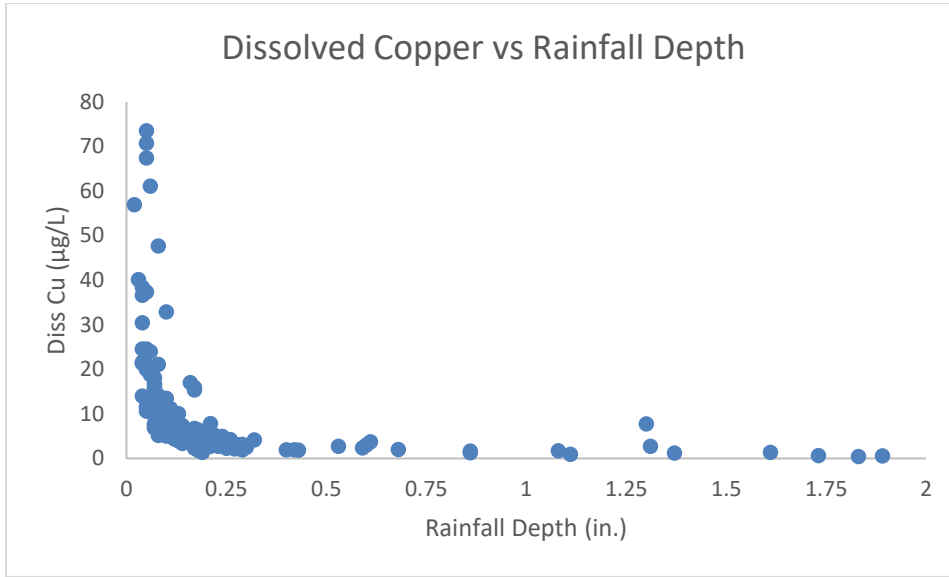


Figure 13 - Dissolved Copper vs Rainfall Depth

Table 1 - Dissolved Copper at Rainfall Depth Modified Quartiles

RD Percentile	0-20%	21-50%	51-75%	76-100%
RD Amount	0-0.06 in.	0.07-0.12 in.	0.13-0.24 in.	0.25-1.89 in.
<i>n</i>	27	36	30	30
Median	21.60	10.39	4.67	2.14
Mean	29.75	12.32	5.77	2.37
C/V	0.67	0.66	0.69	0.61

Diss Cu concentrations were highest (mean 29.33 ug/L) during the first quarter (Q1) of RD (0-0.06 in), followed by a large dip (mean 12.32 ug/L) in the second quarter (Q2), then a smaller dip (mean 5.77 ug/L) in the third quarter (Q3), and then another smaller dip (mean 2.37 ug/L) in the fourth (Q4) quarter.

Diss Cu removal is 58.57% reduction from Q1 to Q2; an 80.62% reduction from Q1 to Q3; and 92.04% reduction from Q1 to Q4.

Statistical comparisons confirmed this trend, with the Wilcoxon finding Q1 > Q2; Q2 > Q3; Q3 > Q4.

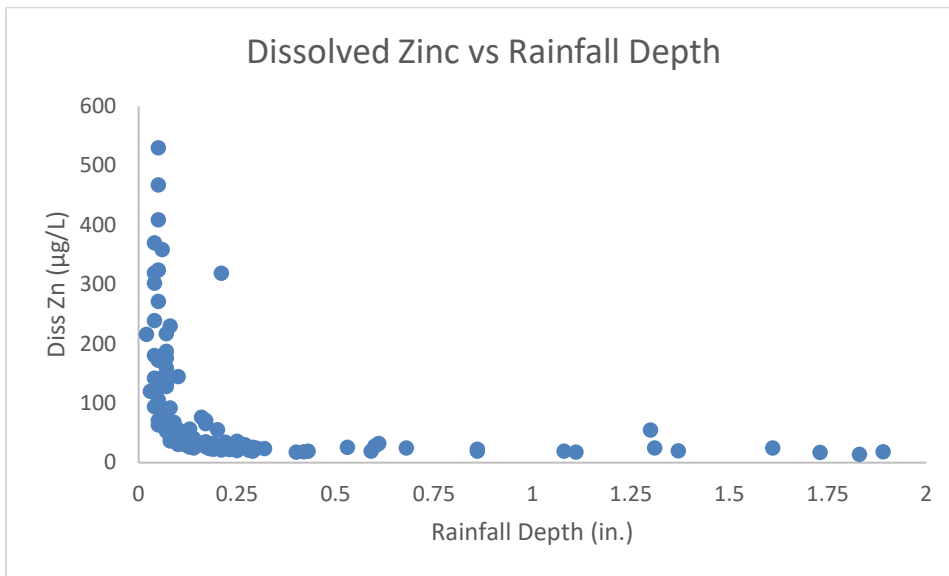


Figure 14 - Dissolved Zinc vs Rainfall Depth

Table 2 - Dissolved Zinc at Rainfall Depth Modified Quartiles

RD Percentile	0-20%	21-50%	51-75%	76-100%
RD Amount	0-0.06 in.	0.07-0.12 in.	0.13-0.24 in.	0.25-1.89 in.
<i>n</i>	27	36	30	30
Median	172.00	54.10	29.78	23.12
Mean	208.95	83.22	44.14	23.93
C/V	0.64	0.69	1.22	0.32

Diss Zn was highest (mean 208.95 ug/L) in Q1, followed by a significant dip (mean 83.22 ug/L) in Q2, then a smaller dip (mean 44.14 ug/L) in Q3, and then an even smaller dip (mean 23.93 ug/L) in Q4.

Diss Zn removal is 60.17% reduction from Q1 to Q2; 78.88% reduction from Q1 to Q3; and 88.55% reduction from Q1 to Q4.

Statistical comparisons confirmed this trend, with the Wilcoxon finding Q1 > Q2; Q2 > Q3; Q3 > Q4.

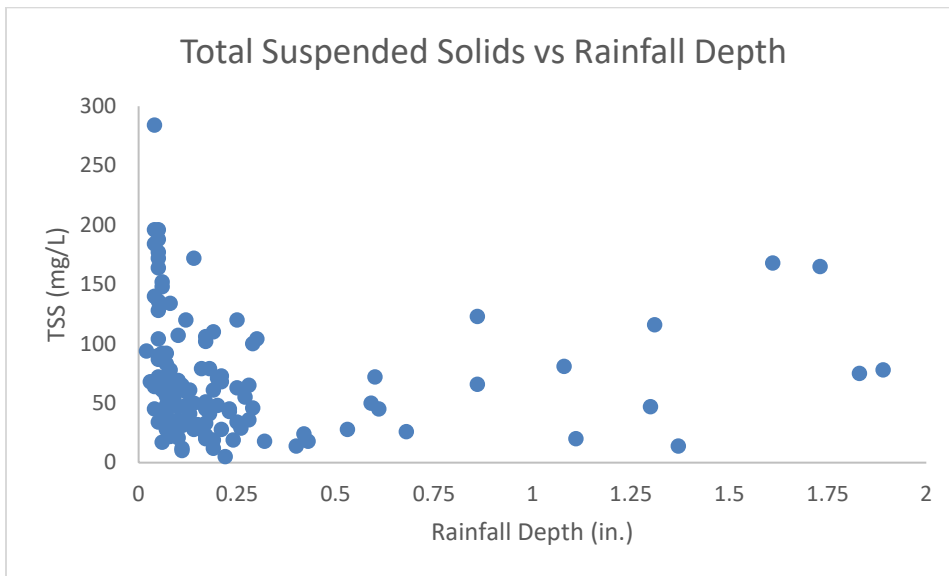


Figure 15 - TSS vs Rainfall Depth

Table 3 - TSS at Rainfall Depth Modified Quartiles

RD Percentile	0-20%	21-50%	51-75%	76-100%
RD Amount	0-0.06	0.07-0.12	0.13-0.24	0.25-1.89
<i>n</i>	27	36	30	30
Median	104	49	45	53
Mean	119	54	53	63
C/V	0.54	0.52	0.67	0.68

TSS concentrations were highest (mean 118.67 mg/L) during Q1, followed by a large dip (mean 54.25 mg/L) in Q2, then leveled out with similar values in the Q3 and Q4 (means 53.20 mg/L and 63.33 mg/L respectively).

TSS removal is 54.28% reduction from Q1 to Q2; a 55.17% reduction from Q1 to Q3; and 46.63% reduction from Q1 to Q4.

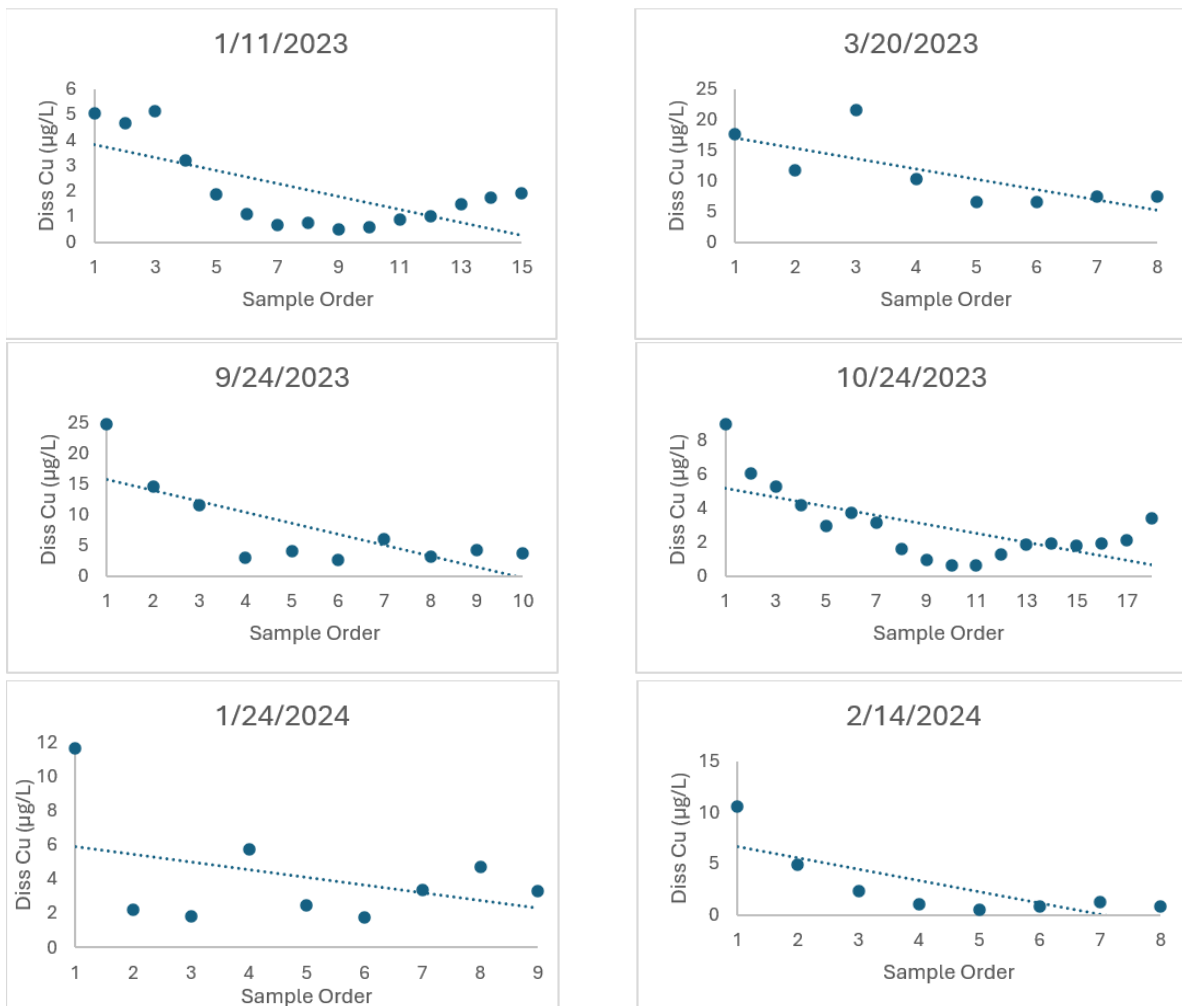
Statistical analysis confirmed this trend. The Kruskal-Wallis found no statistical difference between the means of Q2, Q3, and Q4; and the Wilcoxon found Q1 statistically greater than all the other quarters; basically $Q1 > (Q2 = Q3 = Q4)$.

5.0 Pt. Defiance Ferry Terminal Results

Staff collected eight storm events at Pt. Defiance, between 1/11/2023 to 5/21/2024, meeting target Study goals. Additional grab samples were collected on 10/21/2022. Tables in Appendix B detail pollutant, hydrological and meteorological data for each storm.

5.1 Pollutant Concentrations Over Storm Durations

Figures 16-18 below demonstrate sequential changing pollutant concentrations throughout storm events for Diss Cu, Diss Zn, and TSS. Total phosphorus (TP) and Nitrate + Nitrite (N+N) were also collected for two storms. However, Figures and discussions about TP and N+N are limited to Section 5.5, since these constituents are not a primary Study focus.



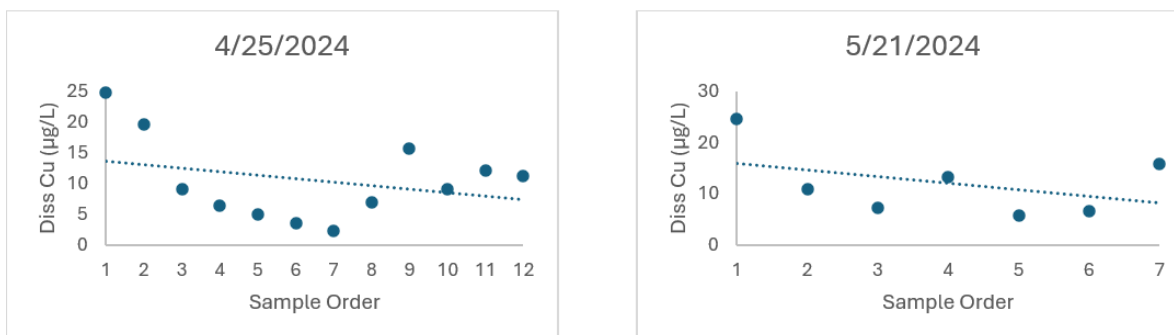
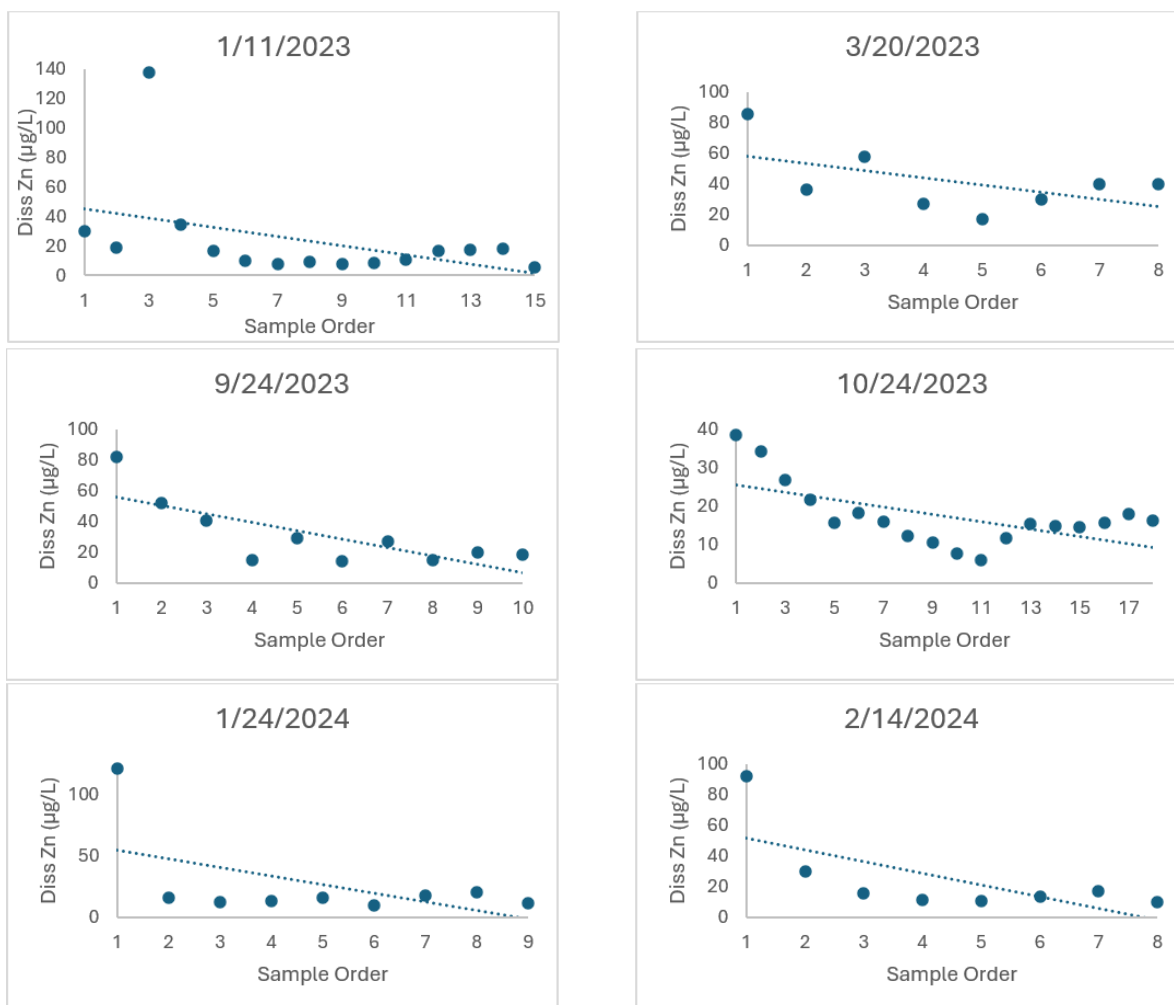


Figure 16 - Pt. Defiance Dissolved Copper Concentrations vs Sample Order for Individual Storm Events

Diss Cu displays a trend of highest concentrations near the beginning of storm events, with six of eight events displaying highest concentrations in the initial sample, and the other two events displaying highest concentrations within the first three samples. These peaks were followed by an overall drop, with occasional later events spikes.



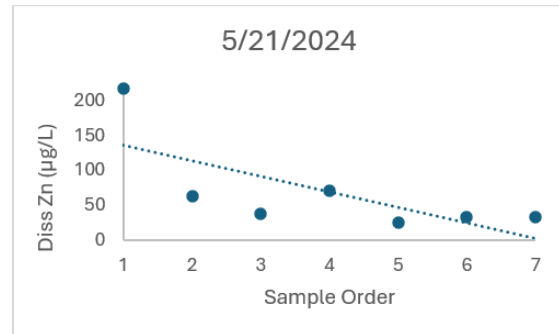
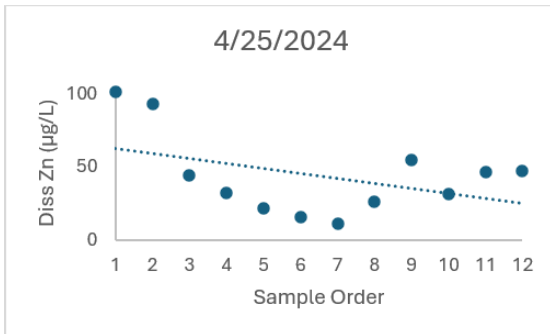
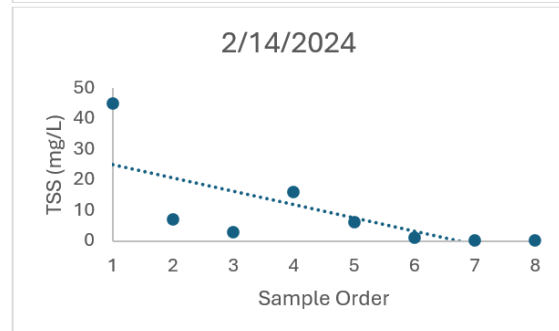
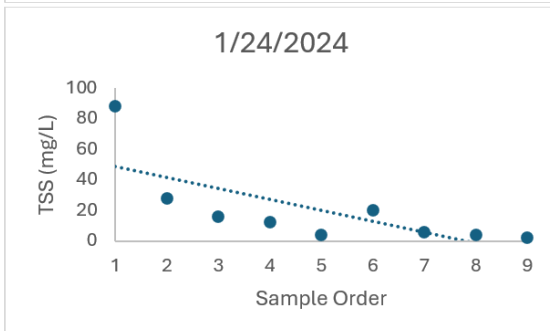
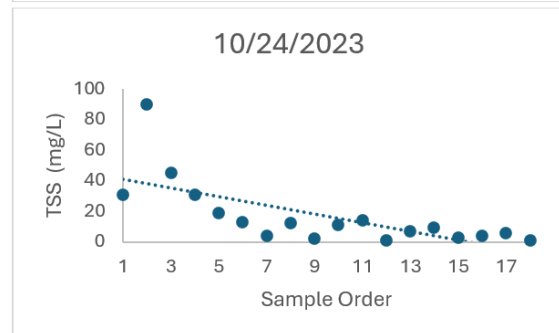
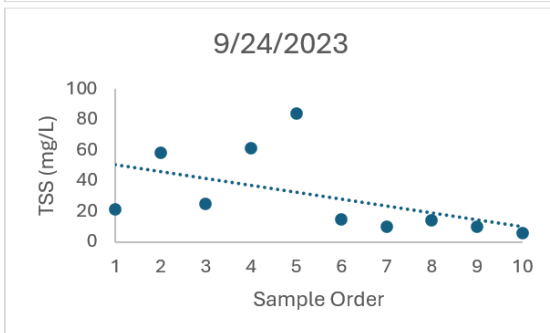
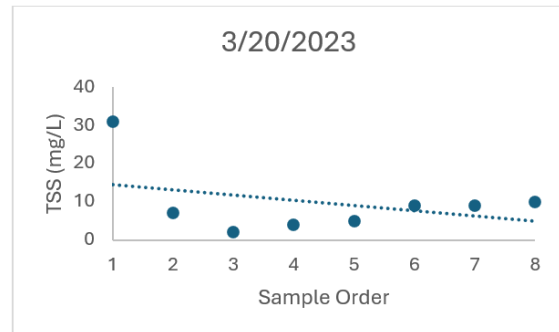
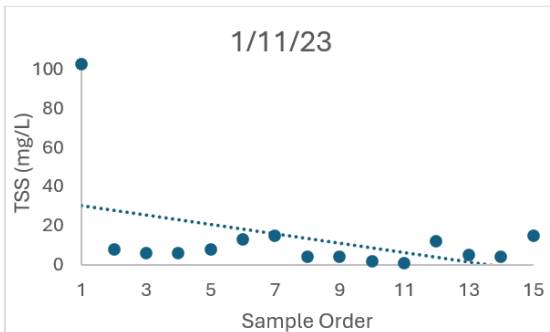


Figure 17 - Pt. Defiance Dissolved Zinc Concentrations vs Sample Order for Individual Storm Events

Diss Zn displays a trend of highest concentrations near beginning of storm events, with seven of eight events having highest concentrations in initial samples, and one event (1/11/23) showing a very high spike in the third sample. These peaks were followed by overall diminishing values but some trended upwards near an event's end.



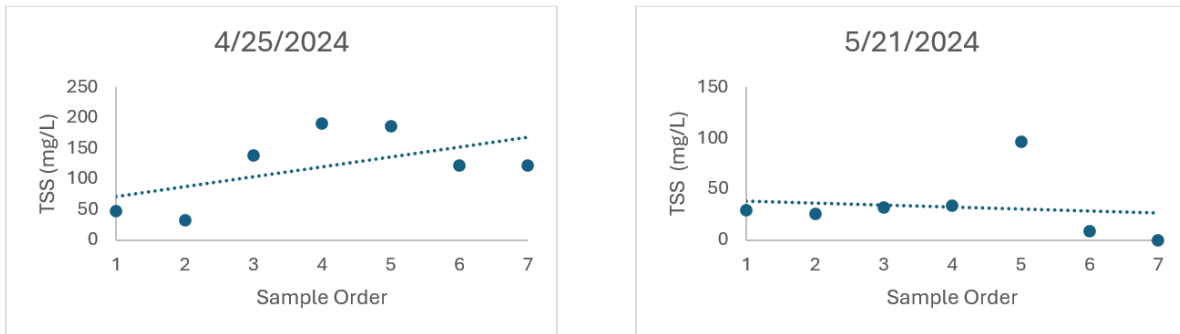


Figure 18 - Pt. Defiance TSS Concentrations vs Sample Order for Individual Storm Events

TSS displays a slight trend (five out of the eight storms) of higher initial concentrations followed by lower values. However, TSS is much bouncier than Diss Cu/Zn, demonstrating many spikes in concentration later in storm events and much less of a consistent pattern.

5.2 Grab samples: Gasoline, Diesel, Heavy Oil, and Fecal Coliform

WSDOT obtained grab samples for one event (10/21/2022). Per standard grab sampling protocols only one sample was collected for each constituent, primarily to determine any red flag concentrations. This did not occur, and constituent levels were within expectations for the site. As only one storm event/sample was collected for each constituent, grabs analysis is not a feature of this Study. Specific grabs concentrations are presented in Appendix B.

5.3 Pollutant Concentrations in Response to Meteorological/Hydrological Variables

The variables examined were:

- Rainfall Depth (RD)
- Antecedent Dry Period (ADP)
- Rainfall Intensity

Runoff volume wasn't measured at Pt. Defiance, hence volume isn't a variable and flow intensity was replaced by rainfall intensity.

Variables were assessed at the cumulative storm events level, rather than the individual storm event level, to increase n values and assess larger overall patterns.

Of variables assessed, only RD demonstrated patterns. Statistical outputs and comparative plots for the other variables are presented in Appendices E and G.

5.4 Rainfall Depth

Figures 19-21 display consolidated storm events pollutant values corresponding to the RD, separated out by pollutant type. Tables 4-6 assign summary statistics to

RD subsets, denoted by quartile percentages. Quartile separations of RD were largely matched by decile separations, so only quartiles are represented here. Tables with First Sample (FS)/0-5%/decile RD percentages are in Appendix C.

Statistical tests, the Kruskal-Wallis and Wilcoxon Rank Sum (Wilcoxon), were conducted using the R statistical program. R outputs and code are presented in Appendix I.

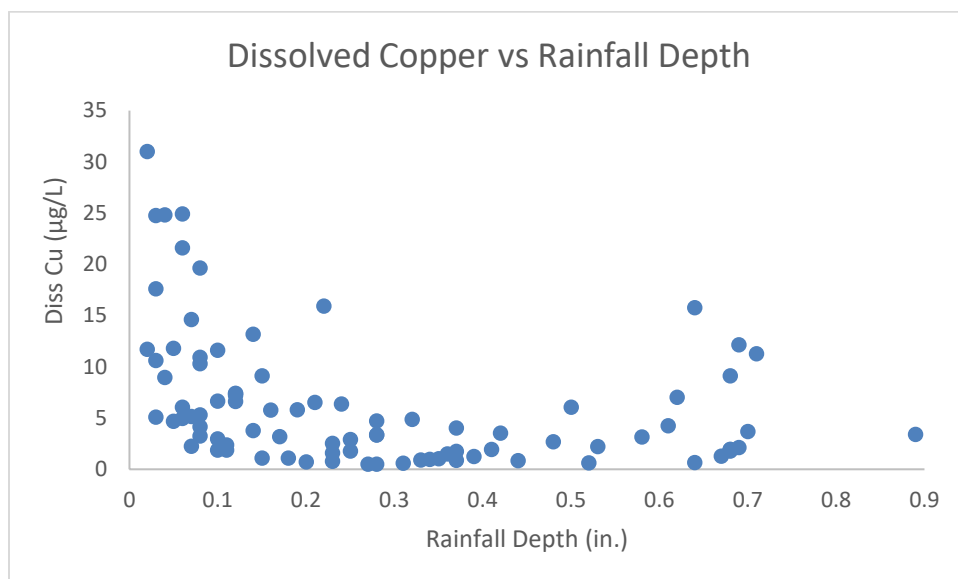


Figure 19 - Dissolved Copper vs Rainfall Depth

Table 4 - Dissolved Copper at Rainfall Depth Quartiles

RD Percentile	0-25%	26-50%	51-75%	76-100%
RD Amount	0-0.08	0.09-0.23	0.24-0.41	0.42-0.89
<i>n</i>	23	24	19	22
Median	10.6	4.75	1.75	2.905
Mean	12.34	5.28	2.26	4.41
C/V	0.68	0.78	0.76	0.94

Diss Cu concentrations were highest (mean 12.3 ug/L) during Q1 (0-0.08 in), followed by a substantial dip (mean 5.2 ug/L) in Q2, then a smaller dip (mean 2.7 ug/L) in Q3, and then a small uptick (mean 4.41 ug/L) in Q4.

In terms of Diss Cu removal, this translates to a 57.23% reduction from Q1 to Q2; an 81.70% reduction from Q1 to Q3; and 64.28% reduction from Q1 to Q4.

Statistical comparisons confirmed this trend. The Wilcoxon found Q1 > Q2; Q2 > Q3; Q3 < Q4; and Q2 = Q4.

The reason for the uptick at the 75th percentile/Q4 is believed to be due to sediment build-up in the sampling container, which by the end of some larger storms had

been observed to accrue sediment.

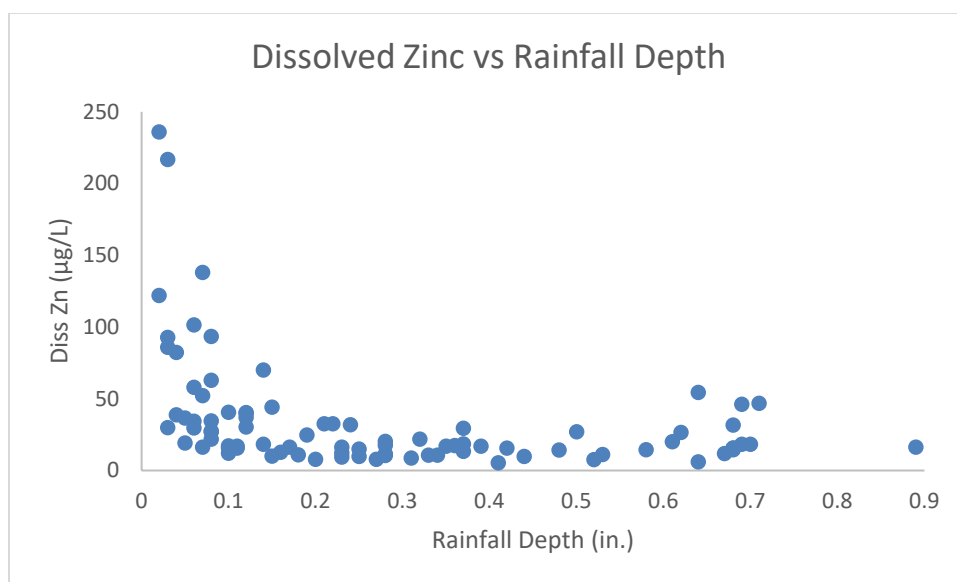


Figure 20 - Dissolved Zinc vs Rainfall Depth

Table 5 - Dissolved Zinc at Rainfall Depth Quartiles

RD Percentile	0-25%	26-50%	51-75%	76-100%
RD Amount	0-0.08	0.09-0.23	0.24-0.41	0.42-0.89
<i>n</i>	23	24	19	22
Median	52.2	16.95	14.8	15.595
Mean	71.99	24.23	15.41	20.69
C/V	0.83	0.63	0.45	0.63

At the quartile level, Diss Zn concentrations were highest (mean 72 ug/L) during Q1, followed by a large dip (mean 24.2 ug/L) in Q2, then a slight dip (mean 15.4 ug/L) in Q3, and then a slight uptick (mean 20.7 ug/L) in Q4.

In terms of Diss Zn removal, this translates to a 66.34% reduction from Q1 to Q2; an 78.59% reduction from Q1 to Q3; and 71.25% reduction from Q1 to Q4.

Statistical comparisons via the Kruskal-Wallis test failed to find any differences between Q2, Q3, Q4, suggesting that after high Diss Zn concentrations dropped during Q1, concentrations then leveled off with slight bounciness but statistically equivalent. The Wilcoxon confirmed this trend, finding Q1 statistically greater than all the other quarters, basically $Q1 > (Q2 = Q3 = Q4)$.

The visually observed uptick in Q4 is presumed due to the late storm event sediment accrual. This uptick was not enough to meet statistical significance.

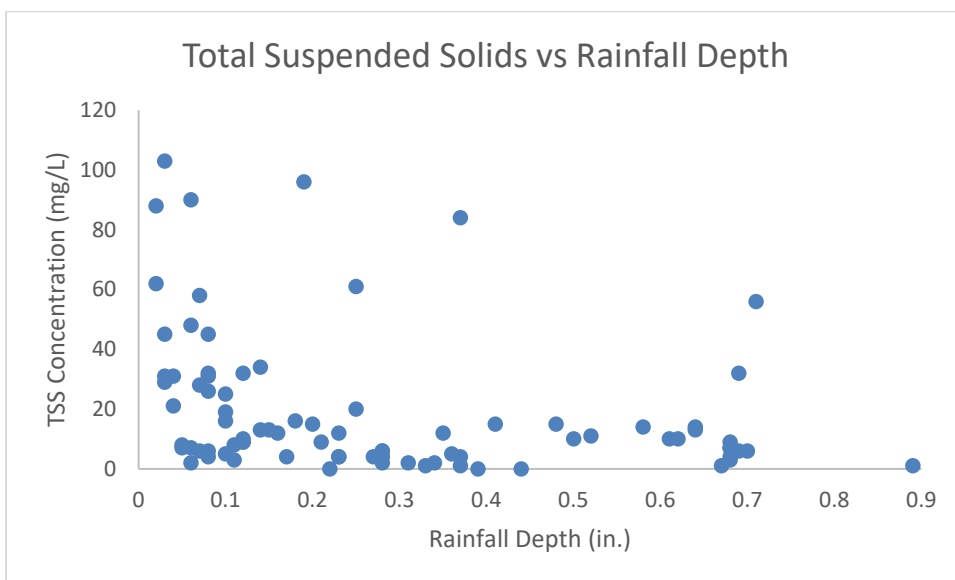


Figure 21 - TSS vs Rainfall Depth

Table 6 - TSS at Rainfall Depth Quartiles

RD Percentile	0-25%	26-50%	51-75%	76-100%
RD Amount	0-0.08	0.09-0.23	0.24-0.41	0.42-0.89
<i>n</i>	23	23	17	20
Median	31	12	4	10
Mean	35	16	14	12
C/V	0.83	1.21	1.71	1.09

TSS concentrations were highest (mean 35 mg/L) during tQ1 (0-0.08 in), followed by a substantial dip (mean 16 mg/L) in Q2, then relatively leveling out with similar values in the Q3 and Q4 (means 14 mg/L and 12 mg/L respectively).

TSS removal is a 54.33% reduction from Q1 to Q2; a 61.49% reduction from Q1 to Q3; and 67.26% reduction from Q1 to Q4.

The Kruskal-Wallis failing to find any difference between the means values of Q2, Q3, and Q4; and the Wilcoxon finding Q1 greater than the other quarters. Basically, $Q1 > (Q2 = Q3 = Q4)$.

It is observed that the coef. of variance (C/V) was high, exceeding 1.0 in quartiles Q2 - Q4. This indicates high variation in the data, which should be accounted for in management practices.

Note: one event (4/25/24) demonstrated five outlier TSS values believed to be biased. Results were removed from characterization but retained and discussed in Appendix J.

Nitrate+Nitrite and Total Phosphorus vs Rainfall Depth

N+N and TP were not focuses of this Study, and only collected during two storm events, 1/11/2023 and 10/24/2023, as supplemental data. Analysis is presented in Figures 22-24 and Tables 7-9. Detailed analysis is not presented due to lack of data.

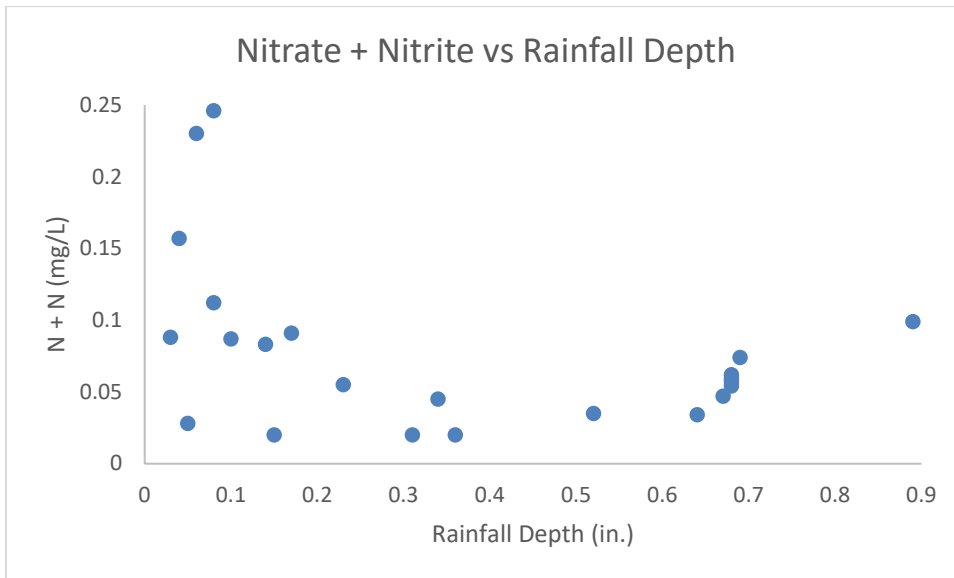


Figure 22 - Nitrate+Nitrite vs Rainfall Depth

Table 7 - Nitrate+Nitrite at Rainfall Depth Quartiles

RD Percentile	0-25%	26-50%	51-75%	76-100%
RD Amount	0-0.1	0.11-0.27	0.28-0.52	0.53-0.89
<i>n</i>	7	4	4	8
Median	0.112	0.069	0.028	0.058
Mean	0.135	0.062	0.030	0.061
C/V	0.59	0.52	0.41	0.32

Despite the low *n* value, the available data displayed a trend that matched patterns observed for Diss Cu & Diss Zn.

N+N concentrations were highest (mean 0.135 ug/L) during Q1, followed by a substantial dip (mean 0.062 ug/L) in Q2, then a smaller dip (mean 0.030 ug/L) in Q3, and then a small uptick (mean 0.061 ug/L) in Q4.

N+N removal is a 54.03% reduction from Q1 to Q2; an 77.85% reduction from Q1 to Q3; and 55.14% reduction from Q1 to Q4.

The uptick to N+N concentrations from Q3 to Q4 is speculated due to sediment accrual in the sampling pan for later storm event samples, discussed previously.

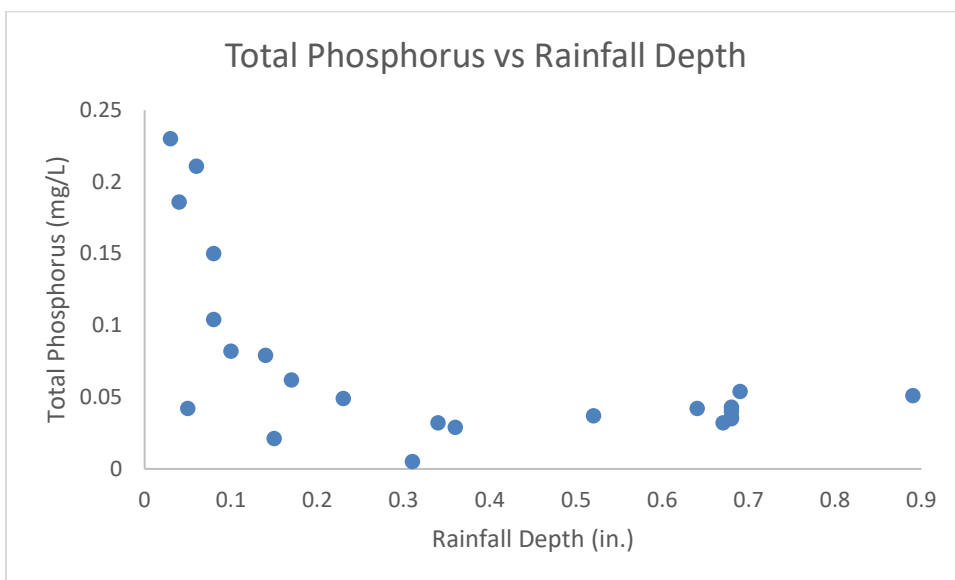


Figure 23 - Total Phosphorus vs Rainfall Depth

Table 8 - Total Phosphorus at Rainfall Depth Quartiles

RD Percentile	0-25%	26-50%	51-75%	76-100%
RD Amount	0-0.1	0.11-0.27	0.28-0.52	0.53-0.89
<i>n</i>	7	4	4	8
Median	0.150	0.056	0.031	0.041
Mean	0.144	0.053	0.026	0.042
C/V	0.49	0.46	0.55	0.18

TP concentrations were highest (mean 0.144 ug/L) during Q1, followed by a substantial dip (mean 0.053 ug/L) in Q2, then a smaller dip (mean 0.026 ug/L) in Q3, and then a small uptick (mean 0.042 ug/L) in Q4.

TP removal is a 63.26% reduction from Q1 to Q2; an 82.06% reduction from Q1 to Q3; and 77.01% reduction from Q1 to Q4.

Like N+N, the uptick in TP concentrations from Q3 to Q4 is speculated due to sediment accrual in the sampling pan for later storm event samples.

6.0 Discussion

Both Scatter Cr and Pt. Defiance demonstrated a consistent trend of the highest TSS, Diss Cu, Diss Zn, N+N, and TP (pollutants) near the beginning of storm events, followed by a reduction in sequential samples.

When pollutant concentrations were examined via paired rainfall depth (RD), a sharper, L-shaped curve emerged. Pollutant concentrations occurring within the first ~0-0.06/0.08 inches RD were followed by a sharp (~60%) drop by 0.012/0.23 RD (Scatter Cr and Pt. Defiance respectively).

This 0.12/0.23 drop off point is conservative. Actual pollutant drop offs were closer to 0.07/0.09 RD, when examining decile separations (Appendix C), but the more conservative quartile separations are used due to higher n values.

This sharp pollutant reduction was followed by a relative leveling out at lower concentrations. This trend was most consistent with Diss Cu & Zn, and bouncier but overall consistent with TSS. Note: Pt. Defiance demonstrated a small uptick in pollutants post 0.60 RD, but this is believed to be due to sediment accrual in the sampling container. (See Section 5.3 for detail). Regardless, this uptick did not negate the overall strong pollutant reduction.

N+N and TP, during the two storm events monitored at Pt. Defiance, also demonstrated the L-shaped curve and are hypothesized to follow this pattern during most storms.

The existence of a clear, consistent numerical point (0.012/0.23 RD), by which pollutant concentrations are significantly lower, is significant and could be a good demarcation line separating the dirtier first flush phase from the subsequent cleaner runoff.

For example, most ferry terminals are limited in space for BMP implementation. However, if only the first 0.23 RD of storm events need acute treatment, then smaller, less volumetrically demanding BMPs could be followed by spillover to less intensive designs such as catchbasins or ditches. This would allow treatment in areas previously thought unsuitable due to space constraints.

Conversely, if the most acute pollutant phases are limited to initial storm runoff, then smaller iterations of existing BMPs could be implemented. For instance, a compost-amended biofiltration swale (CABS) might only need compost amendment in the first quarter of swale length to achieve treatment goals, leading to less cost and materials, and reduced nutrient export.

Finally, it's noted that the trend described above only applies to the pollutants studied, though it likely applies to other mass-limited constituents. Other pollutants, such as those that are transport-limited, may display different patterns. If those pollutants become part of WSDOT regulatory compliance, then future characterization will be needed to incorporate them in BMP design.

7.0 Conclusions

All monitored pollutants, (TSS, Diss Cu, Diss Zn, N+N, and TP) exhibited highest concentrations in the initial ~0-0.06/0.08 inches of rainfall depth (RD), followed by a sharp reduction (~60%) by 0.012/0.23 RD. Diss Cu and Diss Zn then followed a relative leveling out of concentrations at lower values for the remainder of storm events. TSS concentrations were bouncier but remained statistically consistent and low.

This L-shaped curve occurred for most storm events at both sites. This consistency, across two very different facility types, indicates the bi-phase of “dirty” vs “cleaner” stormwater runoff may apply to other ferry terminals and rest areas, and potentially other facility types.

Implications of this L-curve are significant, offering new BMP design opportunities such as lower volumetric requirements for intensive BMPs, reductions in certain treatment amendments (i.e. compost), and enhanced treatment train designs. Findings are expected to impact subsequent BMP development at ferry terminal and rest area facilities.

8.0 Recommendations/Application/Implementation

Three primary recommendations arise from this Study:

- 1) Develop novel BMPs for Ferry Terminals and Rest Areas that incorporate information found in this Study. Ferry terminals, in particular, should take precedence due to space limitations, nearshore pollutant concerns, and lack of current BMPs.
- 2) Expand intra-storm pollutant distribution research to WSDOT maintenance facilities. Note: the WSDOT Stormwater Monitoring Team is currently conducting such a study, projected for completion in 2027.
- 3) Expand the suite of pollutants monitored, based on emergent regulatory concerns (i.e. 6PPD quinone, non-transport limited pollutants) and WSDOT needs.

9.0 Acknowledgements

Many people supported this Study:

- Nicholas Wegener of the Stormwater Monitoring Team (Monitoring Team) provided half of the sampling efforts, was the primary data tables manager, refined the figures listed in this Report, and supported other requested tasks. It's not an exaggeration to say this Study may not have succeeded without Nick's help.
- Justin Adams of the Monitoring Team constructed the monitoring sites, often overcoming unique challenges, and maintained the sites.
- Chris Gustafson of the Monitoring Team assisted in mapping/finding the appropriate sites for study and formatted the final report for publication.
- Doug Howie (WA State Dept. of Ecology), Carla Milesi (UW), and Alex Nguyen (WSDOT), all participated in the Study's Technical Advisory Committee (TAC), giving important feedback to the Study's progress and design. Carla, additionally, reviewed the final report in detail and gave valuable advice.
- The Ferries Office (Adrienne Stutes, Kevin Bartoy, Jennie Buswell, and the Pt. Defiance Ferries Staff) worked with and accommodated our efforts.
- The WSDOT Maintenance Office, Stormwater Branch, Monitoring Team, and any other groups who helped in this Study.

10.0 References

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Appendix A

Scatter Creek Storm Events Sample and Paired Meteorological/Hydrological Results

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Rainfall (in.) at Sample Time	Volume (L) at Sample Time	Volume Preceding 5 min	Volume Preceding 15 min	Flow Rate-15min
Scatter Cr	1/4/2023	284	24.5	370	0.04	1500.7	672.7	0	1.67
Scatter Cr	1/4/2023	184	21.6	319	0.04	2445.7	1500.7	128.3	2.57
Scatter Cr	1/4/2023	196	14	239	0.04	2445.7	1500.7	128.3	2.57
Scatter Cr	1/4/2023	140	21.3	302	0.04	3159.4	2445.7	672.7	2.76
Scatter Cr	1/4/2023	164	10.6	125	0.05	3910.1	3159.4	1500.7	2.68
Scatter Cr	1/4/2023	196	11.6	141	0.05	4570.3	3910.1	2445.7	2.36
Scatter Cr	1/4/2023	188	21.1	324	0.05	4570.3	3910.1	2445.7	2.36
Scatter Cr	1/4/2023	128	20	271	0.05	5196	4570.3	3159.4	2.26
Scatter Cr	1/4/2023	148	10.4	137	0.06	6587.7	5915.8	4570.3	2.24
Scatter Cr	1/4/2023	152	11.2	172	0.06	6587.7	5915.8	4570.3	2.24
Scatter Cr	1/4/2023	92	18.1	217	0.07	7325.9	6587.7	5196	2.37
Scatter Cr	1/4/2023	72	15.1	176	0.07	8127.6	7325.9	5915.8	2.46
Scatter Cr	1/4/2023	72	16.6	187	0.07	8127.6	7325.9	5915.8	2.46
Scatter Cr	1/4/2023	40	6.82	83.9	0.07	8916.4	8127.6	6587.7	2.59
Scatter Cr	1/4/2023	48	7.58	81.8	0.07	9553.6	8916.4	7325.9	2.48
Scatter Cr	1/4/2023	44	11.9	133	0.07	10013.4	9553.6	8127.6	2.10
Scatter Cr	1/4/2023	60	11.5	141	0.07	10013.4	9553.6	8127.6	2.10
Scatter Cr	1/4/2023	44	6.98	82.2	0.07	10013.4	9553.6	8127.6	2.10
Scatter Cr	1/4/2023	60	15.9	146	0.07	11177.7	10988.4	10409.5	0.85
Scatter Cr	1/4/2023	36	16.7	159	0.07	12020.5	11957.3	11791.7	0.25
Scatter Cr	1/4/2023	56	10.1	86.7	0.07	12020.5	11957.3	11791.7	0.25
Scatter Cr	1/4/2023	28	9.64	128	0.07	12842.7	12828.4	12797.8	0.05
Scatter Cr	3/19/2023	68	40.1	120	0.03	1062.4	969.4	841.2	0.25
Scatter Cr	3/19/2023	45	30.4	93.9	0.04	2088.9	1995.9	1805.8	0.31
Scatter Cr	3/19/2023	72	24.5	71.1	0.05	3288.7	2978.4	2504.7	0.87
Scatter Cr	3/19/2023	34	20	63.4	0.05	4178.8	3901.8	3288.7	0.99
Scatter Cr	3/19/2023	17	18.8	63	0.06	5005.2	4821.7	4424.7	0.65
Scatter Cr	3/20/2023	38	15.6	52.9	0.07	6347.1	5993.3	5440	1.01
Scatter Cr	3/20/2023	27	13.6	47.9	0.08	7198.7	6738.9	5993.3	1.34
Scatter Cr	3/20/2023	22	11.4	45.1	0.08	8167	7658.5	6738.9	1.59
Scatter Cr	3/20/2023	55	10.6	41.4	0.09	9169.5	8685.7	7658.5	1.68
Scatter Cr	3/20/2023	64	9.57	38.5	0.09	10284.7	9713.9	8685.7	1.78
Scatter Cr	3/20/2023	47	8.49	34.7	0.1	11373.5	10834.3	9713.9	1.84
Scatter Cr	3/20/2023	31	7.91	34.1	0.11	12451.9	11907.5	10834.3	1.80
Scatter Cr	3/20/2023	12	7.32	34	0.11	13509.6	12975.6	11907.5	1.78
Scatter Cr	3/20/2023	10	6.94	35.2	0.11	14033.4	13509.6	12451.9	1.76
Scatter Cr	10/9/2023	94	56.9	216	0.02	1095.4	825.5	278.1	0.91
Scatter Cr	10/9/2023	64	38.4	180	0.04	2229.8	1915.7	1497.9	0.81
Scatter Cr	10/9/2023	67	36.6	142	0.04	3190	2988.8	2532.6	0.73

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Rainfall (in.) at Sample Time	Volume (L) at Sample Time	Volume Preceding 5 min	Volume Preceding 15 min	Flow Rate-15min
Scatter Cr	10/10/2023	92	12.6	73.1	0.06	5042.1	3900.6	2042.6	3.33
Scatter Cr	10/10/2023	49	10.9	67.9	0.09	10384.6	9910.4	9172.7	1.35
Scatter Cr	10/10/2023	61	10	56.3	0.13	15442.7	14666.7	13716.6	1.92
Scatter Cr	10/10/2023	102	5.37	34.2	0.17	21100.8	19245.9	16475.7	5.14
Scatter Cr	10/10/2023	110	3.76	27.3	0.19	26116.5	23456.9	19245.9	7.63
Scatter Cr	10/10/2023	48	2.81	24.7	0.2	31080.5	29914.9	26116.5	5.52
Scatter Cr	10/10/2023	43	3.17	26	0.23	35268.5	34053.9	32039.9	3.59
Scatter Cr	10/10/2023	120	3.94	28.6	0.25	40794.8	39871.1	36567.5	4.70

Scatter Cr	11/1/2023	172	37.3	172	0.05	3136.3	2617.6	1908.5	1.36
Scatter Cr	11/1/2023	134	21.1	92.1	0.08	6778.7	5098.8	3136.3	4.05
Scatter Cr	11/1/2023	107	13.5	46.4	0.1	10608.2	8488.7	5098.8	6.12
Scatter Cr	11/1/2023	65	11.2	42.3	0.11	12879.7	10608.2	6778.7	6.78
Scatter Cr	11/1/2023	60	9.28	40.6	0.12	15199.4	12879.7	8488.7	7.46
Scatter Cr	11/1/2023	31	7.35	35.9	0.14	19577.5	17423.5	12879.7	7.44
Scatter Cr	11/1/2023	32	6.34	33.1	0.15	21674.1	19577.5	15199.4	7.19
Scatter Cr	11/1/2023	33	6.74	32.5	0.17	25829.1	23910	19577.5	6.95
Scatter Cr	11/1/2023	23	6.54	34.8	0.17	27325.4	25829.1	21674.1	6.28
Scatter Cr	11/1/2023	12	5.7	32.3	0.19	30841	29822.9	27325.4	3.91
Scatter Cr	11/1/2023	5	5.24	34.2	0.22	34217.8	32840.1	30841	3.75
Scatter Cr	11/1/2023	29	4.17	31.2	0.26	37345.3	34217.8	31829.5	6.13
Scatter Cr	11/1/2023	36	3.06	24.1	0.28	54635	37345.3	32840.1	24.22
Scatter Cr	11/1/2023	46	3.1	25.7	0.29	71924.7	54635	34217.8	41.90
Scatter Cr	11/1/2023	14	1.94	17.8	0.4	121865.5	104575.8	97803.5	26.74
Scatter Cr	11/1/2023	24	1.94	18.3	0.42	139155.2	121865.5	101151.8	42.23
Scatter Cr	11/1/2023	18	1.83	18.9	0.43	156444.9	139155.2	104575.8	57.63
Scatter Cr	11/1/2023	28	2.71	25.4	0.53	181356.1	179942.5	176577.7	5.31
Scatter Cr	11/1/2023	45	3.71	32.3	0.61	196117.1	194951.4	193485.4	2.92
Scatter Cr	11/1/2023	26	1.96	24.5	0.68	210107	207882.9	204505.7	6.22
Scatter Cr	11/2/2023	47	7.74	54.7	1.3	532136.9	531887.7	531235.3	1.00

Scatter Cr	2/27/2024	136	11.4	91.6	0.05	3248.5	2594.2	1428.7	2.02
Scatter Cr	2/27/2024	83	7.67	57.3	0.07	6299.5	5417.5	3897.1	2.67
Scatter Cr	2/27/2024	78	5.17	36.5	0.08	9005.8	8492.2	7147.5	2.06
Scatter Cr	2/27/2024	35	4.99	30.4	0.1	12013.1	11659.3	11065	1.05
Scatter Cr	2/27/2024	41	3.95	26.2	0.13	15279.6	14776	13733.5	1.72
Scatter Cr	2/27/2024	50	4.3	27.7	0.14	18267.6	17979.7	17521	0.83
Scatter Cr	2/28/2024	51	4.15	26.9	0.17	21124.8	20674.4	19867.9	1.40
Scatter Cr	2/28/2024	19	3.06	22.5	0.19	24383.3	23711.4	22241.1	2.38
Scatter Cr	2/28/2024	73	2.73	21.3	0.21	27195.8	26619.6	25636.7	1.73
Scatter Cr	2/28/2024	45	2.67	21.6	0.23	30081.6	29266.8	27827.2	2.50
Scatter Cr	2/28/2024	63	2.23	20.3	0.25	33794.4	32791.2	30984.3	3.12
Scatter Cr	2/28/2024	65	2.17	20.8	0.28	37272.7	35921.5	33794.4	3.86
Scatter Cr	2/28/2024	100	1.88	18.9	0.29	40455.7	38893.2	35921.5	5.04
Scatter Cr	2/28/2024	104	2.46	23.8	0.3	43429.6	41961.3	38893.2	5.04

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Rainfall (in.) at Sample Time	Volume (L) at Sample Time	Volume Preceding 5 min	Volume Preceding 15 min	Flow Rate-15min
Scatter Cr	2/28/2024	72	2.95	27.6	0.6	100056.3	98783	97069.8	3.32
Scatter Cr	2/28/2024	66	1.61	22.6	0.86	150013.1	148028.5	145115.7	5.44
Scatter Cr	2/28/2024	81	1.68	19.4	1.08	200680.5	198846.8	195008.4	6.30
Scatter Cr	2/28/2024	116	2.71	24.3	1.31	250805	248473.3	244845.9	6.62
Scatter Cr	2/28/2024	168	1.32	24.3	1.61	302160.7	298582.5	296391	6.41
Scatter Cr	2/28/2024	165	0.6	17.2	1.73	354150	336820.2	302160.7	57.77
Scatter Cr	2/28/2024	75	0.41	13.6	1.83	406139.2	388809.5	354150	57.77
Scatter Cr	2/28/2024	78	0.56	18.2	1.89	461522.1	444192.3	423469	42.28

Scatter Cr	6/2/2024	44	23.95	86.32	0.06	3484	2818	1723.7	1.96
Scatter Cr	6/2/2024	58	14.1	51.62	0.08	6448.8	5393.1	3484	3.29
Scatter Cr	6/2/2024	21	10.17	38.06	0.1	9073.3	7800	5393.1	4.09
Scatter Cr	6/2/2024	48	6.766	29.59	0.12	12550.9	10588.3	7800	5.28
Scatter Cr	6/2/2024	28	5.238	24.64	0.14	18231.9	16688.6	12550.9	6.31
Scatter Cr	6/2/2024	41	6.387	28.28	0.18	24484.3	23133.1	20817.5	4.07
Scatter Cr	6/2/2024	28	4.381	21.77	0.21	30670.7	29607.3	27067.7	4.00
Scatter Cr	6/2/2024	19	4.95	25.17	0.24	36824.1	35935.3	34162.8	2.96
Scatter Cr	6/2/2024	18	4.164	23.64	0.32	48059.7	46941.9	45317.6	3.05
Scatter Cr	6/2/2024	50	2.36	19.1	0.59	96555.9	93528.4	88899.9	8.51
Scatter Cr	6/2/2024	123	1.252	19.36	0.86	145091.1	141934.6	134020.5	12.30
Scatter Cr	6/2/2024	20	0.903	17.66	1.11	192136.2	189410.6	183592.1	9.49
Scatter Cr	6/3/2024	14	1.193	19.8	1.37	241520.7	238591.2	232300.6	10.24

Scatter Cr	9/10/2024	104	73.52	529.6	0.05	2659.5	1125.7	0	2.96
Scatter Cr	9/10/2024	177	70.75	467.1	0.05	3984.4	2659.5	0	4.43
Scatter Cr	9/10/2024	87	67.4	408.7	0.05	5063.2	3984.4	1125.7	4.38
Scatter Cr	9/10/2024	61	61.09	358.6	0.06	6182	5740.9	3984.4	2.44
Scatter Cr	9/10/2024	32	47.66	229.9	0.08	9180.8	8935	8425	0.84
Scatter Cr	9/10/2024	36	32.83	144.8	0.1	12011.6	11636.9	10853.6	1.29
Scatter Cr	9/11/2024	79	16.96	76.18	0.16	16486.9	14535.2	14065.3	2.69
Scatter Cr	9/11/2024	45	15.94	70.95	0.17	20002	18606.4	14535.2	6.07
Scatter Cr	9/11/2024	20	15.34	65.26	0.17	21559.3	20961.3	18606.4	3.28

Scatter Cr	10/30/2024	90	13.13	105.2	0.05	3062.3	2774.3	2352.3	0.79
Scatter Cr	10/30/2024	69	5.6	55.29	0.1	7545.6	5815.3	3983.3	3.96
Scatter Cr	10/30/2024	120	4.35	47.64	0.12	10166.1	7545.6	4804.7	5.96
Scatter Cr	10/30/2024	172	3.337	40.3	0.14	27455.9	10166.1	5815.3	24.05
Scatter Cr	10/30/2024	106	2.259	31.27	0.17	44745.6	27455.9	7545.6	41.33
Scatter Cr	10/30/2024	79	1.755	23.72	0.18	62035.3	44745.6	10166.1	57.63
Scatter Cr	10/30/2024	61	1.332	25.14	0.19	79325	62035.3	27455.9	57.63
Scatter Cr	10/30/2024	71	3.417	55.22	0.2	87483.4	79325	44745.6	47.49
Scatter Cr	10/30/2024	68	7.786	318.7	0.21	103750.6	87483.4	62035.3	46.35
Scatter Cr	10/30/2024	34	2.333	36.02	0.25	109488.6	107169	103750.6	6.38
Scatter Cr	10/30/2024	55	2.108	29.96	0.27	129205.7	111956	107169	24.49

Appendix B

Pt. Defiance Ferry Terminal Storm Events Sample and Paired Meteorological Results

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Nitrate + Nitrite (mg/L)	Total P (mg/L)	Rainfall (in.) at Sample Time	Rainfall 15min Prior
Pt. Defiance	10/21/22	62.0	31	236			0.02	
Pt. Defiance	01/11/23	103.0	5.07	29.8	0.088	0.23	0.03	0.02
Pt. Defiance	01/11/23	8.0	4.68	19.1	0.028	0.042	0.05	0.00
Pt. Defiance	01/11/23	6.0	5.15	138			0.07	0.01
Pt. Defiance	01/11/23	6.0	3.23	34.4			0.08	0.00
Pt. Defiance	01/11/23	8.0	1.86	16.9			0.11	0.02
Pt. Defiance	01/11/23	13.0	1.08	9.88	<0.02	0.021	0.15	0.01
Pt. Defiance	01/12/23	15.0	0.69	7.65			0.2	0.01
Pt. Defiance	01/12/23	4.0	0.77	9.26			0.23	0.01
Pt. Defiance	01/12/23	4.0	0.49	7.69			0.27	0.01
Pt. Defiance	01/12/23	2.0	0.58	8.71	<0.02	<0.005	0.31	0.01
Pt. Defiance	01/12/23	1.0	0.9	10.7			0.33	0.01
Pt. Defiance	01/12/23	12.0	1.01	16.8			0.35	0.01
Pt. Defiance	01/12/23	5.0	1.47	17.3	<0.02	0.029	0.36	0.00
Pt. Defiance	01/12/23	4.0	1.75	18.5			0.37	0.00
Pt. Defiance	01/12/23	15.0	1.93	5.3			0.41	0.00
Pt. Defiance	03/20/23	31.0	17.6	85.7			0.03	0.01
Pt. Defiance	03/20/23	7.0	11.8	36.5			0.05	0.00
Pt. Defiance	03/20/23	2.0	21.6	58			0.06	0.00
Pt. Defiance	03/20/23	4.0	10.3	27.3			0.08	0.01
Pt. Defiance	03/20/23	5.0	6.65	17			0.1	0.00
Pt. Defiance	03/20/23	9.0	6.62	30.2			0.12	0.01
Pt. Defiance	03/20/23	9.0	7.39	39.9			0.12	0.00
Pt. Defiance	03/20/23	10.0	7.39	40.2			0.12	0.00
Pt. Defiance	09/24/23	21.0	24.8	82.3			0.04	0.02
Pt. Defiance	09/24/23	58.0	14.6	52.2			0.07	0.00
Pt. Defiance	09/24/23	25.0	11.6	40.5			0.1	0.00
Pt. Defiance	09/24/23	61.0	2.9	14.8			0.25	0.03
Pt. Defiance	09/24/23	84.0	4.02	29.4			0.37	0.02
Pt. Defiance	09/24/23	15.0	2.66	14.1			0.48	0.01
Pt. Defiance	09/25/23	10.0	6.05	26.9			0.5	0.01
Pt. Defiance	09/25/23	14.0	3.15	14.4			0.58	0.01
Pt. Defiance	09/25/23	10.0	4.22	20.1			0.61	0.01
Pt. Defiance	09/25/23	6.0	3.66	18.3			0.7	0.01
Pt. Defiance	10/24/23	31.0	8.95	38.70	0.157	0.186	0.04	0.01
Pt. Defiance	10/24/23	90.0	6.04	34.30	0.23	0.211	0.06	0.01
Pt. Defiance	10/24/23	45.0	5.30	26.90	0.246	0.15	0.08	0.02
Pt. Defiance	10/24/23	31.0	4.15	21.70	0.112	0.104	0.08	0.02
Pt. Defiance	10/24/23	19.0	2.96	15.60	0.087	0.082	0.1	0.02
Pt. Defiance	10/24/23	13.0	3.75	18.30	0.083	0.079	0.14	0.01

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Nitrate + Nitrite (mg/L)	Total P (mg/L)	Rainfall (in.) at Sample Time	Rainfall 15min Prior
Pt. Defiance	10/24/23	4.0	3.16	16.10	0.091	0.062	0.17	0.01
Pt. Defiance	10/24/23	12.0	1.58	12.10	0.055	0.049	0.23	0.02
Pt. Defiance	10/24/23	2.0	0.95	10.60	0.045	0.032	0.34	0.03
Pt. Defiance	10/24/23	11.0	0.61	7.55	0.035	0.037	0.52	0.06
Pt. Defiance	10/24/23	14.0	0.65	5.91	0.034	0.042	0.64	0.07
Pt. Defiance	10/24/23	1.0	1.26	11.80	0.047	0.032	0.67	0.00
Pt. Defiance	10/24/23	7.0	1.84	15.50	0.062	0.035	0.68	0.00
Pt. Defiance	10/25/23	9.0	1.91	14.70	0.059	0.036	0.68	0.00
Pt. Defiance	10/25/23	3.0	1.78	14.50	0.054	0.04	0.68	0.00
Pt. Defiance	10/25/23	4.0	1.92	15.60	0.057	0.043	0.68	0.00
Pt. Defiance	10/25/23	6.0	2.12	18.10	0.074	0.054	0.69	0.00
Pt. Defiance	10/25/23	1.0	3.39	16.20	0.099	0.051	0.89	0.00

Pt. Defiance	01/24/24	88.0	11.70	122.00			0.02	0.01
Pt. Defiance	01/24/24	28.0	2.22	16.10			0.07	0.01
Pt. Defiance	01/24/24	16.0	1.86	12.00			0.1	0.01
Pt. Defiance	01/24/24	12.0	5.75	12.70			0.16	0.02
Pt. Defiance	01/24/24	4.0	2.50	16.10			0.23	0.02
Pt. Defiance	01/24/24	20.0	1.76	9.64			0.25	0.00
Pt. Defiance	01/24/24	6.0	3.35	17.50			0.28	0.01
Pt. Defiance	01/24/24	4.0	4.70	20.20			0.28	0.00
Pt. Defiance	01/24/24	2.0	3.32	11.50			0.28	0.00

Pt. Defiance	02/14/24	45.0	10.6	92.6			0.03	0.02
Pt. Defiance	02/14/24	7.0	4.95	29.6			0.06	0.00
Pt. Defiance	02/14/24	3.0	2.35	15.6			0.11	0.01
Pt. Defiance	02/14/24	16.0	1.07	10.9			0.18	0.03
Pt. Defiance	02/15/24	6.0	0.5	10.5			0.28	0.04
Pt. Defiance	02/15/24	1.0	0.85	13.4			0.37	0.01
Pt. Defiance	02/15/24	< 1	1.25	16.9			0.39	0.00
Pt. Defiance	02/15/24	< 1	0.82	9.7			0.44	0.01

Pt. Defiance	04/25/24	48.0	24.9	101.5			0.06	0.01
Pt. Defiance	04/25/24	32.0	19.64	93.3			0.08	0.01
Pt. Defiance	04/25/24	138.0	9.105	44.03			0.15	0.02
Pt. Defiance	04/25/24	191.0	6.344	31.71			0.24	0.02
Pt. Defiance	04/25/24	186.0	4.86	21.71			0.32	0.02
Pt. Defiance	04/25/24	122.0	3.529	15.59			0.42	0.04
Pt. Defiance	04/25/24	122.0	2.194	11.1			0.53	0.04
Pt. Defiance	04/25/24	10.0	6.998	26.4			0.62	0.01
Pt. Defiance	04/25/24	13.0	15.75	54.35			0.64	0.01
Pt. Defiance	04/25/24	7.0	9.1	31.56			0.68	0.01
Pt. Defiance	04/25/24	32.0	12.14	46.04			0.69	0.00
Pt. Defiance	04/25/24	56.0	11.25	46.86			0.71	0.01

Site	Sample Date	TSS (mg/L)	Diss Cu (µg/L)	Diss Zn (µg/L)	Nitrate + Nitrite (mg/L)	Total P (mg/L)	Rainfall (in.) at Sample Time	Rainfall 15min Prior
Pt. Defiance	05/21/24	29.0	24.74	216.8			0.03	0.03
Pt. Defiance	05/21/24	26.0	10.91	62.92			0.08	0.01
Pt. Defiance	05/21/24	32.0	7.19	37.04			0.12	0.01
Pt. Defiance	05/21/24	34.0	13.17	69.93			0.14	0.01
Pt. Defiance	05/21/24	96.0	5.806	24.69			0.19	0.02
Pt. Defiance	05/21/24	9.0	6.502	32.58			0.21	0.00
Pt. Defiance	05/21/24	ND	15.9	32.46			0.22	0.00

Appendix C – Rainfall Depth vs First Sample (FS)/0-5 Percent/Decile Pollutant Concentrations

Scatter Cr Diss Cu (µg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles												
RD Percentile	First Sample	0-5%	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.04	0.05	0.06	0.07	0.08-0.09	0.1-0.12	0.13-0.17	0.18-0.21	0.22-0.28	0.29-0.61	0.68-1.89
<i>n</i>	9	9	12	6	14	9	13	15	11	11	11	12
Median	24.50	30.40	20.55	15.70	11.70	11.40	7.91	6.34	3.42	3.06	2.46	1.29
Mean	32.60	31.53	31.78	23.01	12.16	16.01	9.95	7.59	3.92	3.28	2.64	1.83
C/V	0.66	0.41	0.77	0.84	0.34	0.79	0.74	0.63	0.51	0.35	0.30	1.08

Scatter Cr Diss Zn (µg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles												
RD Percentile	First Sample	0-5%	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.04	0.05	0.06	0.07	0.08-0.09	0.1-0.12	0.13-0.17	0.18-0.21	0.22-0.28	0.29-0.61	0.68-1.89
<i>n</i>	9	9	12	6	14	9	13	15	11	11	11	12
Median	120	216	156.5	111.66	130.5	47.9	38.06	34.2	25.14	26	23.64	19.6
Mean	195.98	220.21	230.81	148.34	123.70	72.32	47.16	41.08	54.63	27.09	22.86	22.97
C/V	0.80	0.43	0.71	0.75	0.41	0.85	0.64	0.42	1.61	0.20	0.20	0.46

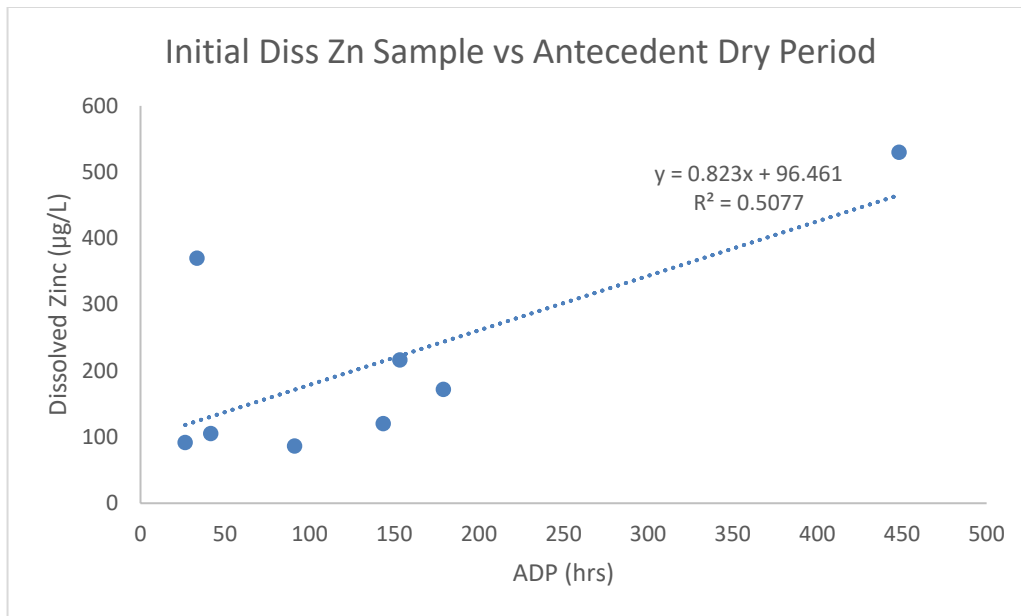
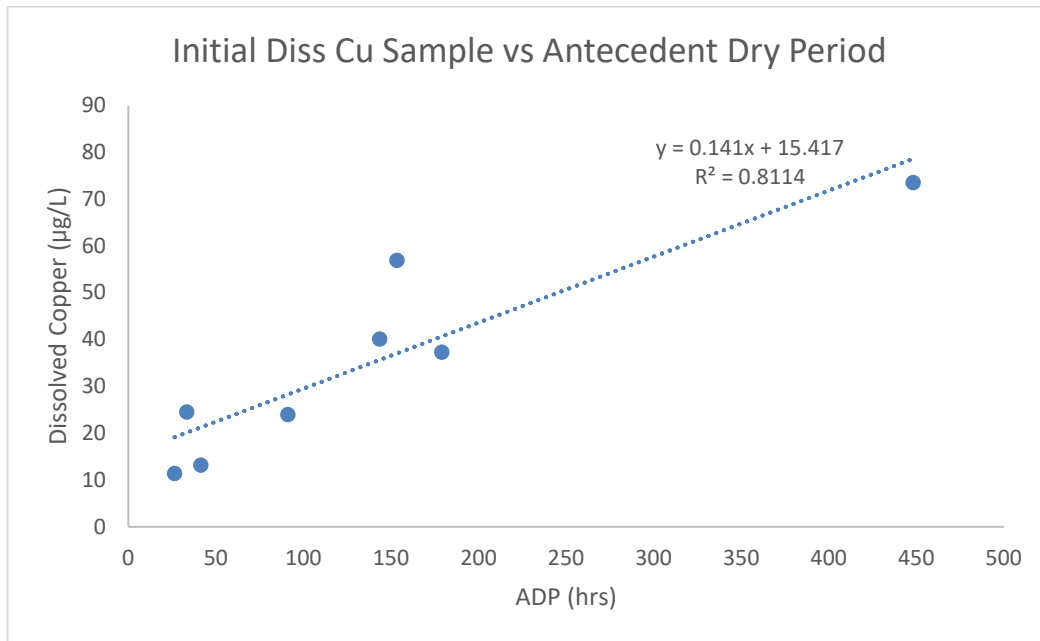
Scatter Cr TSS (mg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles												
RD Percentile	First Sample	0-5%	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.04	0.05	0.06	0.07	0.08-0.09	0.1-0.12	0.13-0.17	0.18-0.21	0.22-0.28	0.29-0.61	0.68-1.89
<i>n</i>	9	9	12	6	14	9	13	15	11	11	11	12
Median	94	94	132	77	52	55	47	45	61	43	45	77
Mean	120	127	129	86	55	58	51	58	55	47	47	82
C/V	0.59	0.63	0.40	0.65	0.34	0.59	0.66	0.71	0.53	0.65	0.68	0.64

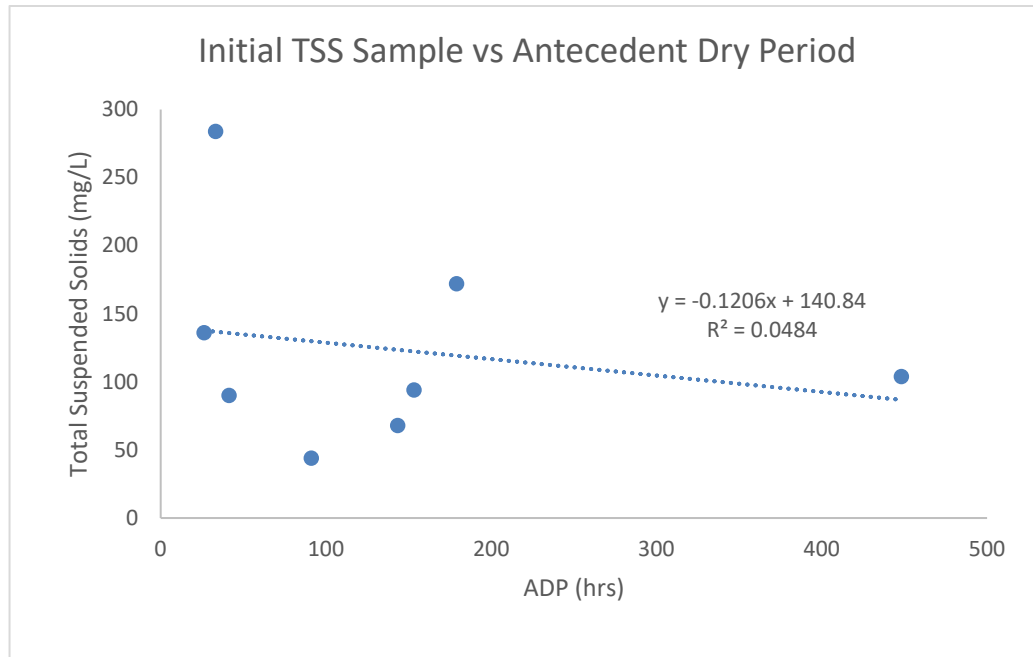
Pt. Defiance Diss Cu (µg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles											
RD Percentile	First Sample	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.05	0.06-.08	0.09-0.1	0.11-0.15	0.16-0.23	0.24-0.28	0.31-0.37	0.38-0.50	0.51-0.68	0.69-0.89
n	9	10	13	4	10	10	8	9	6	13	5
Median	17.6	11.75	6.04	4.805	6.905	2.83	3.11	1.01	2.295	1.92	3.66
Mean	17.71	15.09	10.23	5.77	5.99	4.37	2.92	1.82	2.71	3.95	6.51
C/V	0.51	0.60	0.75	0.76	0.63	1.06	0.69	0.85	0.70	1.10	0.73

Pt. Defiance Diss Zn (µg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles											
RD Percentile	First Sample	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.05	0.06-.08	0.09-0.1	0.11-0.15	0.16-0.23	0.24-0.28	0.31-0.37	0.38-0.50	0.51-0.68	0.69-0.89
n	9	10	13	4	10	10	8	9	6	13	5
Median	92.6	84	34.4	16.3	33.62	14.4	13.15	16.8	14.845	14.7	18.3
Mean	111.71	95.95	53.56	21.28	32.20	17.45	15.44	16.35	14.75	18.73	29.10
C/V	0.64	0.79	0.69	0.61	0.56	0.53	0.50	0.40	0.50	0.68	0.55

Pt. Defiance TSS (mg/L) at Rainfall Depth First Sample, 5th Percentile, and Deciles											
RD Percentile	First Sample	0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
RD Amount	--	0-0.05	0.06-.08	0.09-0.1	0.11-0.15	0.16-0.23	0.24-0.28	0.31-0.37	0.38-0.50	0.51-0.68	0.69-0.89
n	9	10	13	4	9	10	7	8	5	12	5
Median	45	31	28	18	10	11	6	3	10	10	6
Mean	51	43	29	16	15	17	15	14	8	9	20
C/V	0.56	0.76	0.88	0.52	0.75	1.63	1.45	2.06	0.84	0.50	1.16

Appendix D – Scatter Cr Antecedent Dry Period (ADP) Scatter Plots and Analysis



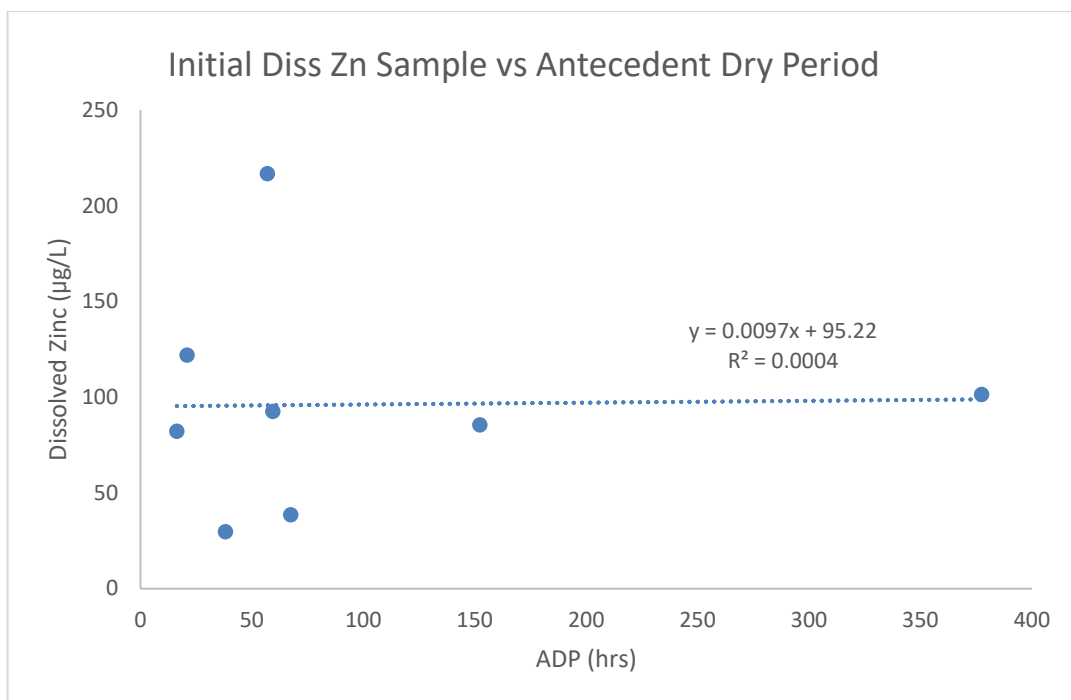
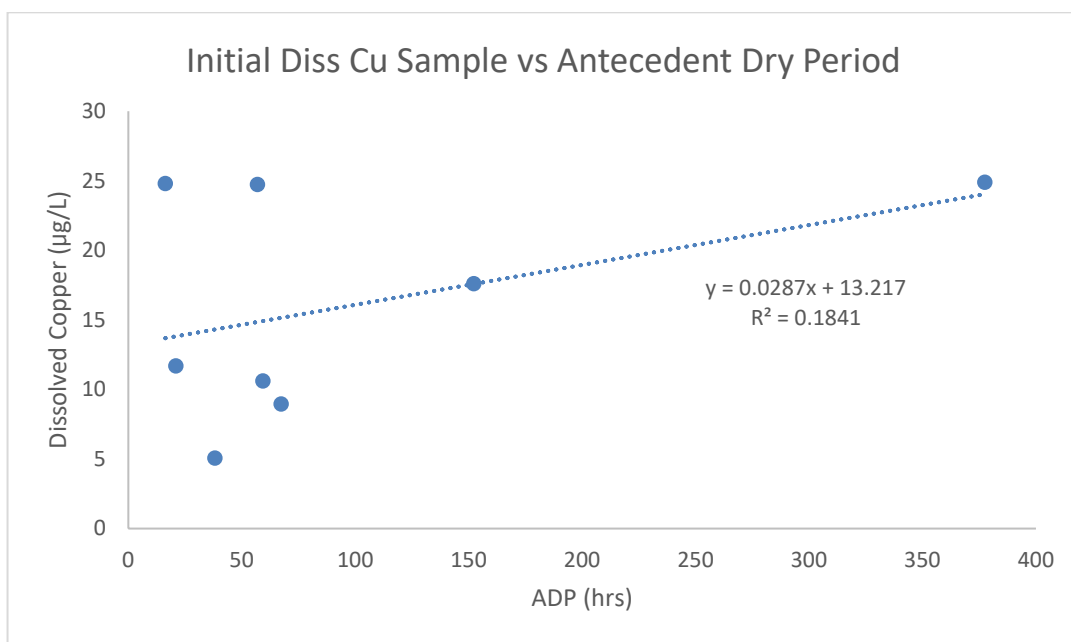


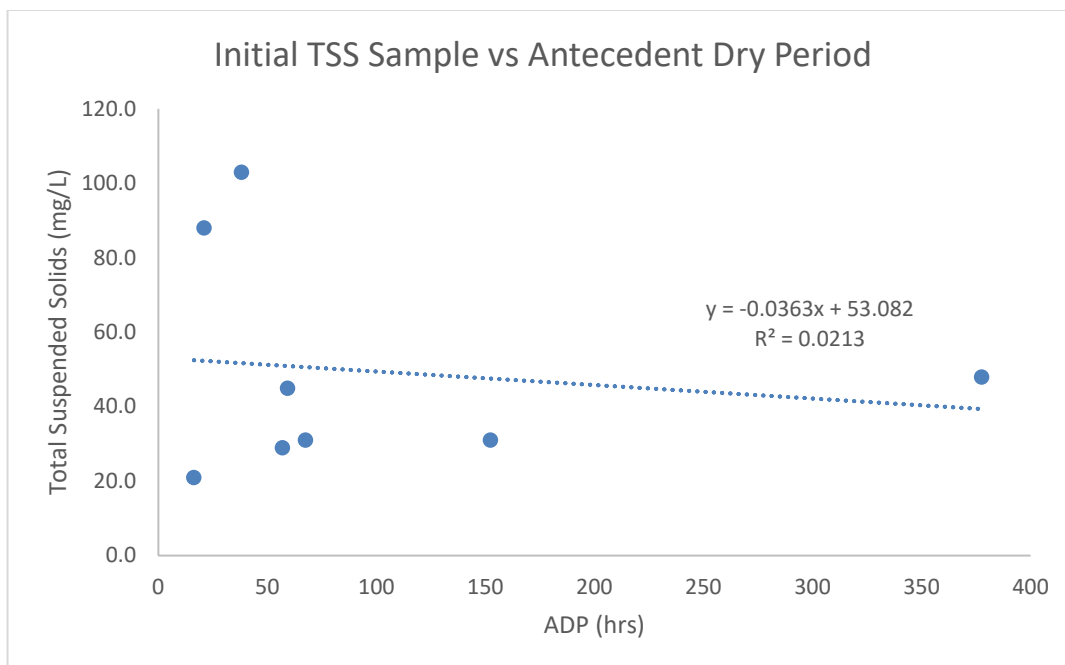
Antecedent Dry Period (ADP) and Corresponding First Samples for Scatter Cr							
Site	Sample Date	ADP Hours	ADP Rainfall Amount	Ratio of ADP Hours to ADP Amount	TSS First Sample Values	Diss Cu First Sample Values	Diss Zn First Sample Values
Scatter Cr	1/4/2023	33:35:00	0.02	0.01	284	24.5	370
Scatter Cr	3/19/2023	143:55:00	0.03	0.01	68	40.1	120
Scatter Cr	10/9/2023	153:40:00	0.01	0.00	94	56.9	216
Scatter Cr	11/1/2023	179:10:00	0.01	0.00	172	37.3	172
Scatter Cr	2/27/2024	26:40:00	0.01	0.01	136	11.4	91.6
Scatter Cr	6/2/2024	91:10:00	0	0.00	44	23.95	86.32
Scatter Cr	9/10/2024	448:25:00	0.1	0.01	104	73.52	529.6
Scatter Cr	10/30/2024	41:50:00	0	0.00	90	13.13	105.2

Scatter Cr ADP Analysis:

Increasing ADP coincided with increasing Diss Cu concentrations in first samples taken, displaying a linear trend. It also displayed a moderate correlation with Diss Zn, though this was largely driven by the single largest ADP of the events (448 hrs) coinciding with the largest events Diss Zn value (529.6 µg/L). This suggests that ADP may have an impact on early storm event Diss Cu/Zn values at Scatter Cr. ADP did not display a relationship with TSS values.

Appendix E - Pt. Defiance Antecedent Dry Period (ADP) Scatter Plots and Analysis



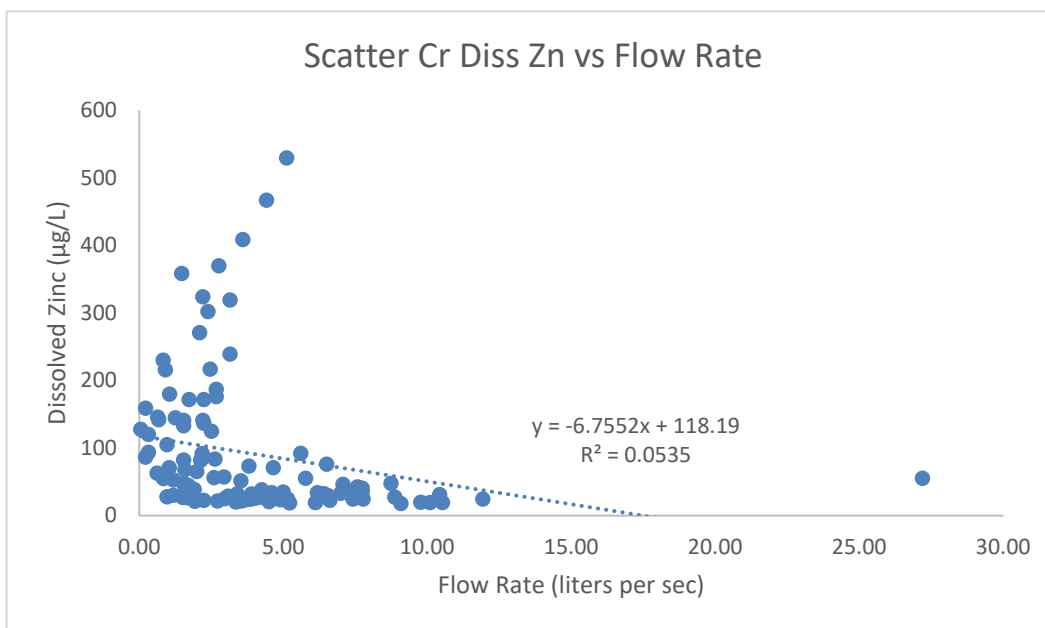
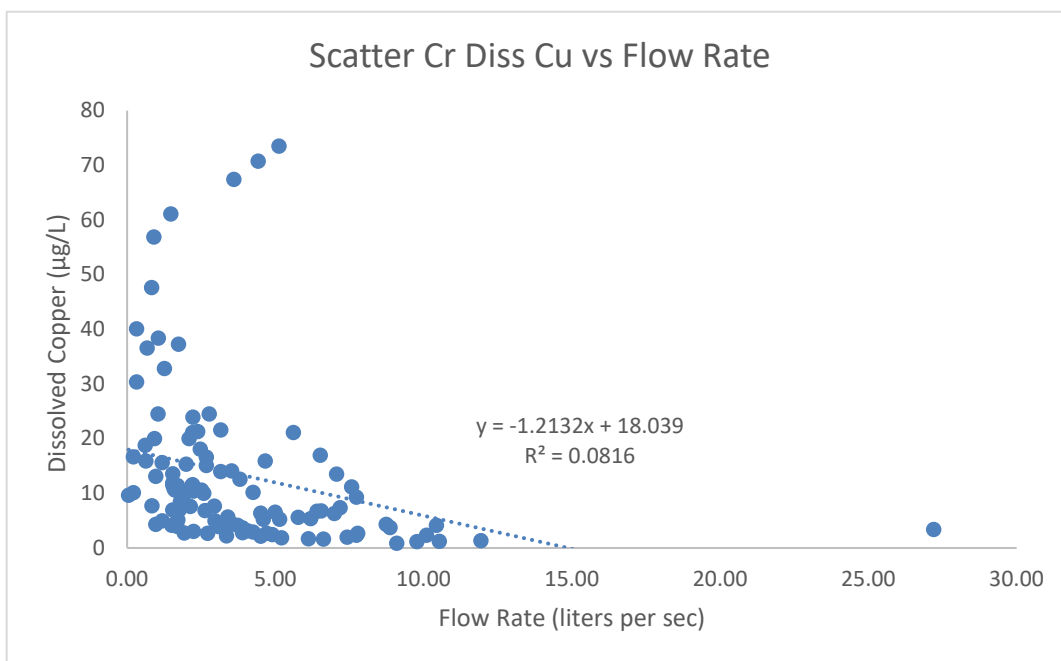


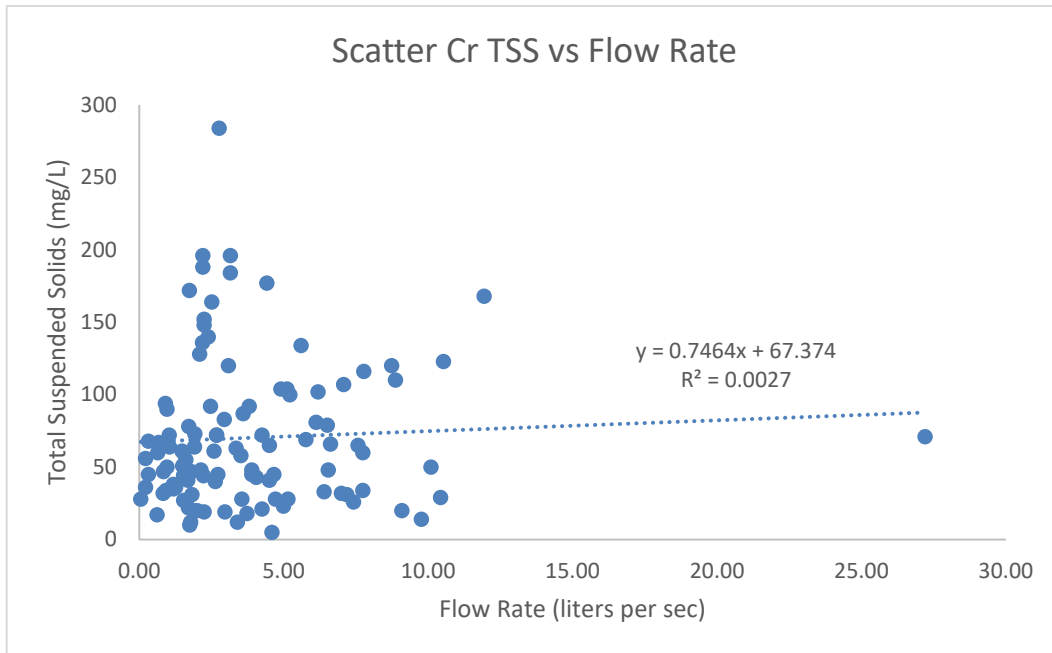
Antecedent Dry Period (ADP) and Corresponding First Samples for Pt. Defiance							
	Sample Date	ADP Hours	ADP Rainfall Amount	Ratio of ADP Hours to ADP Amount	TSS First Sample Values	Diss Cu First Sample Values	Diss Zn First Sample Values
Pt. Defiance	1/11/2023	38:20:00	0.01	0.01	103.0	5.07	29.8
Pt. Defiance	3/20/2023	152:35:00	0.01	0.00	31.0	17.6	85.7
Pt. Defiance	9/24/2023	16:30:00	0	0.00	21.0	24.8	82.3
Pt. Defiance	10/24/2023	67:45:00	0.01	0.00	31.0	8.95	38.70
Pt. Defiance	1/24/2024	21:00:00	0	0.00	88.0	11.70	122.00
Pt. Defiance	2/14/2024	59:35:00	0.01	0.00	45.0	10.6	92.6
Pt. Defiance	4/25/2024	377:50:00	0.03	0.00	48.0	24.9	101.5
Pt. Defiance	5/21/2024	57:00:00	0	0.00	29.0	24.74	216.8

Pt. Defiance ADP Analysis:

ADP did not demonstrate a pattern with any of the above pollutants. However, it is noted that sample collection at Pt. Defiance, which was time-weighted, did not have the same real-time flow-weighted resolution as Scatter Cr. As such, it is possible that ADP was a factor at Pt. Defiance but just not discernable from the Study sampling methods.

Appendix F – Scatter Cr Flow Rate Plots and Analysis

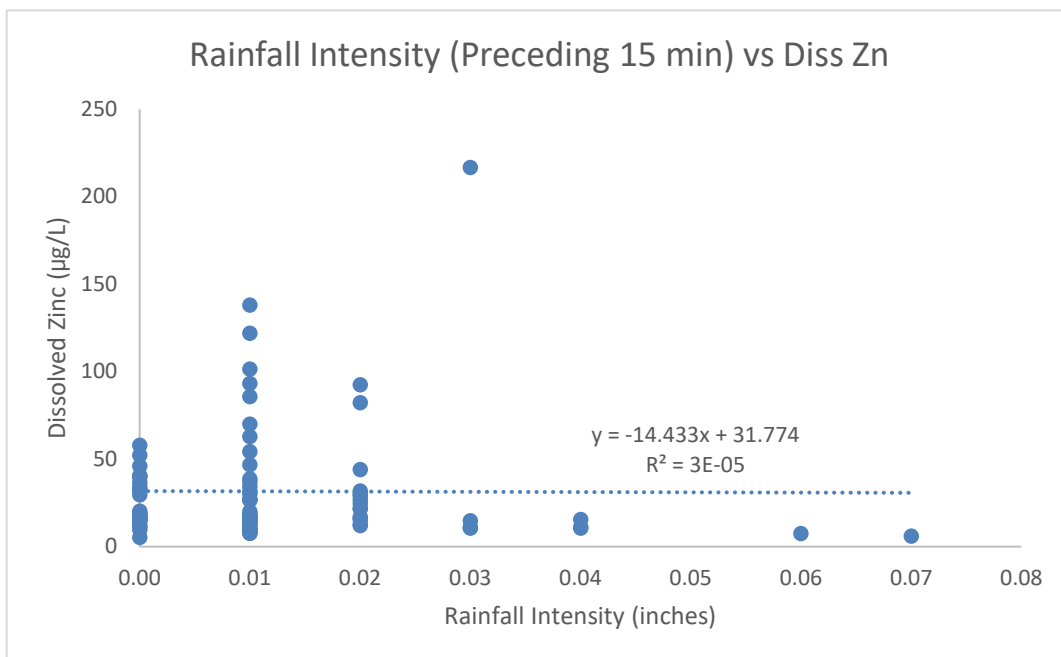
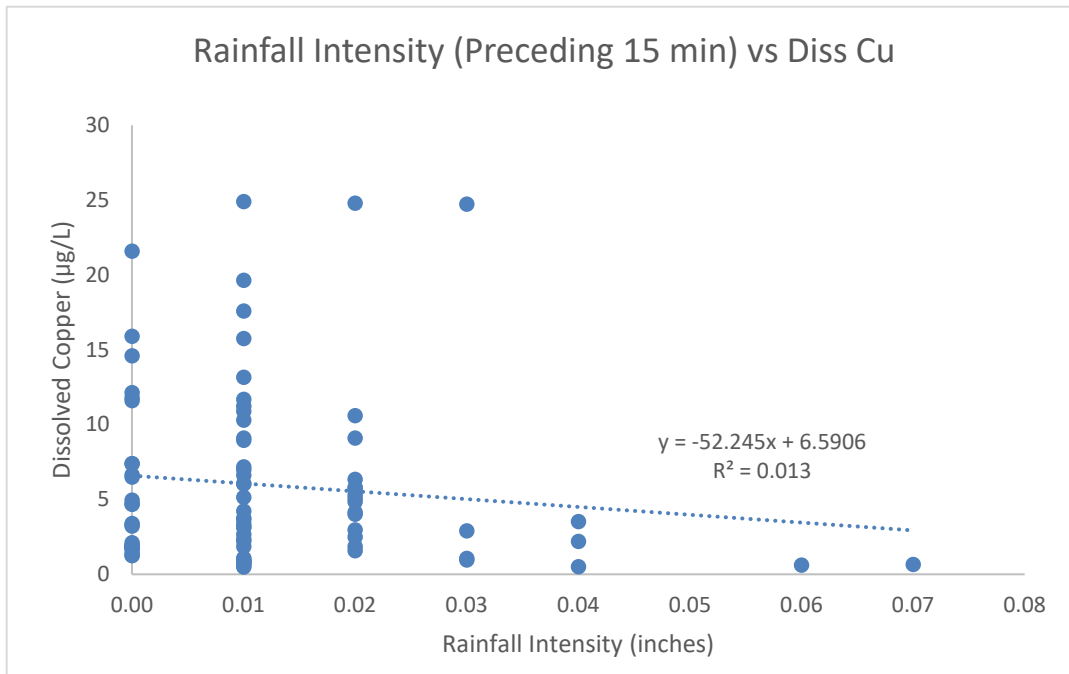


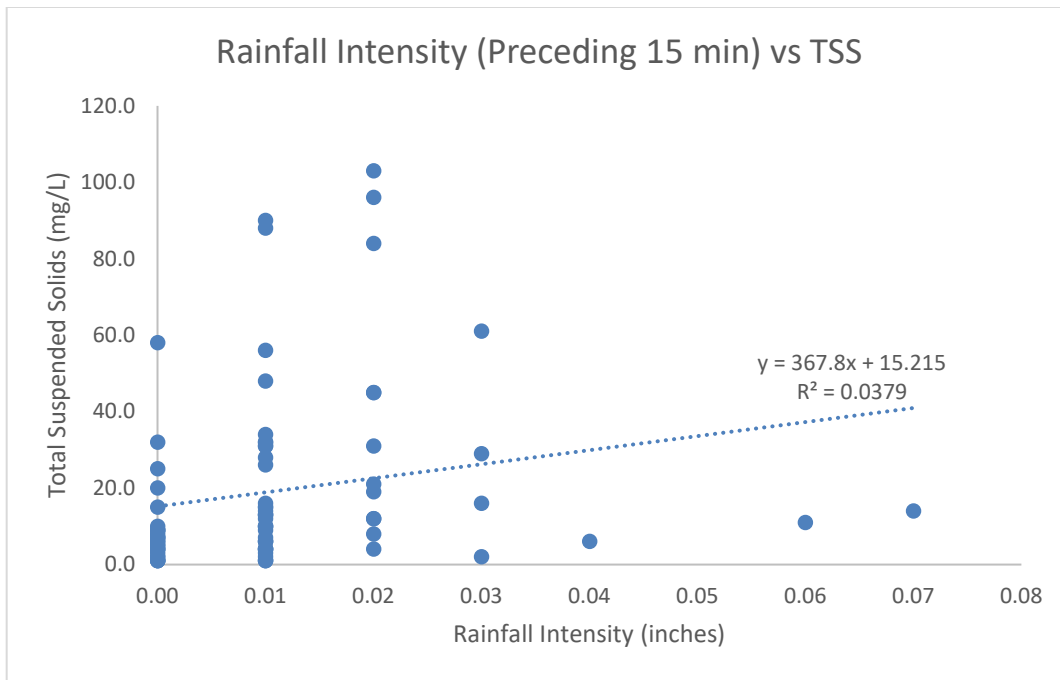


Scatter Cr Flow Rate Analysis:

Flow rate did not demonstrate a pattern with any of the above pollutants. However, Study design was not oriented towards accurate assessment of flow rate impact. As such, sample collection coincided with potential confounding variables, such as increased flow rate occurring during late “cleaner” pollutant phases of storm events, distorting trend analysis. Altogether, flow rate impact on pollutant concentrations is unknown.

Appendix G – Pt. Defiance Rainfall Intensity Plots and Analysis

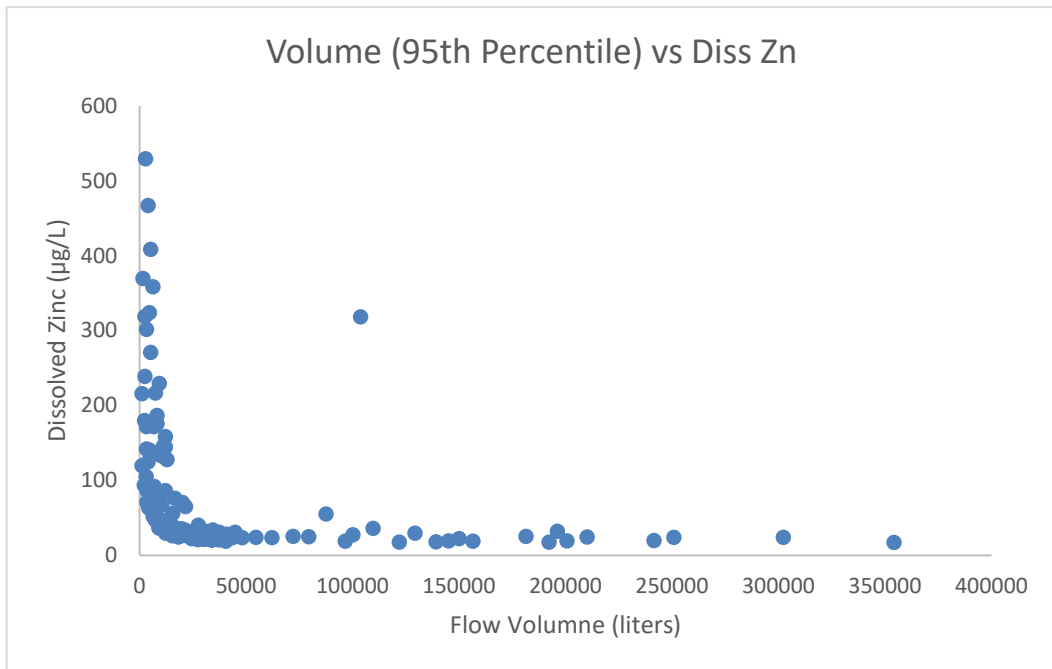
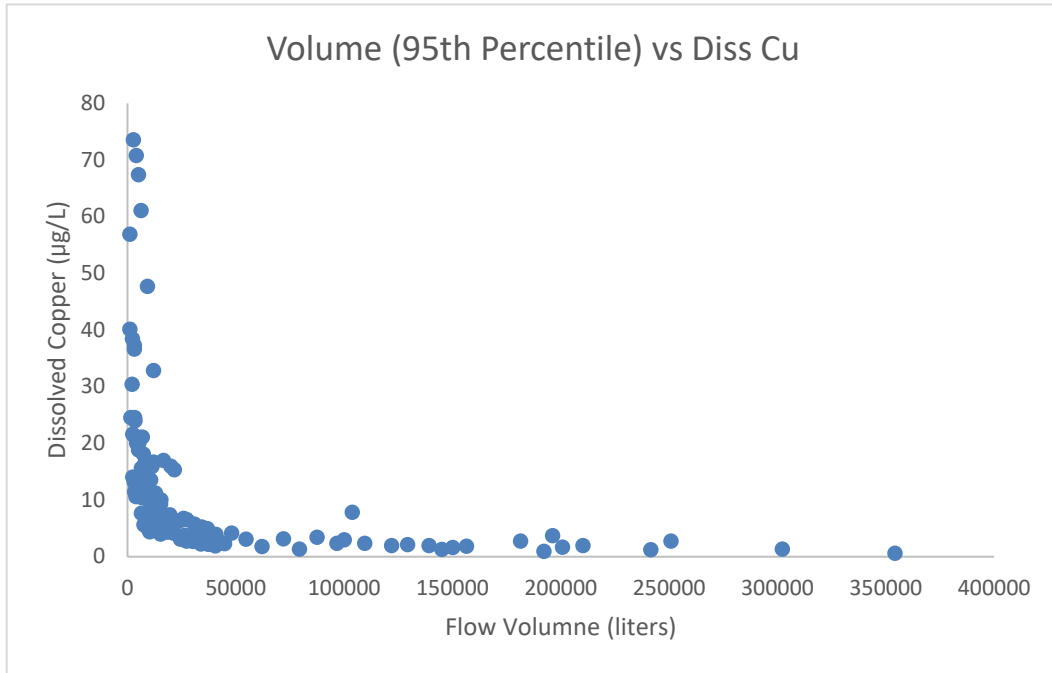


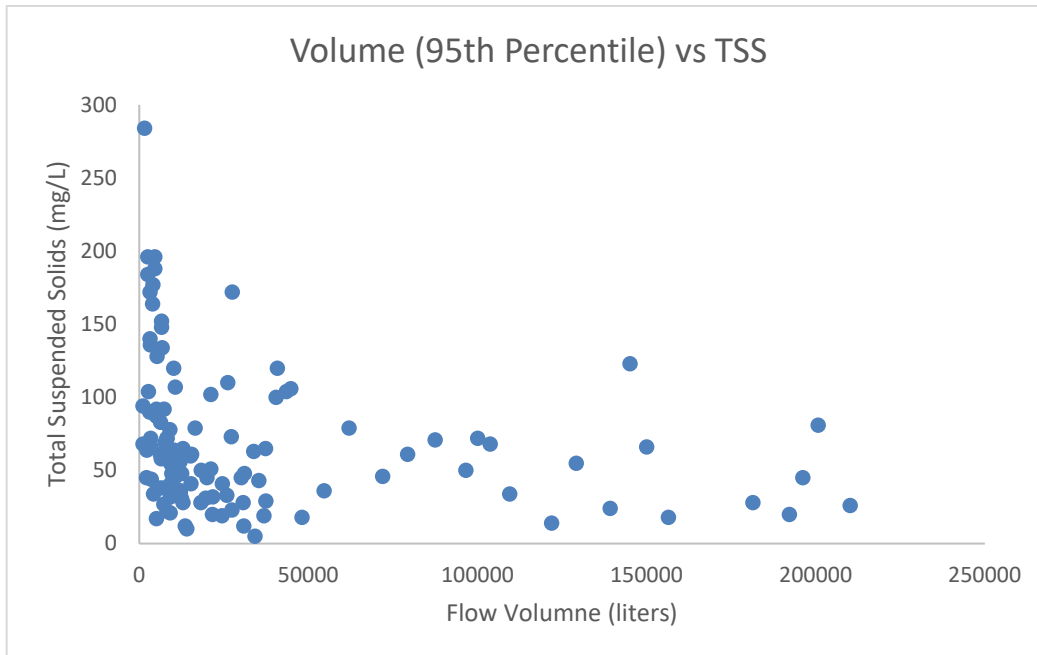


Pt. Defiance Rainfall Intensity Analysis:

Rainfall intensity did not demonstrate a pattern with any of the above pollutants. However, as mentioned with other variables, Study design was not oriented towards accurate assessment of rainfall intensity impact. Sample collection was time-weighted, vs rainfall dominated, so sample collection in response to preceding rainfall was random in addition to other confounding variables, such as diminishing pollutant concentrations over storm durations, regardless of rainfall intensity.

Appendix H – Scatter Cr Volume Plots and Analysis





Volume Analysis:

Note: three statistical outlier volume values, exceeding 400,000 liters, distorted the visual accessibility and resolution of the above scatter plots. In response, the 95th percentile of volumes are utilized in the above graphs to enhance readability for the viewer. Plot trends or basic findings are unaffected.

As mentioned in Section 4.2, volume vs pollutant concentrations largely mirror the L-curve exhibited in rainfall depth (RD) vs pollutant concentrations, reinforcing RD as a rough volume proxy. Specifically, the highest pollutant concentrations were exhibited during the initial, smaller volumes, and then as those pollutants were transported/"washed away" in runoff, subsequent larger cumulative volumes displayed lower concentrations.

Regarding management, specific volumes are unhelpful design criteria since every facility generates different volumes from its impervious surface size and drainage patterns. However, RD associated volumes, such as the predicted volume from the initial 0.08 inches of rainfall, is useful in sizing appropriate BMP technologies to manage the dirtier first flush phase demarcated in this Study.

Appendix I – Statistical Outputs

R Statistical Software (R version 4.4.2 (2024-10-31) -- "Pile of Leaves")

Copyright (C) 2024) was utilized to conduct Kruskal-Wallis and Wilcoxon Rank Sum statistical tests.

Basic scatter plots, trend lines, and R^2 values were generated in Excel (Microsoft 365).

Scatter Cr quartile and decile R Outputs:

Quantile comparisons. TSS	Diss Cu	Diss Zn
> kruskal.test(list(T1,T2,T3,T4))	kruskal.test(list(C1,C2,C3,C4))	> kruskal.test(list(Z1,Z2,Z3,Z4))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(T1, T2, T3, T4)	data: list(C1, C2, C3, C4)	data: list(Z1, Z2, Z3, Z4)
Kruskal-Wallis chi-squared = 15.454, df = 3, p-value = 0.001467	Kruskal-Wallis chi-squared = 87.714, df = 3, p-value < 2.2e-16	Kruskal-Wallis chi-squared = 90.188, df = 3, p-value < 2.2e-16
> kruskal.test(list(T2,T3,T4))	> kruskal.test(list(C2,C3,C4))	> kruskal.test(list(Z2,Z3,Z4))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(T2, T3, T4)	data: list(C2, C3, C4)	data: list(Z2, Z3, Z4)
Kruskal-Wallis chi-squared = 0.67959, df = 2, p-value = 0.7119	Kruskal-Wallis chi-squared = 48.602, df = 2, p-value = 2.793e-11	Kruskal-Wallis chi-squared = 38.982, df = 2, p-value = 3.429e-09
> kruskal.test(list(T3,T4))	> kruskal.test(list(C3,C4))	> kruskal.test(list(Z3,Z4))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(T3, T4)	data: list(C3, C4)	data: list(Z3, Z4)
Kruskal-Wallis chi-squared = 0.61426, df = 1, p-value = 0.4332	Kruskal-Wallis chi-squared = 22.877, df = 1, p-value = 1.727e-06	Kruskal-Wallis chi-squared = 16.834, df = 1, p-value = 4.08e-05
> kruskal.test(list(T2,T3))	> kruskal.test(list(C2,C3))	> kruskal.test(list(Z2,Z4))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(T2, T3)	data: list(C2, C3)	data: list(Z2, Z4)
Kruskal-Wallis chi-squared = 0.027799, df = 1, p-value = 0.8676	Kruskal-Wallis chi-squared = 16.154, df = 1, p-value = 5.839e-05	Kruskal-Wallis chi-squared = 31.29, df = 1, p-value = 2.222e-08
	> kruskal.test(list(C2,C4))	> wilcox.test(Z1,Z2,alt="greater")
wilcox.test*		
> wilcox.test(T1,T2,alt="greater")	Kruskal-Wallis rank sum test	Wilcoxon rank sum test with continuity correction
Wilcoxon rank sum test with continuity correction	data: list(C2, C4)	data: Z1 and Z2
data: T1 and T2	Kruskal-Wallis chi-squared = 35.793, df = 1, p-value = 2.194e-09	W = 832, p-value = 2.055e-08
W = 665.5, p-value = 0.001014	> wilcox.test(C1,C2,alt="greater")	alternative hypothesis: true location shift is greater than 0
alternative hypothesis: true location shift is greater than 0	Wilcoxon rank sum test with continuity correction	Warning message:
Warning message:		In wilcox.test.default(Z1, Z2, alt = "greater") :
In wilcox.test.default(T1, T2, alt = "greater") :	data: C1 and C2	cannot compute exact p-value with ties
cannot compute exact p-value with ties	W = 704, p-value = 0.0001359	> wilcox.test(Z2,Z3,alt="greater")
> wilcox.test(T1,T3,alt="greater")	alternative hypothesis: true location shift is greater than 0	Wilcoxon rank sum test with continuity correction
Wilcoxon rank sum test with continuity correction	Warning message:	data: Z2 and Z3
	In wilcox.test.default(C1, C2, alt = "greater") :	W = 511, p-value = 0.000414
data: T1 and T3	cannot compute exact p-value with ties	alternative hypothesis: true location shift is greater than 0
W = 902.5, p-value = 0.0004164	> wilcox.test(C2,C3,alt="greater")	Warning message:
alternative hypothesis: true location shift is greater than 0	Wilcoxon rank sum exact test	In wilcox.test.default(Z2, Z3, alt = "greater") :
Warning message:		cannot compute exact p-value with ties
In wilcox.test.default(T1, T3, alt = "greater") :	data: C2 and C3	> wilcox.test(Z3,Z4,alt="greater")
cannot compute exact p-value with ties	W = 547, p-value = 1.304e-05	
> wilcox.test(T1,T4,alt="greater")	alternative hypothesis: true location shift is greater than 0	Wilcoxon rank sum test with continuity correction
Wilcoxon rank sum test with continuity correction	> wilcox.test(C3,C4,alt="greater")	data: Z3 and Z4
data: T1 and T4		W = 727.5, p-value = 2.106e-05
W = 828, p-value = 0.006679	Wilcoxon rank sum test with continuity correction	alternative hypothesis: true location shift is greater than 0
alternative hypothesis: true location shift is greater than 0	data: C3 and C4	Warning message:
Notes: no difference between 2nd,3rd,4th qtr's.	W = 773.5, p-value = 8.96e-07	In wilcox.test.default(Z3, Z4, alt = "greater") :
Difference between 1st and rest.	alternative hypothesis: true location shift is greater than 0	Notes: differences between all qtr's.
Qtr 1 is significantly greater than 2,3,4.	Notes: differences between all qtr's.	Z1>Z2>Z3>Z4
>	C1>C2>C3>C4	different than what we see in the decile patterns.
	different than what we see in the decile patterns.	

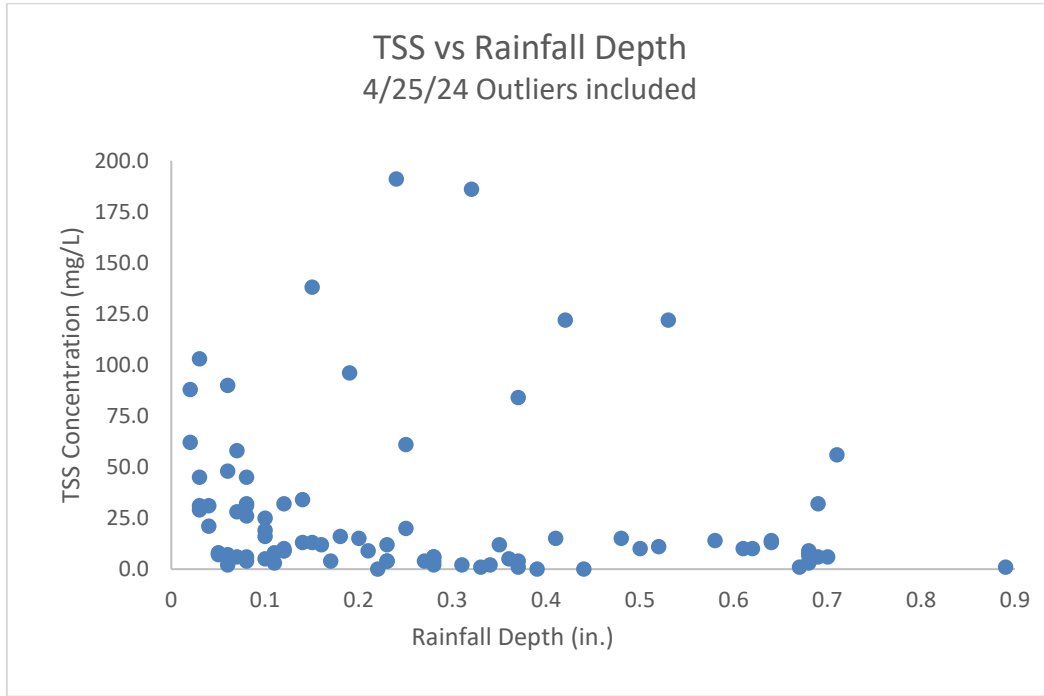
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Pt. Defiance quartile and decile R Outputs:

Qtr comparisons		
TSS		
kruskal.test(list(T1,T2,T3,T4))	kruskal.test(list(T2,T3,T4))	kruskal.test(list(T1,T2))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(T1, T2, T3, T4)	data: list(T2, T3, T4)	data: list(T1, T2)
Kruskal-Wallis chi-squared = 8.969, df = 3, p-value = 0.02971	Kruskal-Wallis chi-squared = 2.1377, df = 2, p-value = 0.3434	Kruskal-Wallis chi-squared = 4.1368, df = 1, p-value = 0.04196
Notes: no kruskal differences between qtr's 2,3,4. Significant between 1st and 2nd, indicating qtr 1 is where most of the action is located.		
> wilcox.test(T1,T2,alt="greater")	> wilcox.test(T1,T3,alt="greater")	> wilcox.test(T1,T4,alt="greater")
W = 371.5, p-value = 0.02152	W = 317, p-value = 0.006559	W = 346, p-value = 0.01774
Wilcoxon rank sum test with continuity correction		
Notes: Wilcox confirmed qtr 1 statistically > than 2,3,4		
DISS CU		
> kruskal.test(list(C1,C2,C3,C4))	> kruskal.test(list(C2,C3,C4))	
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	
data: list(C1, C2, C3, C4)	data: list(C2, C3, C4)	
Kruskal-Wallis chi-squared = 30.475, df = 3, p-value = 1.096e-06	Kruskal-Wallis chi-squared = 8.1523, df = 2, p-value = 0.01697	
> kruskal.test(list(C3,C4))	> kruskal.test(list(C2,C3))	> kruskal.test(list(C1,C2))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(C3, C4)	data: list(C2, C3)	data: list(C1, C2)
Kruskal-Wallis chi-squared = 3.8448, df = 1, p-value = 0.0499	Kruskal-Wallis chi-squared = 7.7739, df = 1, p-value = 0.005301	Kruskal-Wallis chi-squared = 9.6551, df = 1, p-value = 0.001888
Note: Differences between all 4 qtrs. Not same pattern as zinc. Presumably due to sediment in pan bias.		
> wilcox.test(C1,C2,alt="greater")	> wilcox.test(C1,C3,alt="greater")	> wilcox.test(C1,C4,alt="greater")
W = 422, p-value = 0.0009787	W = 413, p-value = 1.636e-08	W = 423, p-value = 2.67e-05
Wilcoxon rank sum test with continuity correction		
> wilcox.test(C2,C3,alt="greater")	> wilcox.test(C2,C4)	wilcox.test(C3,C4,alt="less")
Wilcoxon rank sum test with continuity correction	Wilcoxon rank sum test with continuity correction	Wilcoxon rank sum exact test
data: C2 and C3	data: C2 and C4	data: C3 and C4
W = 342, p-value = 0.002752	W = 303, p-value = 0.3972	W = 134, p-value = 0.02536
alternative hypothesis: true location shift is greater than 0		alternative hypothesis: true location shift is less than 0
Note: 2nd qtr > 3rd, but not different than 4th. 3rd less than 4th obviously. Basically Cu upticks at end, as observed, to a significant degree. Qtr 1 is still greater than 2nd, 4th. Need to break down to decile level for all qtr's?		
DISS Zn		
> kruskal.test(list(Z1,Z2,Z3,Z4))	> kruskal.test(list(Z2,Z3,Z4))	> kruskal.test(list(Z2,Z3))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(Z1, Z2, Z3, Z4)	data: list(Z2, Z3, Z4)	data: list(Z2, Z3)
Kruskal-Wallis chi-squared = 33.049, df = 3, p-value = 3.146e-07	Kruskal-Wallis chi-squared = 3.4535, df = 2, p-value = 0.1779	Kruskal-Wallis chi-squared = 3.41, df = 1, p-value = 0.0648
> kruskal.test(list(Z3,Z4))	> kruskal.test(list(Z1,Z2))	> kruskal.test(list(Z1,Z3))
Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
data: list(Z3, Z4)	data: list(Z1, Z2)	data: list(Z1, Z3)
Kruskal-Wallis chi-squared = 1.0936, df = 1, p-value = 0.2957	Kruskal-Wallis chi-squared = 14.678, df = 1, p-value = 0.000127	Kruskal-Wallis chi-squared = 24.658, df = 1, p-value = 6.846e-07
> kruskal.test(list(Z1,Z4))		
Kruskal-Wallis rank sum test		
data: list(Z1, Z4)		
Kruskal-Wallis chi-squared = 20.727, df = 1, p-value = 5.297e-06		
Notes: Qtr's 2,3,4 did not show differences. Qtr 1 showed differences with all the other qtrs. Need to dial down on qtr 1.		
Wilcoxon rank sum test with continuity correction	> wilcox.test(Z1,Z3,alt="greater")	> wilcox.test(Z1,Z4,alt="greater")
> wilcox.test(Z1,Z2,alt="greater")	W = 415, p-value = 1.007e-08	W = 453.5, p-value = 2.795e-06
W = 456, p-value = 6.657e-05		
Qtr 1 obviously greater than all the rest.		

Decile	TSS	DC	DZ
		kruskal.test(list(CF,C1,C2,C3,C4,C5,C6,C7,C8,C9,C10))	kruskal.test(list(ZF,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10))
kruskal.test(list(T1,T2,T3,T4,T5,T6,T7,T8,T9))		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
Kruskal-Wallis rank sum test		data: list(CF, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10) Kruskal-Wallis chi-squared = 46.741, df = 10, p-value = 1.052e-0	data: list(ZF, Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10) Kruskal-Wallis chi-squared = 53.34, df = 10, p-value = 6.437e-08
data: list(T1, T2, T3, T4, T5, T6, T7, T8, T9) Kruskal-Wallis chi-squared = 11.645, df = 8, p-value = 0.1678		> kruskal.test(list(C1,C2,C3,C4,C5,C6,C7,C8,C9,C10))	> kruskal.test(list(Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10))
> kruskal.test(list(TF,T1,T2,T3,T4,T5,T6,T7,T8,T9))		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
Kruskal-Wallis rank sum test		data: list(C1, C2, C3, C4, C5, C6, C7, C8, C9, C10) Kruskal-Wallis chi-squared = 35.744, df = 9, p-value = 4.402e-05	data: list(Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10) Kruskal-Wallis chi-squared = 41.182, df = 9, p-value = 4.635e-06
data: list(TF, T1, T2, T3, T4, T5, T6, T7, T8, T9) Kruskal-Wallis chi-squared = 20.181, df = 9, p-value = 0.01683		> kruskal.test(list(CF,C1))	> kruskal.test(list(ZF,Z1))
> kruskal.test(list(TF,T1))		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
Kruskal-Wallis rank sum test		data: list(CF, C1) Kruskal-Wallis chi-squared = 0.42968, df = 1, p-value = 0.5121	data: list(ZF, Z1) Kruskal-Wallis chi-squared = 0.54382, df = 1, p-value = 0.4609
data: list(TF, T1) Kruskal-Wallis chi-squared = 0.67616, df = 1, p-value = 0.4109		> kruskal.test(list(CF,C2))	> kruskal.test(list(ZF,Z1,Z2))
> kruskal.test(list(TF,T2))		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
Kruskal-Wallis rank sum test		data: list(CF, C2) Kruskal-Wallis chi-squared = 3.7524, df = 1, p-value = 0.05273	data: list(ZF, Z1, Z2) Kruskal-Wallis chi-squared = 5.1998, df = 2, p-value = 0.07428
data: list(TF, T2) Kruskal-Wallis chi-squared = 2.9112, df = 1, p-value = 0.08797		> kruskal.test(list(CF,C3))	> kruskal.test(list(ZF,Z1,Z2,Z3))
> kruskal.test(list(TF,T3))		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
Kruskal-Wallis rank sum test		data: list(CF, C3) Kruskal-Wallis chi-squared = 4.6667, df = 1, p-value = 0.03075	data: list(ZF, Z1, Z2, Z3) Kruskal-Wallis chi-squared = 10.822, df = 3, p-value = 0.01273
data: list(TF, T3) Kruskal-Wallis chi-squared = 6.8999, df = 1, p-value = 0.00862		> kruskal.test(list(C1,C2))	> kruskal.test(list(ZF,Z2))
TSS Notes		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
30% decile is where we see statistical change from First Flush samples		data: list(C1, C2) Kruskal-Wallis chi-squared = 1.8615, df = 1, p-value = 0.1724	data: list(ZF, Z2) Kruskal-Wallis chi-squared = 4.8589, df = 1, p-value = 0.0275
		> kruskal.test(list(C1,C3))	> kruskal.test(list(Z1,Z2))
		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
		data: list(C1, C3) Kruskal-Wallis chi-squared = 3.92, df = 1, p-value = 0.04771	data: list(Z1, Z2) Kruskal-Wallis chi-squared = 2.0346, df = 1, p-value = 0.1538
		> kruskal.test(list(C3,C4))	> kruskal.test(list(Z1,Z3))
		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
		data: list(C3, C4) Kruskal-Wallis chi-squared = 0.045199, df = 1, p-value = 0.8316	data: list(Z1, Z3) Kruskal-Wallis chi-squared = 5.12, df = 1, p-value = 0.02365
		data: list(C3, C4, C5, C6, C7) Kruskal-Wallis chi-squared = 10.664, df = 4, p-value = 0.03061	data: list(Z3, Z4, Z5, Z6, Z7, Z8) Kruskal-Wallis chi-squared = 9.0389, df = 5, p-value = 0.1075
		> kruskal.test(list(C6,C7))	> kruskal.test(list(Z3,Z4,Z5,Z6,Z7,Z8,Z9))
		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
		data: list(C6, C7) Kruskal-Wallis chi-squared = 0.75, df = 1, p-value = 0.3865	data: list(Z3, Z4, Z5, Z6, Z7, Z8, Z9) Kruskal-Wallis chi-squared = 9.3297, df = 6, p-value = 0.1559
		> kruskal.test(list(C6,C7,C8))	> kruskal.test(list(Z3,Z4,Z5,Z6,Z7,Z8,Z9,Z10))
		Kruskal-Wallis rank sum test	Kruskal-Wallis rank sum test
		data: list(C6, C7, C8) Kruskal-Wallis chi-squared = 1.2862, df = 2, p-value = 0.5257	data: list(Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10) Kruskal-Wallis chi-squared = 12.81, df = 7, p-value = 0.07689
		> kruskal.test(list(C6,C7,C8,C9))	
		Kruskal-Wallis rank sum test	Diss Zn Notes 20% decile is where we see statistical change from FF samples. 30-100%, no statistical difference though trending towards significance with inclusion of Z10, 90-100%. Assuming that end of storm uptick affects like Cu but not to same degree.
		data: list(C6, C7, C8, C9) Kruskal-Wallis chi-squared = 2.626, df = 3, p-value = 0.453	
		> kruskal.test(list(C6,C7,C8,C9,C10))	
		Kruskal-Wallis rank sum test	
		data: list(C6, C7, C8, C9, C10) Kruskal-Wallis chi-squared = 6.8116, df = 4, p-value = 0.1462	
		Diss Cu Notes	
		20-30% decile is where we see statistical change from First Flush samples 30-70% no difference uptick at 70; no difference between 60-100 Uptick assumed due to sediment issue.	

APPENDIX J – Pt. Defiance 4/25/24 Storm Event TSS Outliers Included Scatter Plot and Analysis



Pt. Defiance TSS Outlier Analysis:

As mentioned in Section 5.4, TSS concentrations followed a general pattern except for five outlier samples, all which occurred ~7am-11am during the 4/25/24 storm event. Staff witnessed unusual conditions during this event, specifically unusual floating “plastic like particles” in the runoff previously unencountered onsite (or in WSDOT’s other stormwater monitoring). These samples displayed high enough TSS concentrations, higher than others for the entire project, to derail the overall Study characterization pattern. For this reason, these outliers were removed from basic characterization analysis. However, capturing unusual conditions and pollutant pulses is important for stormwater management and to avoid “cherry picking” data. As such, a separate scatter plot above is included to display these samples, for reference.

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