Agricultural Stormwater Loading Variability and Implications on Constructed Wetlands Performance for Pollutant Attenuation

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DEDICATION

Dedicated to my family, my husband, my son, my cat

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ABSTRACT

The United States Environmental Protection Agency (USEPA) reports that over 40% of waters nationwide are affected by non-point sources pollutant (NPS). Agricultural runoff has been shown to cause harmful algal blooms and ecological degradation in coastal estuaries and water sources. In order to treat and prevent pollution from agricultural runoff, many best management practices (BMPs) have been developed and researched, including constructed wetlands.

This research had multiple objectives. Chapter 1 presents work conducted to gain better understand constructed wetlands as a BMP for agricultural runoff, through: 1) Quantifying the performance of two wetlands in terms of event-scale runoff sediment reduction and nutrient attenuation, and 2) Identifying the relationship between wetland attenuation performance, and inflow runoff characteristics including volume, pollutant loads, 3) Assessing the need for water quality protection best management practices on an East Tennessee dairy farm and neighboring crop farm.

Chapter 2 presents work conducted to gain a better understanding of the transport properties of pollutants generated from agricultural land by: 1) to detect the strength of first flush effects among potential pollutants from basins draining to constructed stormwater treatment wetlands, 2) identifying how environmental parameters of rainfall intensity, flow duration, and dry periods influence pollutant first flush effects, and 3) Identifying the relationship between wetland attenuation performance, and first flush coefficient.

There were several overarching findings from this research: 1) TSS and ammonia were significantly attenuated at the event scale in both wetlands sampled during this study. 2) TSS attenuation showed a positive correlation with inflow pollutant loads, while total phosphorus attenuation was negatively correlated. 3) Particulate pollutants tend to have a stronger first flush effect, compared to non-particulate nutrients. 4) Particulate pollutant first flush effects differed between sites, which could be attributed to differences in catchment land use. 5) TSS showed a negative correlation between the first flush effects and pollutant attenuation.

TABLE OF CONTENTS

INTRODUCTION……1
CHAPTER 1. PERFORMANCE EVALUATION OF EVENT SCHALE NPS POLLUTANT ATTENUATION IN INTEGRATED CONSTRUCTED WETLANDS FOR TREATMENT OF AGRICULTURAL RUNOFF IN EAST TENNESSEE……3
Abstract……4
Introduction……5
Site Description……6
Wetland Performance Evaluation Sites……...6
Baseline Sampling Sites……..7
Methods……...9
Sampling Protocols and Lab Analysis……9
Pollutant Attenuation……12
Statistical Analysis……13
Results and Discussion……..13
Event Scale Stormwater Pollutant Attenuation of Wetland FW and BP……..13
Parameters Influencing Stormwater Treatment Wetland Performance……25
Baseline Sampling Water Quality……27
Conclusion……40
Future Work……40
CHAPTER 2. EXPLORATORY ANALYSIS TO IDENTIFY FIRST FLUSH PHENOMENA IN AGRICULTURAL RUNOFF FROM A CONCENTRATED DAIRY OPERATION IN EAST TENNESSEE……41
Abstract……42
Keywords……...42
Introduction……43
Materials and Methods……45
Study Site……45
Stormwater Runoff Sampling……47
First Flush Analysis……...48
Statistical Analysis……50
Results……50
Discussion……..66
Conclusion……75
Future Work……75

FUTURE WORK……76
REFERENCES……77
VITA……85

LIST OF TABLES

Table 1. Water Chemistry Lab analyses prepared and performed in the BESSWQ Lab……12
Table 2. Storm event data and runoff inflow volume……..……....14
Table 3. Percentage Pollutant Mass Attenuation by Wetlands FW and BP at an East Tennessee dairy farm. NC – data Not Collected. Pollutant removal in white, pollutant export shaded gray.....17
Table 4. Percent EMC Reduction for Different Pollutant Concentrations in Wetland FW and BP. NC – data Not Collected. Pollutant removal in white, pollutant export shaded gray.....…18
Table 5. Pearson Correlation Coefficient for EMC % Reduction vs Inflow Load (kg) for TSS, TDN, NO3, NH4, PO4, and DOC. ……..27
Table 6. The monthly average concentration from baseline water quality data from 2005 to 2010. NC – data Not Collected due to no flow. ……28
Table 7. Paired Two-Sample T-Test (alpha = 0.05) and Summary Statistics comparing upstream and downstream pollutants for the Little River (LR), Ellejoy Creek (EJ), and agricultural runoff ditch (D), respectively. ……36
Table 8. Comparison of the change in pollutant concentrations (%) in the LIttle River (LR) and Ellejoy Creek (EJ) before and after dairy production……..39
Table 9. Wetlands Designing Data……..47
Table 10. Water Chemistry Lab analysis…….48
Table 11. Pertinent Characteristics of Sampled Storm Events Using Data Collected by precipitation gauge (TE-525MM CSI-Texas Electronics) at the Station of Little River Dairy Farm in Walland, Tennessee. ……..……..……52
Table 12. Average First Flush Coefficient Value Collected from All Sites & Zone Distribution……..53
Table 13. Number of storms (n) per site, used for generating CLCs (Figure 3) and calculating beta-values (Figure 4) for each pollutant……..…54
Table 14. First Flush Coefficient Statistical Characterization of Runoff from the Analysis of 15 storm events in Walland, Tennessee…….……54
Table 15. T-Test Statistic Results Comparing Pollutant β-value……..65
Table 16. T-Test Statistic Results of Sites Comparison of β-value……..……....67
Table 17. Storm Event Characteristics rom Sampled for TSSS at the Dairy Farm in Walland, Tennessee……..…….....68
Table 18. Statistical Results of Correlations Between Storm Event Paramters, and TSS and NO3, respectively ..…….....71
Table 19. Pearson Correlation for Pollutant Attenuation percentage vs First Flush Coefficient value TSS, TDN, NO3, NH4, and PO4 ..…….....73

LIST OF FIGURES

Figure 1. Location and Contributing Area of Front Wetland (FW) and Back Patch (BP)……6
Figure 2. Contributing Area of Little River Dairy Farm Watershed and Sampling Sites Location…….8
Figure 3. Sampling Sites Location for background stream and agricultural runoff ditch water quality analysis. ……9
Figure 4. Inlets and Outlet Location of wetland FW. ……10
Figure 5. Inlets and Outlet Location of wetland BP……11
Figure 6. Event Inflow Volume and Precipitation.……15
Figure 7. EMC for TSS for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect…..20
Figure 8. EMC for NH4 for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect. …..21
Figure 9. EMC for TDN for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect. …..22
Figure 10. EMC for NO3 for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect. …..23
Figure 11. EMC for DOC for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect. …..24
Figure 12. Wetland Percentage EMC Reduction vs. Inflow Load…..26
Figure 13. Box and Whisker plots showing site comparison of annual average pollutant concentration 2005-2011…….30
Figure 14. Pollutant Mean Concentration for the Annual Monthly Trend 2005-2011…..32
Figure 15. Variations in the mean yearly concentration for TSS and BOD. Graph represents sites showing a significant ($P<0.05$) change in pollutant concentration, except for BOD…..34
Figure 16. Variations in the mean yearly concentration for TDN, NO3, and TP. Graphs represent sites that exhibited a significant ($P<0.05$) change in pollutant concentration, except for BOD. .35
Figure 17. The location of the LRAEU and the delineation of the contributing areas for the constructed wetlands…..46
Figure 18. CLCs Curve Zone (Bertrand-Krajewski et al., 1998) ……..49
Figure 19. CLCs of Rainfall Events for Pollutants and Metals …..55
Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP. …..59
Figure 21. Box Whisker Plot of First Flush Coefficient Comparison Collected from FW15, FW24 and BP…..65
Figure 22. Box Plot of the First Flush Coefficient of TSS Site Comparison of FW and BP. …...66
Figure 23. TSS First Flush Coefficient vs Storm Event Parameters ……70
Figure 24. NO3 First Flush Coefficient vs Storm Event Parameters……..72
Figure 25. Correlation of Pollutant Attenuation Percentage vs. First-flush Coefficient Value…74

INTRODUCTION

The United States Environmental Protection Agency (USEPA) reports that over 40% of waters nationwide are affected by non-point source pollution (NPS) (Díaz et al., 2012). Runoff generated from agricultural land often contains fertilizers, pesticides, and animal wastes from livestock operations and has become one of the major sources for sediment and nutrients (nitrogen (N), phosphorus (P)) in US surface waters (USEPA, 2012).

Agricultural runoff has been shown to cause harmful algal blooms and ecological degradation in coastal estuaries and water sources. Several studies have shown that agricultural runoff has directly contributed to degradation in the Mississippi River Basin, Lake Erie, and Chesapeake Bay. The Mississippi River basin contains the largest and most intensively farmed region in the Nation (Larson et al., 1995), including approximately 65 percent of the total harvested cropland in the nation, producing about 80 percent of the corn and soybeans, and much of the cotton, rice, sorghum, and wheat supply (USDA, 1987). As early as 1991, an estimated 5.5 million metric tons of nitrogen fertilizer were applied to croplands in the Mississippi River Basin. It is estimated that approximately two-thirds of all pesticides used for agriculture in the United States are applied to cropland and pasture land in the Mississippi River Basin (Gianessi & Puffer, 1991). These fertilizers and pesticides may contribute to pollution of the surface waters in the Mississippi River Basin (Mitsch et al., 2001; Moore et al., 2001). According to Mitch et al., these additional pollutant loads can be addressed through the use of riparian zones and wetland best management practices (BMPs) (Mitsch et al., 2001).

The effect of agricultural runoff has also been noticed in water bodies like Lake Erie (Richards et al., 2002). These effects were so noticeable that Lake Erie was referred to as the "dead lake" in the 1960's and 1970's (Richards et al., 2002). It has been shown that trends in agricultural practices are consistent with phosphorus loading, which has resulted in harmful algal blooms and hypoxia (Michalak et al., 2013). Excessive nutrient loading has also led to eutrophication in Chesapeake Bay (Boesch et al., 2001; Fisher & Oppenheimer, 1991; Jordan et al., 1997; Pionke et al., 2000). This nutrient load is largely a result of agricultural runoff from both crop and grazed pasture lands in the surrounding area (Boesch et al., 2001; Jordan et al., 1997; Pionke et al., 2000).

Different than municipal point source and industry wastewater, agricultural NPS pollution is not readily identifiable. Agricultural runoff is difficult to characterize due to the variety of agricultural practices. These practices may also vary with geographic location (Chambers et al., 1993). As a result, agricultural NPS can require technically complex management. In order to prevent and control agricultural NPS, specific programs – including cost-share implementation, technical assistance, and economic incentives – were funded by the U.S. Department of Agriculture and state governments (USEPA, 2003; USEPA, 2005; Osmond et al., 2012)

As NPS agricultural runoff is recognized as a significant contributor to surface water pollution and is being addressed through federal government programs, it is important that NPS agricultural runoff is well understood. Once the nature of the variables affecting agricultural runoff pollution transport are better understood, it is then important to evaluate the efficacy of using best management practices (BMPs).

This research sought to address each of these components. Chapter 1 evaluated the use of constructed wetlands as a BMP for agricultural runoff pollutant attenuation. The studies performed in Chapter 2 reflects exploratory analysis to identify the first flush phenomena in an agricultural system in East Tennessee.

CHAPTER 1. PERFORMANCE EVALUATION OF EVENT SCHALE NPS POLLUTANT ATTENUATION IN INTEGRATED CONSTRUCTED WETLANDS FOR TREATMENT OF AGRICULTURAL RUNOFF IN EAST TENNESSEE

Abstract

Non-point source (NPS) pollution affects 40% of waters nationwide, causing more harm to surface water systems when compared to other pollutant point sources. Treatment wetlands are engineered systems, designed to simulate water storage capacity and water quality improvement functions of natural wetlands. This research is composed of two parts. The first component of this research evaluated the constructed wetland performance for receiving agricultural runoff. The second component involves determining the baseline water chemistry for two streams and an agricultural runoff ditch. By sampling these sites, it was possible to determine how land management influenced water quality in nearby streams. It was also possible to determine how conversion from row crops to dairy operation would influence water quality in nearby streams. The objective of this study was to 1) quantify the performance of two constructed treatment wetlands in terms of event-scale runoff sediment and nutrient attenuation, and 2) identify local climatic and watershed characteristics that may influence performance, 3) quantify the effect that farm operation and land management has on agricultural runoff and surface streams. For wetland performance evaluation, a total of 11 storm event runoff samples were collected from wetland FW and wetland BP, from August 2012 to February 2014. For baseline water chemistry analyses, samples collected from nine different sites, located at the Little River Animal and Environmental Unit (LRAEU), from May 2005 to April 2016. Wetland water samples were analyzed for Total Suspended Solids (TSS), Ammonia (NH_4), Nitrite (NO_3), Phosphate(PO_4), Total Dissolved Nitrogen (TDN), Dissolved Organic Carbon (DOC), and Total Phosphorus (TP). Baseline water chemistry samples were analyzed for TSS, biochemical oxygen demand (BOD), NO_3, NH_4, TDN, and TP. The results of this research indicate that: 1) constructed wetlands show significant event-scale attenuation of TSS and ammonia; and 2) TSS attenuation is positively correlated with inflow pollutant loads while PO_4 attenuation is negatively correlated with inflow pollutant loads; 3) dairy farmyard runoff at the study site carried excess loads of pollutants as compared to baseline conditions before dairy construction.

Introduction

The United States Environmental protection Agency (USEPA) reports that over 40% of waters nationwide are affected by non-point sources pollutant (NPS) (Díaz et al., 2012). NPS pollution causes more harm to surface water systems, comparing with discharge from wastewater treatment systems and other point sources (Lu et al., 2009). Runoff generated from agricultural land – containing fertilizers, pesticides from croplands, and animal wastes from livestock operations – have become one of the major sources for sediment and nutrients (nitrogen (N), phosphorus (P)) in US surface water (USEPA, 2012).

Based on its NPS pollution characteristics, historical best management practices (BMPs) were designed to reduce the impacts of agricultural contaminants on water quality. Many of these BMPs used aerobic and anaerobic methods. Lagoons and storage ponds are a technically feasible method to remove N and P from agricultural and livestock farm runoff (Bicudo et al., 1999; Cooke et al., 2011; Lovanh et al., 2009; Lundquist et al., 2011; Miller et al., 2011). Treatment wetlands are engineered systems, designed to simulate water storage capacity and water quality improvement functions of natural wetlands. Treatment wetlands receive and store excess water, while removing water pollutants, thus decreasing hydrologic and nutrient loadings to streams, lakes, and groundwater (Dierberg et al., 2002; Kadlec, 1995; Nichols, 1983; Poe et al., 2003). Treatment wetlands are particularly effective tools in removing NPS pollution from agricultural runoff. This removal is accomplished by providing a wide range of hydraulic load, internal water storage capacity, and contaminants removal capability, through physical, chemical, and biological activities (Higgins et al., 1993; Kovacic et al., 2000; Locke et al., 2011; Moore et al., 2000; Uusi-Kämppä et al., 2000).

When evaluating the efficacy of constructed wetlands, there are inherent difficulties. In particular, there is inconsistency amongst storms. Where wastewater treatment plant wetlands may have a relatively consistent flow, stormwater wetland flow is based on the storm characteristics (intensity, duration).

The objectives of this research were to 1) quantify the performance of two wetlands in terms of event-scale runoff sediment reduction and nutrient attenuation, and 2) identify if any relationship exists between wetland attenuation performance and inflow pollutant loads.

Site Description

Wetland Performance Evaluation Sites

There were two wetlands, front wetland (FW) and back patch (BP) located in LRAEU. The wetland FW (3962097.99m N, 242763.54m E) had a surface area of 0.8 acres, and received agricultural drainage from 70 acres crop field. The vegetation composition of wetland FW was obligate wetland emergent. Two inlets, a 38-centimeter headwall inlet (FW15) and a 61-centimeter headwall inlet (FW24), drained agricultural runoff separately from west side and south side of crop field. Each stemmed from drainage pipes.

The wetland BP (3961708.01m N, 243416.44m E) had approximately 1.2 acres of surface area and captured runoff from 15 acres drainage field. The area draining into wetland BP was composed of cattle path, grass pasture, wooded buffer, and dairy operation areas. The vegetation composition of wetland BP was mixed obligate wetland emergent and cool season grass (Fescue). Wetland BP was fed through a natural wet-weather conveyance, with a 30-centimeter, 120-degree v-notch weir inlet. The locations of Wetland FW and BP are described in Figure 1. The green colored area reflects the area draining to wetland FW, while the yellow area delineates the area draining to wetland BP.

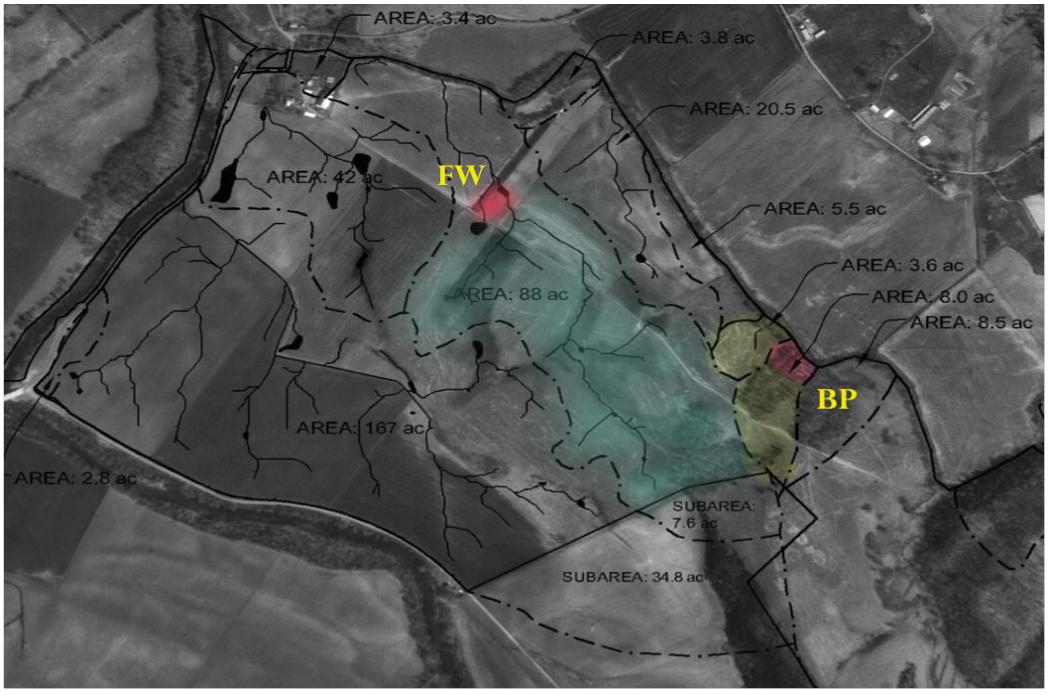


Figure 1. Location and Contributing Area of Front Wetland (FW) and Back Patch (BP).

Baseline Sampling Sites

The research site was located at the Little River Animal and Environmental Unit (LRAEU), and collected runoff from a total area of 300 acres used for crop farmland and over 200 acres used for dairy production and management. In order to better understand how crop farming and dairy operations influence local stream water quality, water samples from nine sampling stations were collected from 2005 to 2016. By collecting data for five years, including before and after conversion from crop land to dairy production, it is possible to better understand how changes in land use influences the NPS pollutant impact on surface streams. These data also served to provide background information as to the NPS pollutant runoff quality, thus allowing for wetland BMPs to be evaluated for their efficacy in treating agricultural NPS runoff.

The sampling site locations are depicted as blue dots in Figure 2. The dashed lines outline the contributing drainage areas for each site. Two surface streams are mapped with the continuous black line in Figure 2. The northern stream is Ellejoy Creek, while the southern stream is Little River. Background sampling sites were located in the upper stream of Little River (LR1) and Ellejoy Creek (EJ1). Water sampled in these sites were not influenced by the fertilizer, or other farm operation. A sampling station was positioned on the upper and lower portion (WL1 and WL2, respectively) of a stream originating on the farm, uninfluenced by the farm drainage areas.

This farm stream discharges into Ellejoy Creek, below WL2 and EJ1. The back-pasture wetland (BP) discharges to Ellejoy Creek, below EJ1. The front wetland (FW) discharges into a grassed waterway (DF), flowing through a combination 15.25-cm and 22.9-cm fiberglass Parshall flume before discharging into Ellejoy Creek. Samples were collected from these flumes at the DF site, and reflects agricultural runoff, as well as treated runoff from wetland FW. By collecting samples from the inlets and outlets of wetland BP and FW, it was also possible to determine the wetland BMP performance, as characterized by farm-scale NPS runoff pollutant attenuation.

EJ2 is located at the end of Ellejoy Creek, upstream of the confluence where it discharges into Little River. The center ditch stations (D1 and D2) monitored the water coming from the row crop land. D2 represented approximately 250-300 acres of the crop farm, plus the crop land on the Pate Farm to the south. This area drains to the wetland FW. A satellite image of the sampling locations can be found in Figure 3, below.



Figure 2. Contributing Area of Little River Dairy Farm Watershed and Sampling Sites Location.



Figure 3. Sampling Sites Location for background stream and agricultural runoff ditch water quality analysis.

Methods

Sampling Protocols and Lab Analysis

Flow-weighted composite water samples were collected using an ISCO model 3700 auto-sampler (Teledyne Inc., NE) installed on the inlets and outlets of wetland FW and BP. At the FW inlet, auto samplers were triggered to begin sampling at first detection of water level measured by an ultrasonic sensor (Magnetrol EchoTel model 355, Cincinnati, OH). A CR800 datalogger (Campbell Scientific Inc., UT) was programmed to compute output flow rate and volume using Manning's Equation flow through concrete culverts. The outlet discharge stage of wetland FW were measured through a combination 15.25 cm and 22.9 cm fiberglass Parshall flume. After flow stage reached 15.25 cm, the ISCO auto-sampler was triggered to collect composite samples into 24 one-liter bottles. The smaller flume was set above the floor of the larger flume. As a result, this 15.25 cm trigger point reflects the point at which flow would pass through both flumes, and thus reflect discharge from the outlet. A CR800 datalogger was connected with a

TFLI water level sensor (Yoder et al., 1999) in outlet of wetland FW to obtain discharge flow data, including flow rate and volume. For wetland BP, both inlet and outlet water stage were measured by a TFLI (Yoder et al., 1999) water level sensor. This sensor was installed on a stainless steel 30-cm 120-degree v-notch weir. Dataloggers were programmed to compute output flow rate and volume using Triangular Weir (V-Notch Weir) Equations. The auto samplers collected a sample after a specific volume of water, called the "set volume," passed the sample location. The FW15 inlet set volume was 7 m^3 while the FW24 inlet set volume was 37 m^3. The FW outlet set volume was 41 m^3. Both the BP inlet and outlet set volumes were 11.5 m^3. Sampling locations for Wetland FW and Wetland BP can be found in Figure 4 and Figure 5, respectively. Water samples were collected from a total of 15 storm events, from August 2012 to April 2014. Events were selected based on a duration greater than six hours, and a precipitation depth of at least 1.4 centimeters. Precipitation events with les than 1.4 centimeters of depth did not result in runoff inflow.



Figure 4. Inlets and Outlet Location of wetland FW.



Figure 5. Inlets and Outlet Location of wetland BP.

For baseline water quality analysis, water samples were collected by ISCO samplers installed at 9 sampling sites from May 2005 to January 2011, before construction of the new dairy operation, to establish a baseline water quality record. Sampling was continued through February 2016, so as to evaluate how the change in land use influences NPS runoff water quality, and to evaluate the efficacy of wetland BMPs in treating agricultural NPS runoff pollutants.

The pollutant concentrations were analyzed using EPA standard analysis methods (APHA, 2005), in the Biosystems Engineering & Soil Science Water Quality Lab at the University of Tennessee. Specific analyses, methods, and instrumentation are listed in Table 1.

Table 1. Water Chemistry Lab analyses prepared and performed in the BESS-WQ Lab.

Constituents	Analytical Methods	Instrument
NO_3, NH_4, PO_4	Chromatography Methods	Dionex-100 Ion
TP	Spectrophotometric methods	Skalar
DOC, Total Dissolved Nitrogen	Combustion method	Shimadzu
TSS	Standard Filter Methods	TSS Filtration Apparatus

Pollutant Attenuation

Event-scale pollutant attenuation performance was quantified as the percentage mass reduction (PMR), as was consistent with previous research (Kadlec 2009). PMR was calculated by taking the difference in total pollutant load between inflow and outflow, and dividing it by total inflow pollutant load. Another method to quantify wetland efficiency was to compare the mean pollutant concentration difference between influent and effluent. The average inlet/outlet concentrations from each event were represented as event mean concentration (EMC). The EMC was calculated by taking the mass of pollutant transported during the event divided by total flow during the event.

$$\text{PMR} = \frac{\sum Q_i C_i - \sum Q_0 C_0}{Q_i C_i} * 100$$

Where Q_i - Inlet Flow Rate (L^3/T)

Q_o - Outlet Flow Rate (L^3/T)

C_i - Inlet Mass Concentration (M/L^3)

C_o – Outlet Mass Concentration (M/L^3)

$$\text{Influent EMC} = \frac{\sum Q_i C_i}{Q_i}, \text{ Effluent EMC} = \frac{\sum Q_o C_o}{Q_o}$$

Where Q_i - Inlet Flow Rate (L^3/T)

Q_o - Outlet Flow Rate (L^3/T)

C_i - Inlet Mass Concentration (M/L^3)

C_o – Outlet Mass Concentration (M/L^3)

Statistical Analysis

The statistical analysis was performed by StatPlus® 5.9 software for Mac. A Paired Two-Sample T-Test was used to identify if there was a statistically significant difference. The analysis assumed unequal variance. Data was evaluated to determine: 1) variation in EMC between influent and effluent for FW and BP wetlands, 2) variation in pollutant attenuation performance between wetland FW and BP; and 3) variation in baseline water quality before and after farm construction. Variation for EMC was quantified for multiple pollutants and was used to evaluate event scale performance for each wetland.

Results and Discussion

Event Scale Stormwater Pollutant Attenuation of Wetland FW and BP

From August 2012 through February 2014, there were 15 total storm events sampled at wetlands FW and BP. Daily precipitation data from September 2012 to February 2014 was also recorded to compare the seasonal hydrologic variation for each of the two wetlands. Table 2 shows the event inflow data, while Figure 6 shows a comparison of the event inflow volumes and precipitation data for the two wetlands over time.

Table 2. Storm event data and runoff inflow volume.

Storm number	Date	Number of Bottles Collected		Event Inflow Volume (L)	Storm Event Begins	Precipitation (mm)	Duration (hrs)	Average Intensity (mm/hr)
1	8/5/2012	FW	Not Constructed	Not Constructed	Rain Gauge Not Installed			
		BP	24	Not Available				
2	8/9/2012	FW	Not Constructed	Not Constructed				
		BP	9	242,700				
3	8/10/2012	FW	Not Constructed	Not Constructed				
		BP	6	158,000				
4	9/18/2012	FW	23	5,144,400	9/17/2012	104.65	26	4.03
		BP	24	1,914,000				
5	12/16/2012	FW	7	1,065,300	12/10/2012	43.69	32	1.37
		BP	10	530,100				
6	12/20/2012	FW	6	939,300	12/20/2012	15.24	6	2.54
		BP	7	376,100				
7	12/24/2012	FW	32	4,753,700	12/24/2012	71.88	59	1.22
		BP	NC	NC				
8	1/30/2013	FW	24	4,122,300	1/30/2013	39.62	10	3.96
		BP	24	1,624,600				
9	4/19/2013	FW	29	1,701,100	4/19/2013	23.37	6	3.90
		BP	8	406,400				
10	8/10/2013	FW	17	296,600	8/8/2013	33.78	9	3.75
		BP	NC	NC				
11	9/26/2013	FW	11	312,200	9/25/2013	14.47	26	0.56
		BP	NC	NC				
12	11/26/2013	FW	24	308,300	11/18/2013	21.34	22	0.97
		BP	NC	NC				
13	12/6/2013	FW	48	5,097,700	12/5/2013	25.15	28	0.90
		BP	24	1,450,600				
14	12/11/2013	FW	NC	NC	12/11/2013	63.75	54	1.18
		BP	13	757,200				
15	2/21/2014	FW	NC	NC	2/21/2014	64.77	44	1.47
		BP	24	1,237,000				

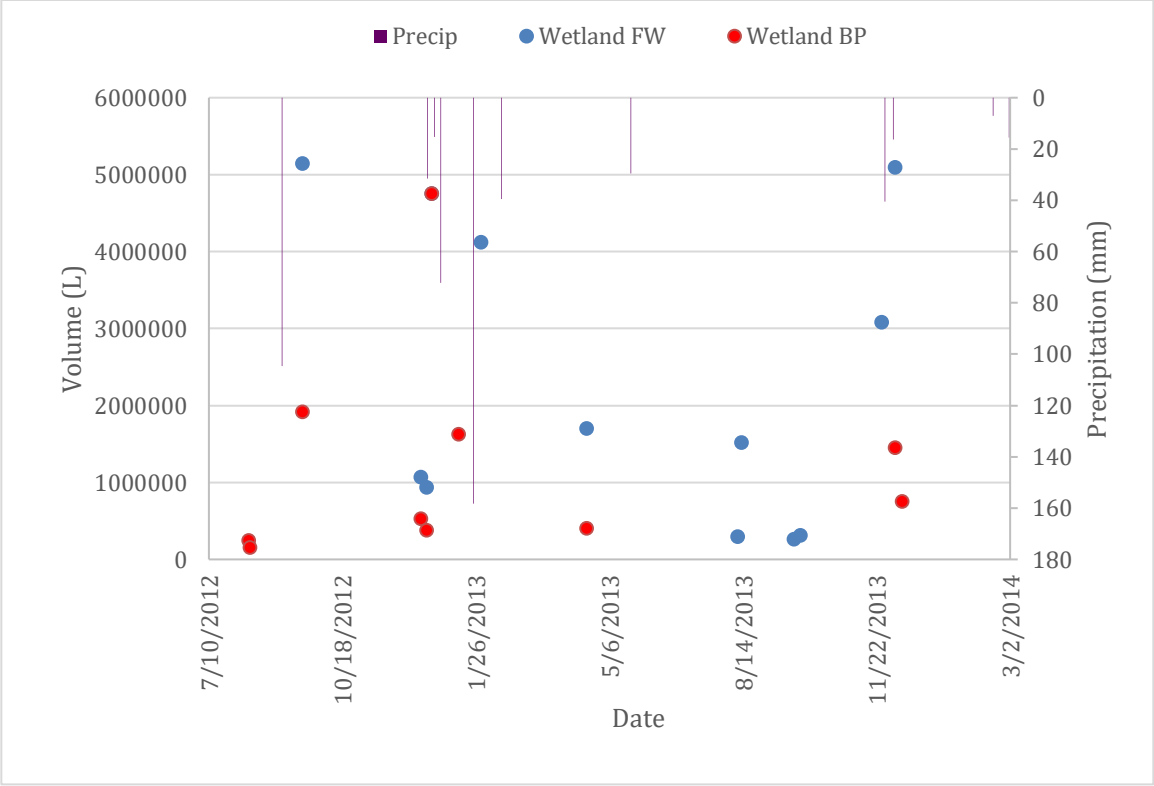


Figure 6. Event Inflow Volume and Precipitation.

The wetland inflow volumes ranged from a low of $1.58*10^5$L in the BP wetland during the month of August and a high of $5.14*10^6$ L in the FW wetland during the month of September. The average inflow volume of wetland FW was $2.36*10^6$ L, and the average inflow volume of wetland BP was $0.87*10^6$ L. This discrepancy in seasonal variation may also be explained by variations with the inlet structures. Because the wet-weather conveyance is natural, it is possible that additional groundwater infiltration influenced the seasonal variation. Table 3 and 4 show the percentage of pollutant loads attenuated and percent EMC reduction, respectively, for each storm event.

In this research, the average outlet TSS EMC for both wetland FW and BP was significantly lower than inlet concentration ($P<0.01$). This information can be seen in Figure 7. For wetland FW, the highest inlet EMC occurred in the winter season. This can be explained by reduced canopy cover after crop harvest, combined with land disturbances from harvest/tillage operations, and other land management practices in the drainage area. Except for the first storm event after construction, the respective inlet and outlet EMC variance was significantly less than for wetland BP. This consistency in inlet and outlet EMC is likely due to the consistency in dairy farm operations.

It should be noted that, for Wetland FW, TSS samples were not collected during the storm event on December 20th, 2012. The Wetland BP site did not collect samples for April 19th, 2013 and February 21st, 2014. These events are listed as "DNC".

Ammonia is another target of runoff pollutant attenuation in agricultural systems. As illustrated in Figure 8, the average removal efficiency for wetland FW and BP were 31% and 50%, respectively. There was a statistically significant EMC decrease in inlet ammonia EMC ($P<0.01$), suggesting that nitrification proceeded well in both wetlands.

It should be noted that, for Wetland FW, NH_4 samples were not collected during the storm event on September 26th, 2013. Wetland FW site did not collect samples for February 21st, 2014. The Wetland BP site did not collect samples for August 8th, August 9th, or April 19th of 2013. These events are listed as "DNC".

Table 3. Percentage Pollutant Mass Attenuation by Wetlands FW and BP at an East Tennessee dairy farm. NC – data Not Collected. Pollutant removal in white, pollutant export shaded gray.

Wetland FW

Event Date	TSS	NH_4	NO_3	PO_4	TDN	DOC	TP
9/18/12	23.62	-57.54	77.45	61.66	79.21	64.40	87.01
12/16/12	-14.35	58.79	-99.07	-45.30	-7.67	-41.53	NC
12/20/12	NC	0.98	-123.8	-101.0	-117.52	-139.7	NC
12/24/12	8.17	-15.09	28.43	NC	-11.27	-37.35	NC
1/30/13	24.25	21.76	21.98	-38.23	-1.65	-6.20	NC
4/19/13	32.04	74.65	64.45	67.24	72.62	40.26	NC
8/10/13	-20.40	47.01	-328.1	66.83	-386.17	NC	NC
9/21/13	-310.3	70.71	-26.81	-61.29	-1175.1	NC	NC
9/26/13	-94.03	NC	NC	NC	NC	NC	NC
11/26/13	-49.18	-17.04	-82.15	-63.91	-67.58	-52.65	NC
12/6/13	-16.30	68.89	-24.04	-44.68	-14.91	NC	NC

Wetland BP

8/5/12	82.42	88.09	80.57	23.42	NC	-187.8	NC
8/9/12	90.05	NC	NC	NC	NC	NC	NC
8/10/12	96.63	NC	NC	NC	NC	NC	NC
9/18/12	95.45	26.32	33.39	29.66	46.93	45.83	66.75
12/16/12	93.13	98.11	74.78	75.24	82.57	62.81	NC
12/20/12	NC	24.24	2.78	22.84	-15.49	-49.34	NC
1/30/13	8.17	-15.09	28.43	NC	-11.27	-37.35	NC
4/19/13	75.03	-13.25	-12.78	-12.08	-12.53	-12.93	NC
12/6/13	92.65	79.31	38.87	17.39	NC	NC	NC
12/11/13	76.07	48.54	71.70	-71.38	37.54	-0.49	NC
2/21/14	NC	NC	NC	-59.36	-91.62	-64.03	NC

Table 4. Percent EMC Reduction for Different Pollutant Concentrations in Wetland FW and BP. NC – data Not Collected. Pollutant removal in white, pollutant export shaded gray.

Wetland FW

Event Date	TSS	NH_4	NO_3	PO_4	TDN	DOC	TP
9/18/12	4.04	-97.93	71.67	51.83	73.88	55.28	83.69
12/16/12	42.77	79.38	0.36	27.28	46.11	29.16	NC
12/20/12	NC	55.74	-0.06	10.15	2.77	-7.16	NC
12/24/12	17.90	-13.79	37.16	NC	-3.58	-36.73	NC
1/30/13	42.25	40.35	40.52	-5.38	22.50	19.03	NC
4/19/13	2.59	63.67	49.04	53.05	60.75	14.37	NC
8/10/13	68.25	86.03	-12.87	91.25	-28.19	NC	NC
9/21/13	-29.42	90.76	59.99	49.12	-302.27	NC	NC
9/26/13	26.62	NC	NC	NC	NC	NC	NC
11/26/13	19.77	32.32	5.79	5.37	11.27	NC	NC
12/6/13	-14.63	69.34	-22.26	-42.60	-13.26	NC	NC

Wetland BP

8/5/12	65.21	76.44	61.55	-51.55	NC	-469.58	NC
8/9/12	82.54	NC	NC	NC	NC	NC	NC
8/10/12	94.81	NC	NC	NC	NC	NC	NC
9/18/12	92.50	-21.52	-9.88	-16.01	12.46	10.65	45.15
12/16/12	81.00	94.79	30.30	31.55	51.82	-2.79	NC
12/20/12	22.05	-0.02	20.61	-18.82	-53.65	NC	-71.41
1/30/13	17.90	-13.79	37.16	NC	-3.58	-36.73	NC
4/19/13	77.84	-0.49	-0.07	0.55	0.16	-0.21	NC
12/6/13	92.59	79.15	38.40	16.75	NC	NC	NC
12/11/13	70.25	36.03	64.82	-113.03	22.36	-24.91	NC
2/21/14	NC	NC	NC	-42.52	70.62	-26.12	NC

The high inlet EMC for ammonia for wetland FW is likely a result of crop farm fertilization. For wetland BP, the inlet ammonia is most likely generated from manure from the dairy operation. Ammonia concentrations appeared to have greater correlation with farm management operation, as opposed to seasonal trend. Figure 9, representing the EMC for TDN, did not show any significant results.

It should be noted that, for Wetland FW, TDN samples were not collected during the storm event on September 26th, 2013. The Wetland BP site did not collect samples for August 8th, August 9th, April 19th, or December 6th of 2013. These events are listed as "DNC".

Nitrate removal, illustrated in Figure 10, was not efficient in wetland FW. This suggests that denitrification was limited in wetland FW. The negative nitrate attenuation occurred mostly in summer. This is likely due to rich aerobic conditions in the wetland from vegetation photosynthesis activities. Wetland BP has relatively higher nitrate attenuation, which could be influenced by microbial activity, but did not significant reduction.

It should be noted that, for Wetland FW, NO_3 samples were not collected during the storm event on September 26th, 2013. The Wetland BP site did not collect samples for August 8th, August 9th, April 19th, or December 6th of 2013. Wetland BP site did not collect samples for February 21st, 2014. These events are listed as "DNC".

Both wetland FW and BP showed negative performance in DOC attenuation, as noted in Figure 11. One possible explanation is that DOC removal is also correlated with denitrification activity. Photosynthesis activity from wetland vegetation results in well oxygenated water, thus limiting the denitrification. Because the wetlands do have vegetation growing in and around them, organic carbon content from vegetative residue will also contribute to DOC concentrations.

It should be noted that, for Wetland FW, DOC samples were not collected during the storm event on September 26th, 2013. No DOC was detected in samples collected in August, September 21st, and December of 2013. The Wetland BP site did not collect samples for August 8th, August 9th, April 19th, or December 6th of 2013. These events are listed as "DNC".

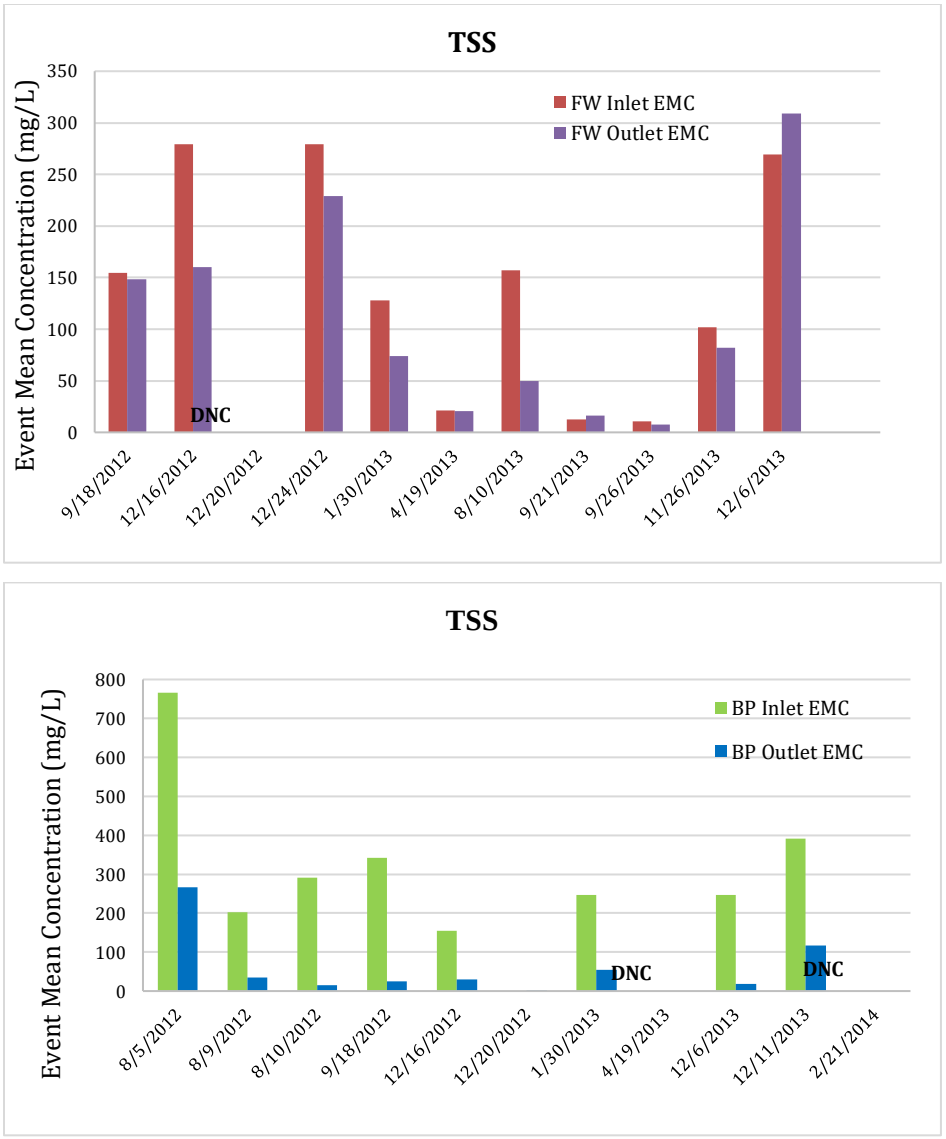


Figure 7. EMC for TSS for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect.

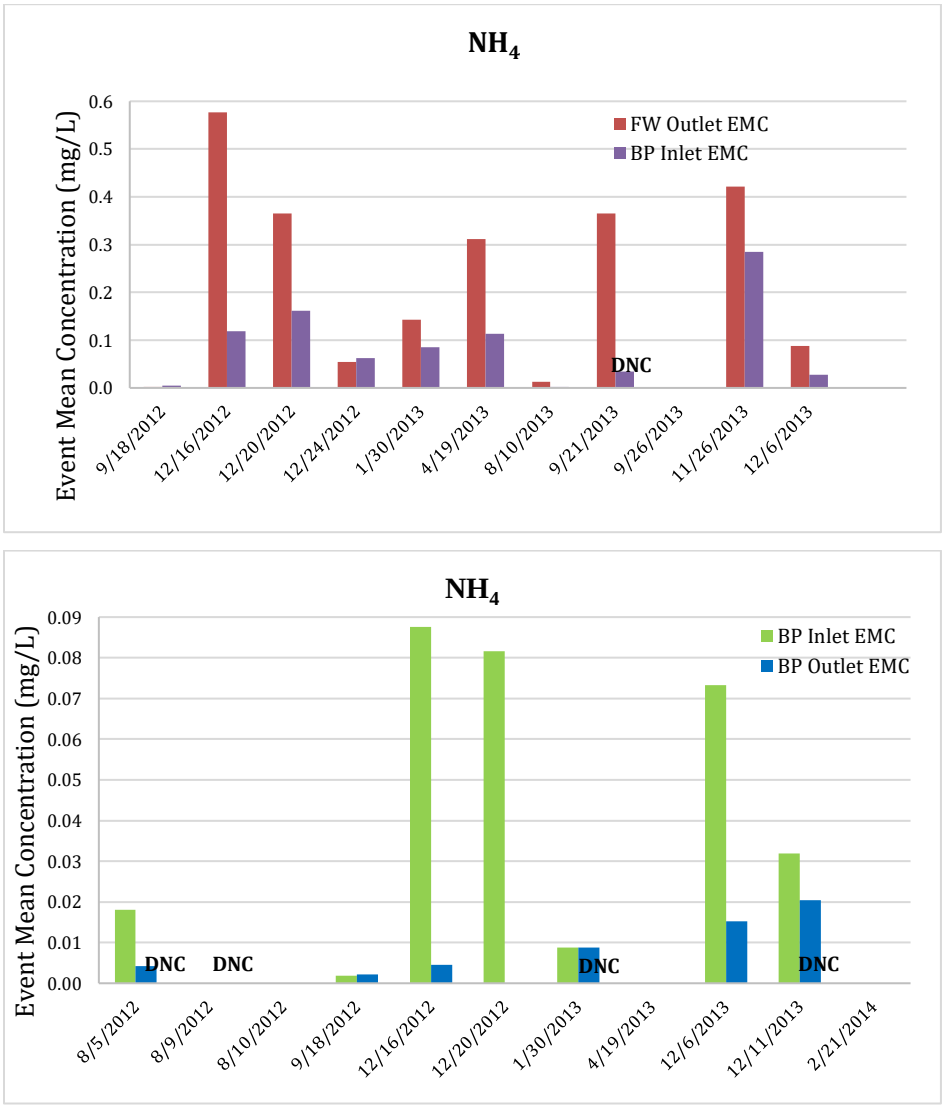


Figure 8. EMC for NH_4 for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect.

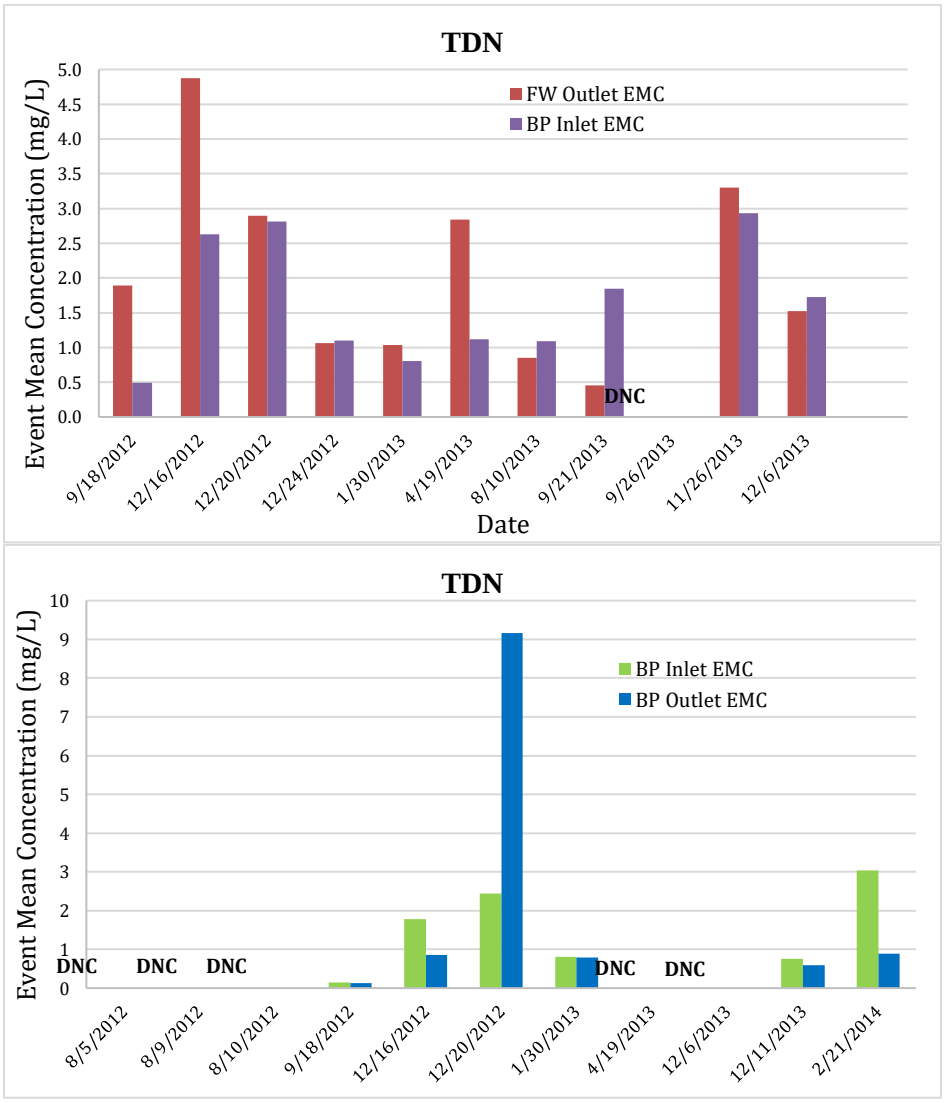


Figure 9. EMC for TDN for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect.

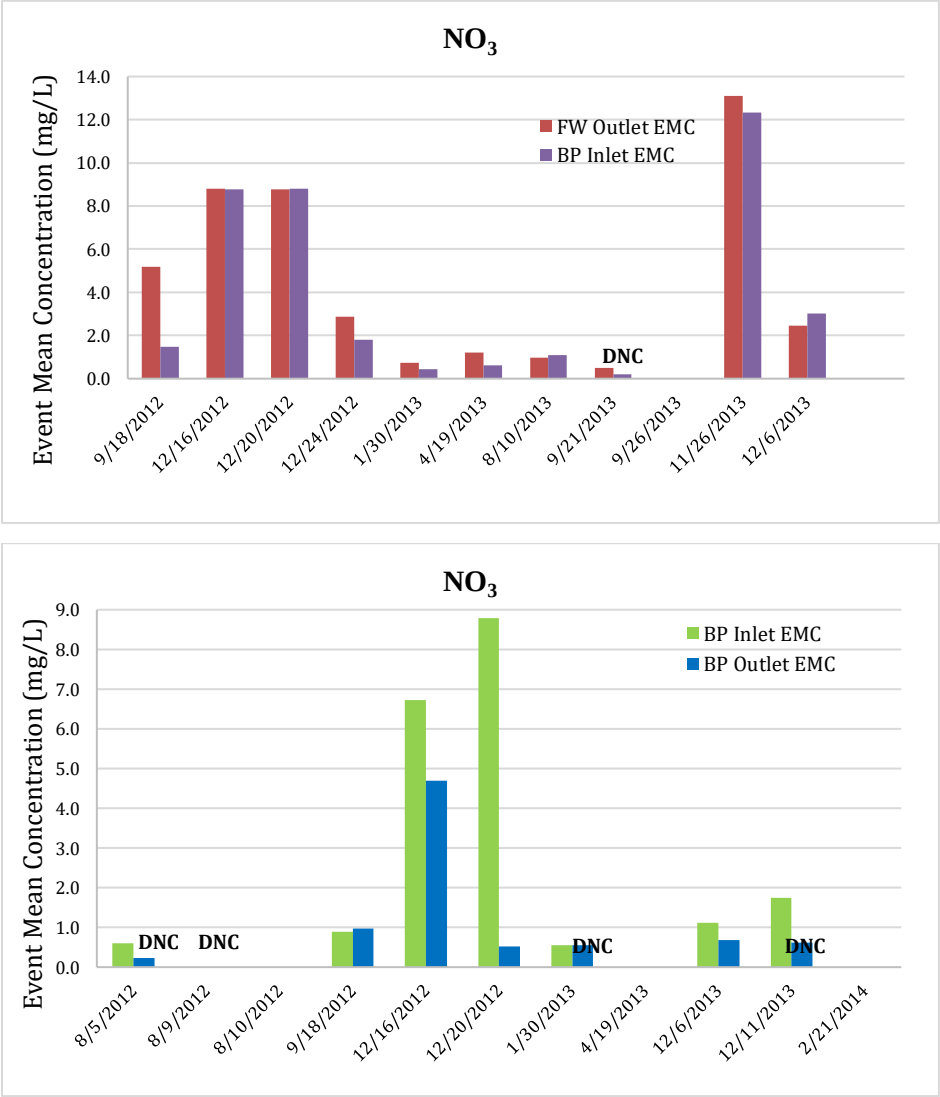


Figure 10. EMC for NO_3 for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect.

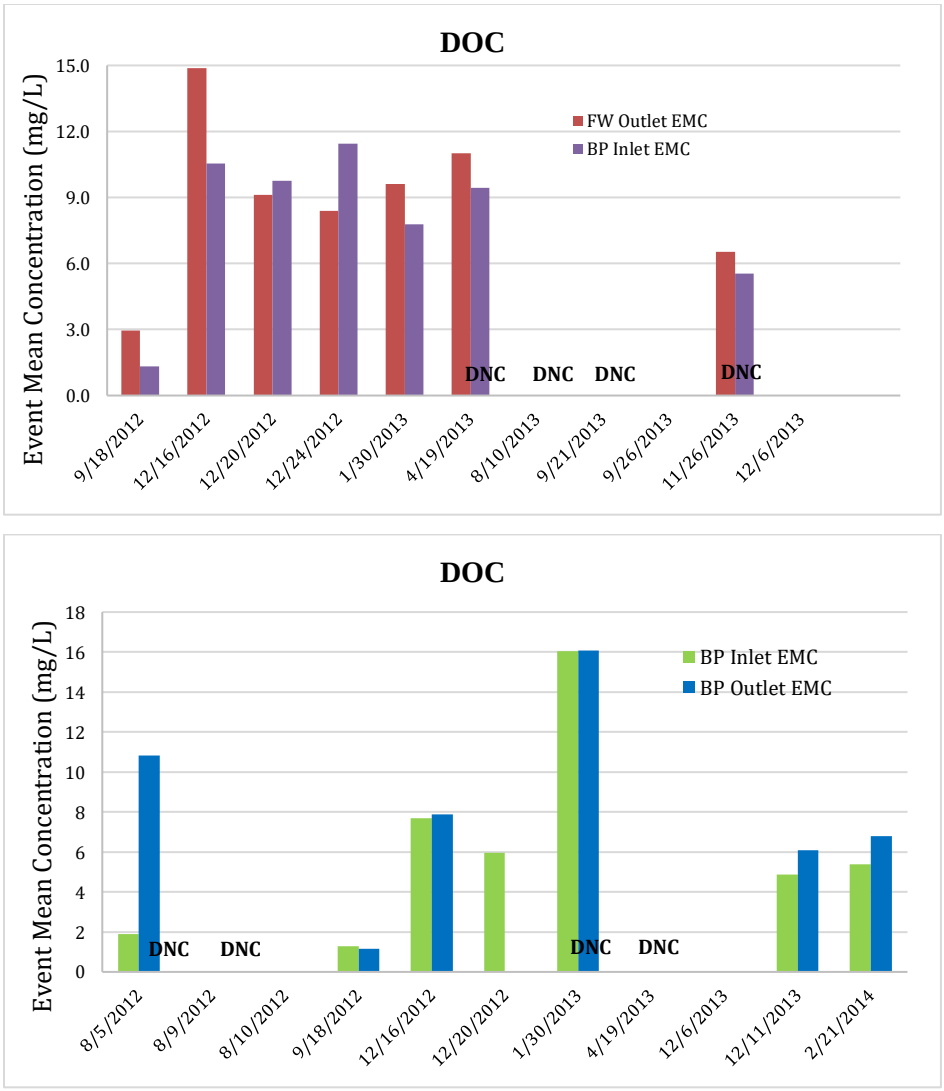


Figure 11. EMC for DOC for Wetland FW and BP. "DNC" indicates that a sample Did Not Collect.

Parameters Influencing Stormwater Treatment Wetland Performance

As shown in Figure 12, TSS showed a positive linear relationship between inflow pollutant load and percent EMC attenuation. The dominant mechanism for TSS attenuation is gravitational settling of particles, and the filtration of solids through vegetative mass in the wetland flow path. As the vegetative mass filters the TSS, and more of the TSS is settled out, it is to be expected that less TSS will be able to pass through the wetland. Because this is a physical process, TSS attenuation was not correlated with seasonal trends or microbial activity.

As illustrated in Figure 12, there was no linear correlation detected, between the EMC percent attenuation and the inflow load of NH_4, NO_3, or TDN. The removal mechanism for soluble nitrogen is a combination of vegetative uptake and microbial activity. Due to the complexity of these biochemical processes, it is difficult to properly evaluate how much nitrogen was attenuated, and how much was simply converted into a different form. This complexity is compounded by the fact that these biochemical reactions can vary, depending on changes (microbial community, climate changes, land use changes, etc.) before and during precipitation events.

For DOC and soluble phosphorus attenuation, shown in Figure 12, the EMC percentage reduction showed a slightly negative correlation with inflow pollutant load. Soluble phosphorus removal is achieved via wetland substrate absorption and vegetative uptake. It is possible that the negative correlation is due to the wetland substrate reaching the absorption capacity. Other studies have also suggested that physical characteristics of the event flow through the wetland may inhibit physical and chemical retention processes (Nairn & Mitsch, 1999).

PO_4 is a byproduct of many fertilizers and manure, and is readily dissolved in water, thus making it a parameter of interest. Because the PO4 is soluble, it is possible that the negative EMC reduction is a result of groundwater infiltration.

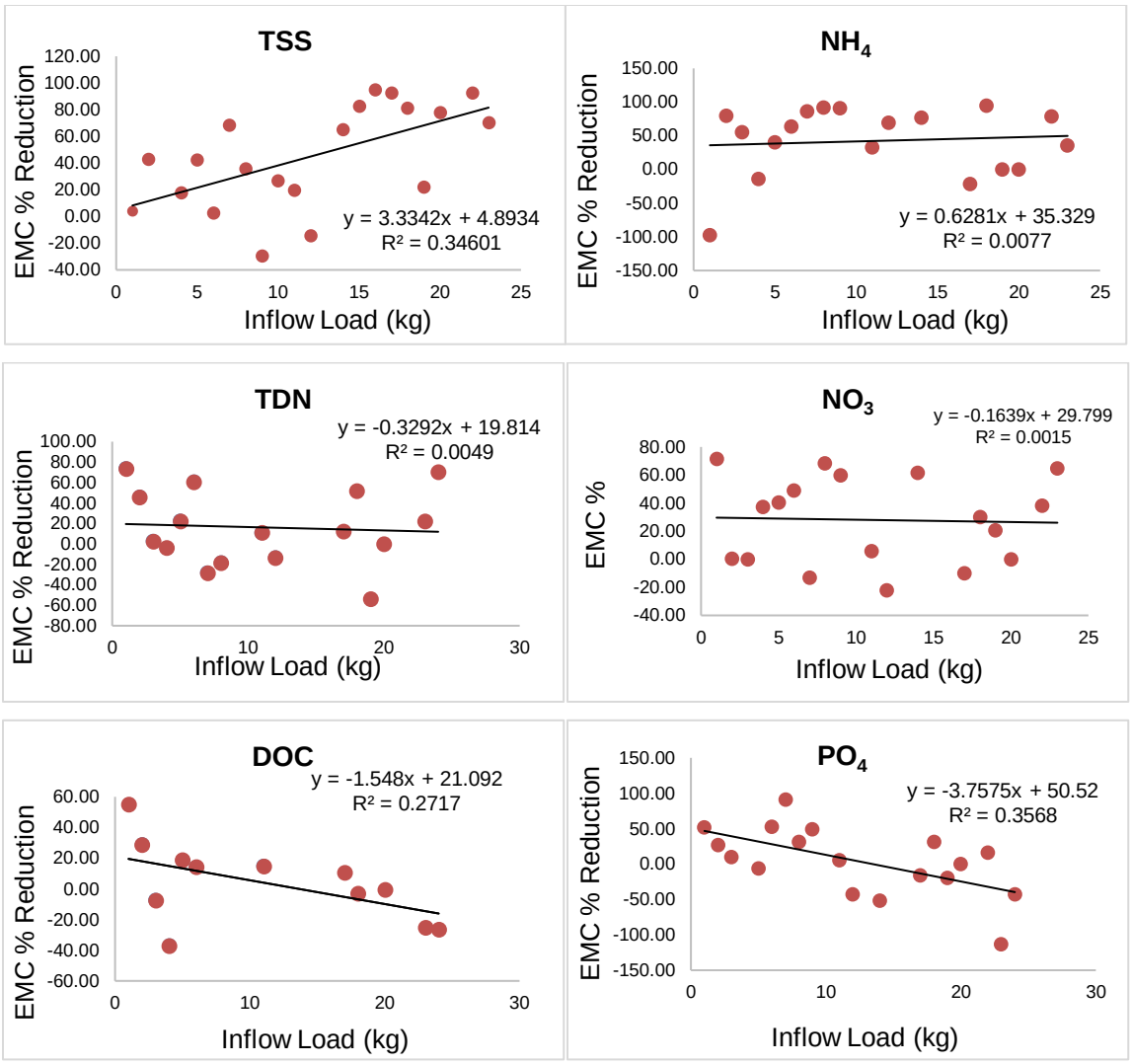


Figure 12. Wetland Percentage EMC Reduction vs. Inflow Load

The percent EMC reduction and inflow load were compared for wetland BP. Because wetland FW had two inlets, with one outlet, it was not used for this comparison. The Pearson correlation coefficients for these comparisons can all be found in Table 5. The Pearson Correlation can range from -1.0 to 1.0. The magnitude of the number reflects the extent to which the parameters are correlated, while the sign indicates whether the correlation is positive or negative. A coefficient ranging from 0.0-0.3 is considered a weak correlation. A coefficient equal to 0.5 is a moderate correlation. A 0.7 correlation coefficient is considered a strong correlation. A perfect correlation has a magnitude of 1.0.

Table 5. Pearson Correlation Coefficient for EMC % Reduction vs Inflow Load (kg) for TSS, TDN, NO_3, NH_4, PO_4, and DOC.

	TSS	TDN	NO_3	NH_4	PO_4	DOC
Pearson Correlation	-0.22	0.38	-0.10	0.13	0.18	0.28

In evaluating the Pearson Correlation Coefficient between the EMC % Reduction and Inflow Load for each pollutant (Table 19), it was determined that TDN had a weak correlation (0.38). All other coefficients were considered to be too weak for a correlation.

Baseline Sampling Water Quality

The monthly average concentration for targeted chemical constituents was collected from the nine sampling stations (Table 6). Monthly averages were calculated by taking the mean value off each month, from 2005 to 2009. Construction on stormwater wetlands began in 2011.

Monthly trends for each site are shown in Figure 13. Figure 14 highlights the water quality difference between each site. It should be noted that D1 and D2 are from an agricultural runoff drainage ditch, while DF collected samples from an agricultural runoff drainage ditch that also received treated runoff from wetland FW. This data provided the baseline water quality information, which allows for surface stream impacts – related to land-use changes and wetland BMPs – to be evaluated.

Table 6. The monthly average concentration from baseline water quality data from 2005 to 2010. NC – data Not Collected due to no flow.

TSS (mg/l)									
	WL1	WL2	LR1	LR2	EJ1	EJ2	D1	D2	DF
Jan	189	221	78	76	314	307	208	227	497
Feb	195	176	40	108	456	269	169	190	219
Mar	227	192	52	56	290	352	256	180	218
Apr	116	162	56	186	254	313	340	243	250
May	203	197	67	138	335	330	303	467	457
Jun	286	243	102	239	386	419	585	2503	366
Jul	255	245	107	142	410	419	276	2296	519
Aug	328	291	115	192	531	370	155	NC	720
TSS (mg/l)									
Sep	263	266	143	112	402	417	358	506	700
Oct	231	211	99	118	369	416	225	328	459
Nov	232	204	92	141	314	286	227	352	399
Dec	273	194	82	130	221	469	1410	176	666
BOD (mg/l)									
	WL1	WL2	LR1	LR2	EJ1	EJ2	D1	D2	DF
Jan	1.25	1.43	1.07	1.25	1.26	1.42	1.63	2.21	2.01
Feb	1.10	0.94	1.04	0.79	1.03	0.96	1.42	1.20	1.87
Mar	1.18	1.32	1.27	1.35	1.19	1.37	1.58	1.41	1.93
Apr	0.87	0.98	0.81	0.83	0.87	1.12	1.90	0.97	1.31
May	0.87	0.93	0.89	0.79	0.71	0.87	0.97	1.15	1.88
Jun	0.69	0.64	0.77	0.91	0.92	0.65	2.57	1.13	4.11
Jul	1.01	0.82	1.01	1.04	0.83	1.02	3.65	NC	5.17
Aug	0.88	0.92	1.00	0.92	0.72	0.97	3.17	NC	NC
Sep	0.65	0.47	0.72	0.80	0.77	1.14	1.50	0.54	6.28
Oct	0.95	1.17	1.04	1.08	0.74	1.07	0.75	0.79	0.79
Nov	1.07	1.31	1.07	0.76	0.95	1.17	1.92	1.61	4.80
Dec	2.40	2.13	1.88	2.11	2.12	2.22	1.97	3.90	3.64
TDN (mg/l)									
	WL1	WL2	LR1	LR2	EJ1	EJ2	D1	D2	DF
Jan	0.44	0.38	0.35	0.33	0.83	0.81	1.15	1.24	0.87
Feb	0.45	0.38	0.34	0.46	0.74	0.74	1.62	1.36	1.15
Mar	0.51	0.49	0.26	0.33	0.80	0.81	1.25	1.34	1.24
Apr	0.48	0.31	0.36	0.37	0.78	0.77	1.39	1.53	1.96
May	0.42	0.34	0.30	0.34	0.81	0.84	2.39	2.13	1.68
Jun	0.57	0.63	0.41	0.39	1.06	1.34	1.25	3.97	2.12

Table 6. The monthly average concentration from baseline water quality data from 2005 to 2010. NC – data Not Collected due to no flow. (Continued)

TDN (mg/l)									
Jul	0.67	0.63	0.35	0.31	1.08	1.08	2.04	2.82	1.80
Aug	0.63	0.60	0.33	0.40	1.04	1.11	1.00	NC	1.19
Sep	0.68	0.60	0.39	0.41	0.88	0.91	0.89	2.21	1.12
Oct	0.34	0.29	0.26	0.22	0.66	0.72	0.64	1.08	1.27
Nov	0.28	0.30	0.19	0.25	0.50	0.57	1.03	1.20	1.35
Dec	0.50	0.30	0.38	0.38	0.82	0.70	1.27	1.92	0.88
NO_3 (mg/l)									
	WL1	WL2	LR1	LR2	EJ1	EJ2	D1	D2	DF
Jan	0.56	0.74	0.65	0.96	1.88	1.98	1.23	1.37	1.50
Feb	1.25	0.87	0.83	1.52	1.66	2.14	2.81	2.52	2.94
Mar	0.92	1.00	0.79	0.74	2.26	2.52	2.27	2.19	1.61
Apr	1.08	0.67	0.87	0.86	2.44	2.62	1.96	2.83	2.24
May	1.42	0.92	0.88	1.04	2.55	3.21	5.19	3.03	2.89
Jun	1.41	1.66	1.27	1.15	3.20	4.31	1.50	6.31	1.19
NO_3 (mg/l)									
Jul	1.59	1.72	0.90	0.72	2.94	3.40	1.94	11.91	1.98
Aug	1.58	1.50	0.99	0.84	3.12	2.59	1.06	NC	0.66
Sep	1.52	1.39	0.82	0.91	2.23	2.91	2.51	2.89	2.63
Oct	0.92	1.28	0.48	0.71	1.77	1.84	0.85	2.57	1.26
Nov	0.99	0.74	0.45	0.93	1.25	1.44	1.38	1.52	0.80
Dec	0.77	1.55	0.97	1.22	2.16	2.26	2.89	5.24	1.61
TP (mg/l)									
	WL1	WL2	LR1	LR2	EJ1	EJ2	D1	D2	DF
Jan	0.17	0.12	0.10	0.11	0.08	0.13	0.19	0.14	0.12
Feb	0.14	0.13	0.12	0.11	0.16	0.15	0.26	0.20	0.10
Mar	0.07	0.06	0.06	0.05	0.07	0.06	0.11	0.10	0.16
Apr	0.09	0.09	0.08	0.04	0.09	0.07	0.17	0.15	0.15
May	0.04	0.03	0.03	0.03	0.04	0.04	0.26	0.22	0.07
Jun	0.07	0.07	0.05	0.12	0.09	0.11	0.18	0.28	0.10
Jul	0.09	0.09	0.08	0.08	0.10	0.09	0.47	0.15	0.42
Aug	0.06	0.08	0.06	0.05	0.08	0.09	0.27	NC	0.11
Sep	0.08	0.08	0.04	0.03	0.07	0.08	0.23	0.22	0.31
Oct	0.10	0.14	0.07	0.06	0.10	0.12	0.28	0.32	0.29
Nov	0.09	0.07	0.03	0.06	0.10	0.06	0.12	0.18	0.25
Dec	0.13	0.09	0.06	0.09	0.06	0.06	0.50	0.15	0.13

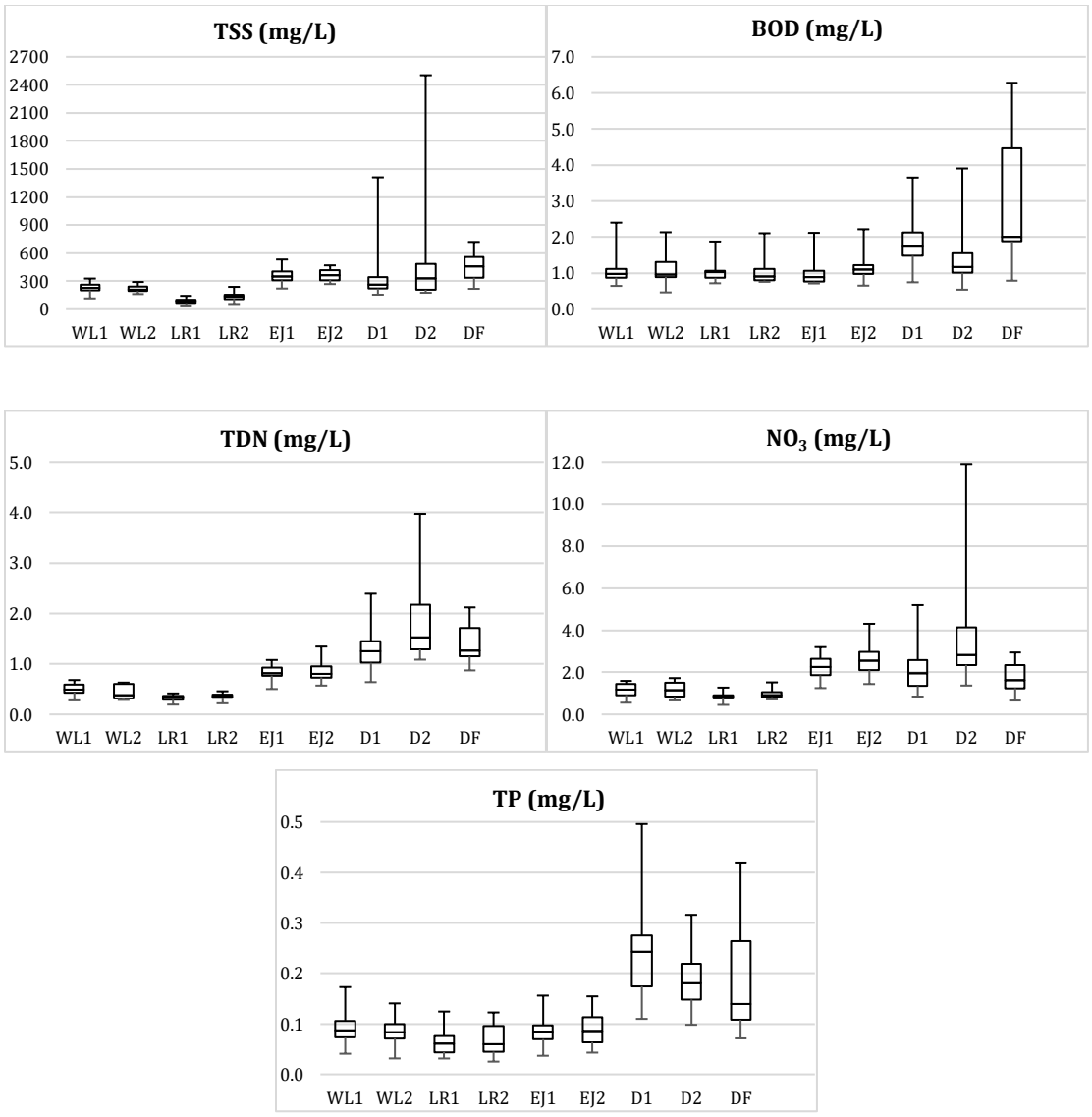


Figure 13. Box and Whisker plots showing site comparison of annual average pollutant concentration 2005-2011

It should be noted that samples from D1, D2, and DF had higher average concentrations, and greater variation in water pollutants than the samples collected from the perennial stream sites (WL, EJ, LR). These results may be attributed to land disturbances related to agricultural practice (planting, harvest, etc.).

BOD did not show a statistically significant difference for any sampling site between the period before and directly after dairy farm production. After a portion of the farm was transitioned to dairy production, there was a significant increase ($P<0.05$) in both NO_3 and TDN in the runoff drainage ditch (D1, D2). These increases were not found to be significant in the other sampling locations. TP concentrations for WL2 and EJ1 showed a significant ($P<0.05$) increase after this transition period.

The Paired Two Sample T-Test was used to evaluate whether there was a significant ($P<0.05$) difference between the paired sites on the Little River, Ellejoy Creek, and the drainage ditch. As illustrated in Table 7, each pair of sampling sites showed a significant difference for either TSS, BOD, TDN, or NO_3 at one noted location. Total Phosphorus was the only parameter that did not show a statistically significant difference between upstream and downstream sampling sites. In each case of significant difference, the downstream location showed an increase in the pollutant concentration.

The LR sites showed a significant difference in TSS ($P=0.003$) and NO_3 ($P=0.047$). Because the Little River has better water quality comparing with Ellejoy Creek, and it is not listed as a 303d impaired stream(TDEC, 2016), variations in TSS and NO_3 will be more discernable relative to Ellejoy Creek, which is listed as impaired by both sediment and nitrates (TDEC, 2016). Because the majority of crop fields drain to the Little River, it is possible that the elevated TSS and NO_3 values are a result of land disturbances from crop land management (hay field management) and fertilization, respectively.

Ellejoy Creek sites showed a significant difference in BOD ($P=0.005$) and NO_3 ($P=0.011$). The drainage ditch showed significant difference in TDN ($P=0.028$). These results provide a characterization of the changing water quality along the study reaches during the period of hay production (2005-2010) and before the onset of dairy operation came to be.

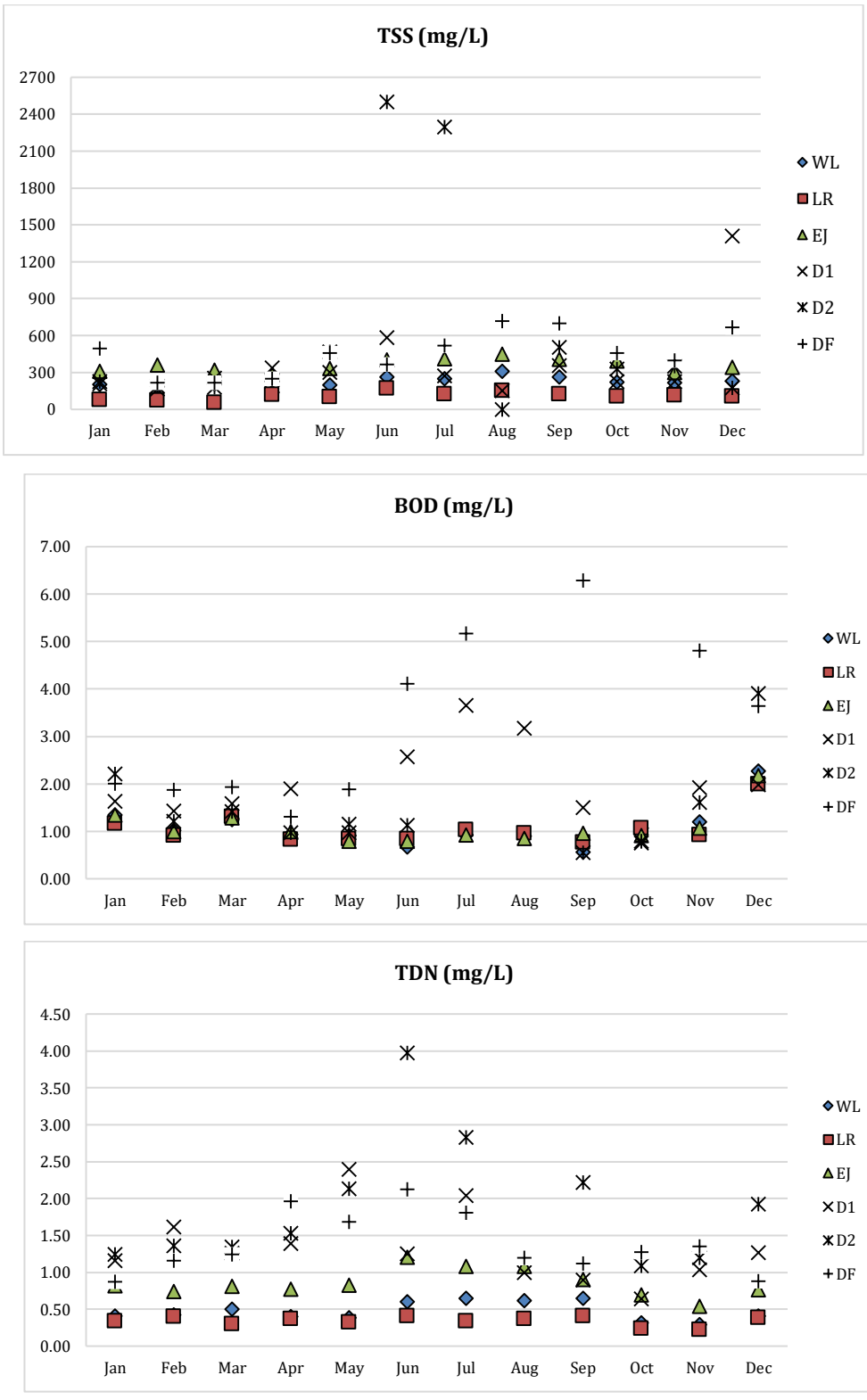


Figure 14. Pollutant Mean Concentration for the Annual Monthly Trend 2005-2011

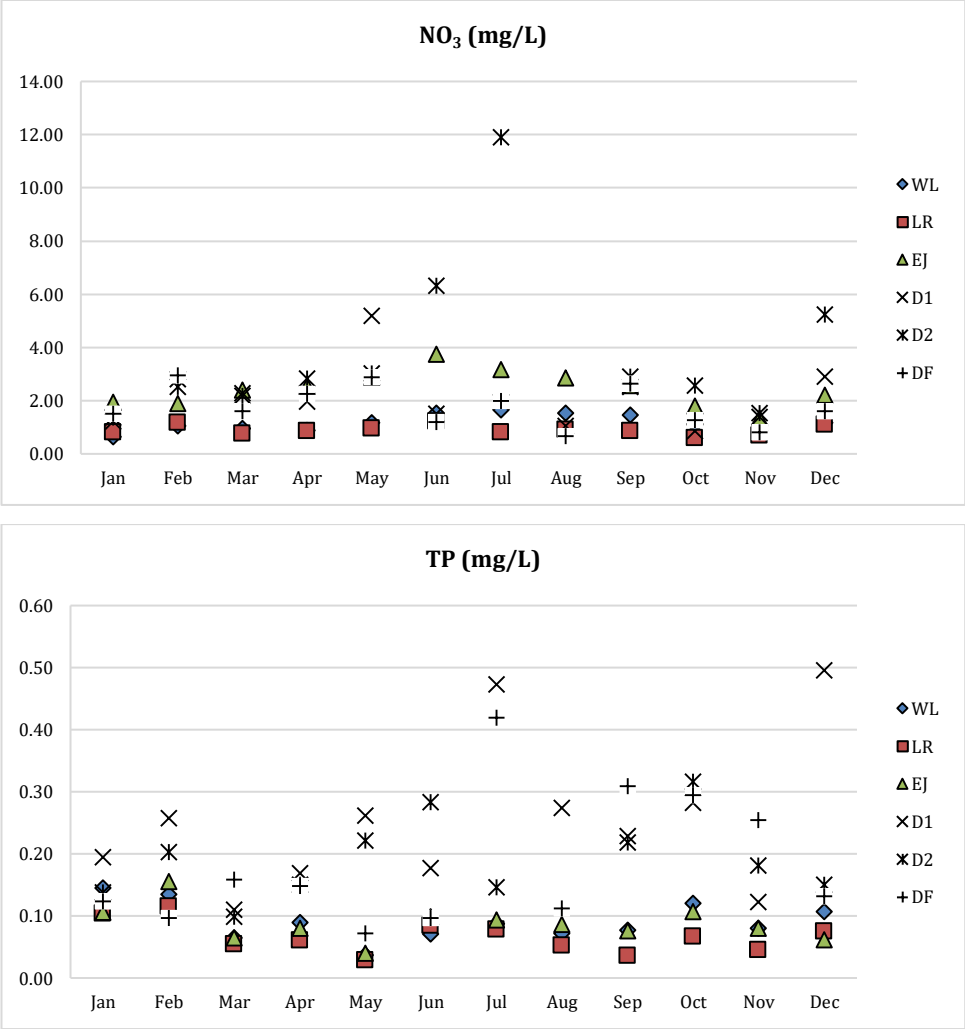


Figure 14. Pollutant Mean Concentration for the Annual Monthly Trend 2005-2011 (Continued)

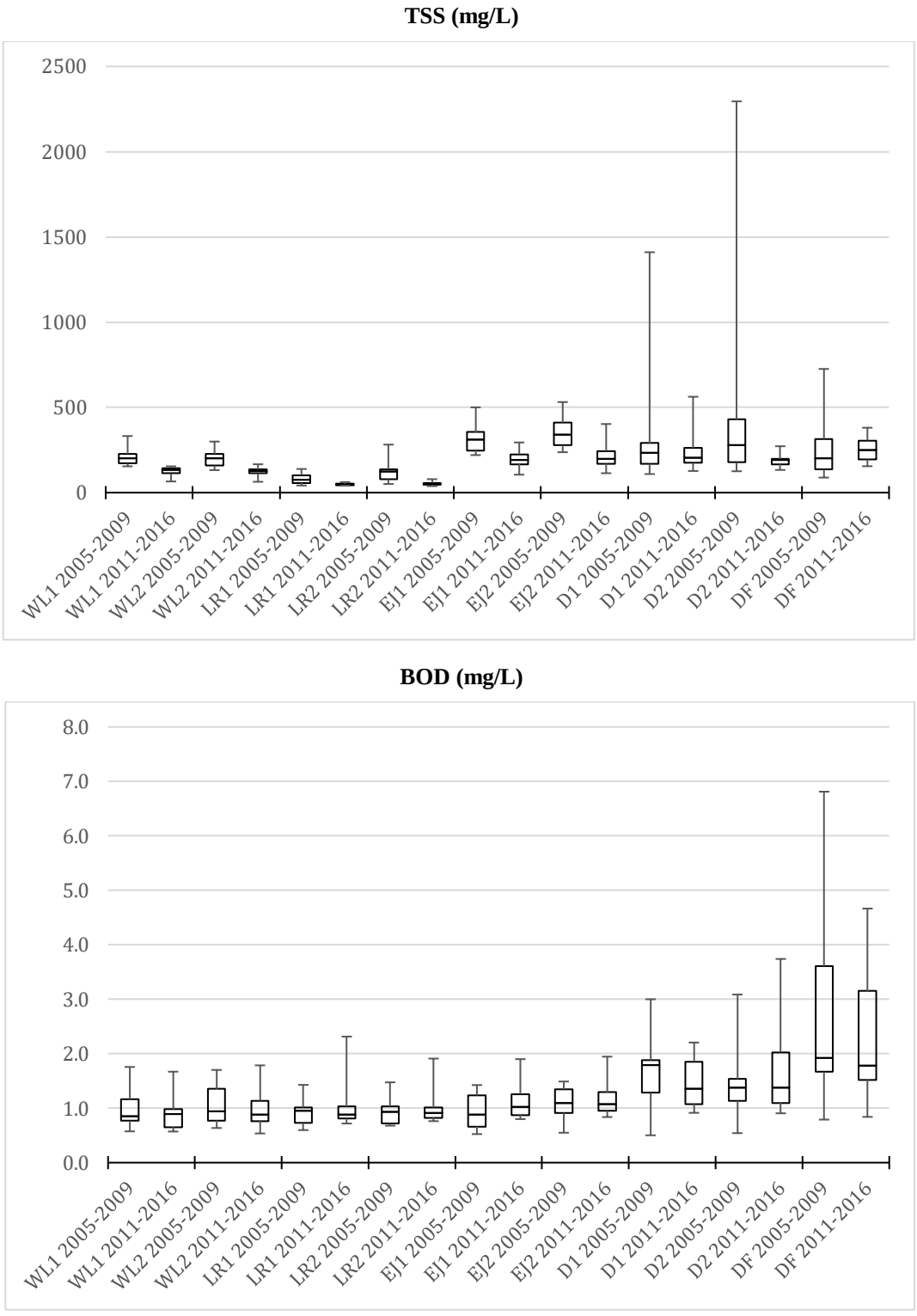
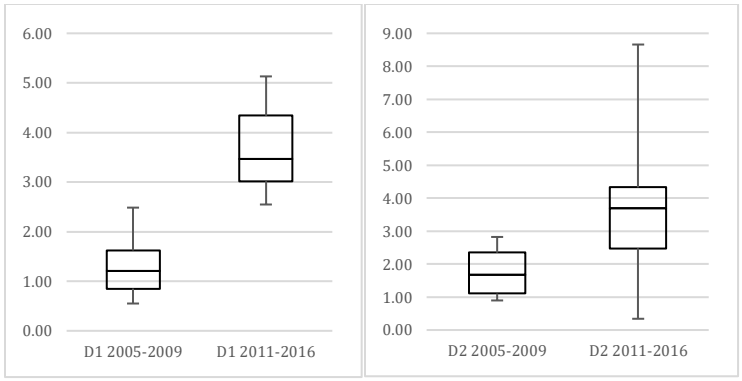
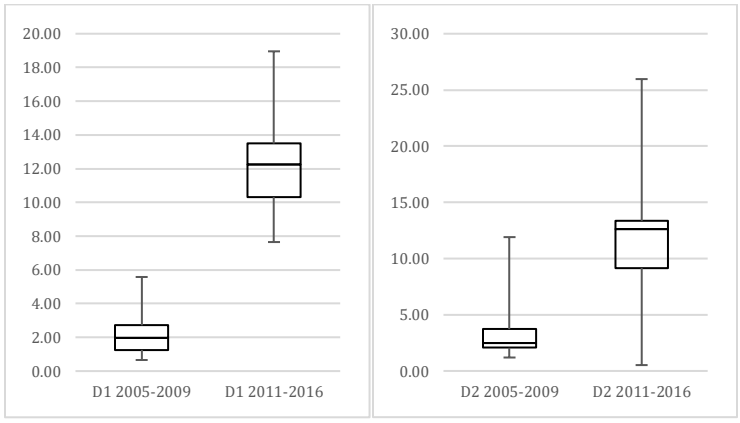


Figure 15. Variations in the mean yearly concentration for TSS and BOD. Graph represents sites showing a significant ($P<0.05$) change in pollutant concentration, except for BOD.

TDN (mg/L)



NO_3 (mg/L)



TP (mg/L)

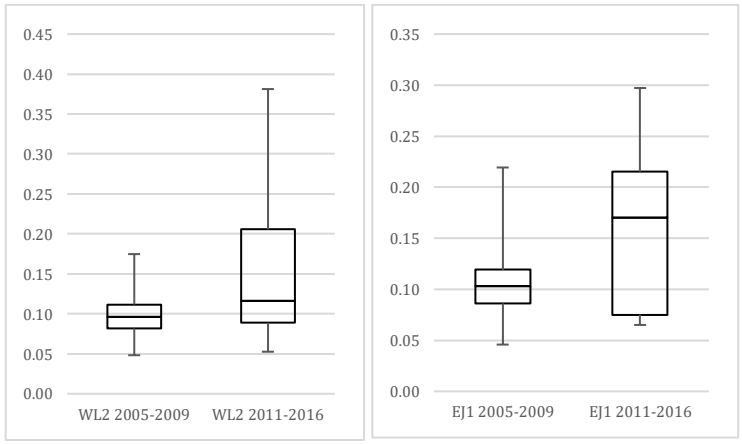


Figure 16. Variations in the mean yearly concentration for TDN, NO_3, and TP. Graphs represent sites that exhibited a significant ($P<0.05$) change in pollutant concentration, except for BOD.

Table 7. Paired Two-Sample T-Test (alpha = 0.05) and Summary Statistics comparing upstream and downstream pollutants for the Little River (LR), Ellejoy Creek (EJ), and agricultural runoff ditch (D), respectively.

		Before and Immediately After Transition from Crop to Dairy Production (2005-2009)					
		LR1	**LR2**	**EJ1**	**EJ2**	**D1**	**D2**
TSS (mg/L)	Mean	81.372	126.55	311.96	350.74	322.09	489.45
	P Value	**0.003**		0.417		0.063	
BOD (mg/L)	Mean	1.047	1.05	1.009	1.165	1.914	1.492
	P Value	0.477		**0.005**		0.23	
TDN (mg/L)	Mean	0.328	0.349	0.832	0.866	1.332	1.891
	P Value	0.090		0.117		**0.028**	
NO_3 (mg/L)	Mean	0.825	0.966	2.287	2.601	2.064	3.853
	P value	**0.047**		**0.011**		0.053	
TP (mg/L)	Mean	0.065	0.068	0.085	0.089	0.232	0.191
	P value	0.352		0.255		0.134	
		After Dairy Production Commenced Operation (2011-2016)					
		LR1	**LR2**	**EJ1**	**EJ2**	**D1**	**D2**
TSS (mg/L)	Mean	47.767	52.414	194.47	223.32	242.917	189.49
	P Value	0.115		0.186		0.077	
BOD (mg/L)	Mean	1.027	1.014	1.133	1.185	1.47	1.661
	P Value	0.468		0.355		0.243	
TDN (mg/L)	Mean	0.291	0.426	0.896	1.021	3.723	3.559
	P Value	**0.047**		0.158		0.409	
NO_3 (mg/L)	Mean	0.794	1.133	2.633	2.921	12.264	11.47
	P value	**0.048**		0.294		0.368	
TP (mg/L)	Mean	0.08	0.096	0.163	0.154	0.28	0.344
	P value	0.282		0.414		0.289	

The Paired Two Sample T-Test was also used to evaluate whether there was a significant ($P<0.05$) difference between LR1 and LR2, EJ1 and EJ2, and D1 and D2, respectively, from 2011-2016. As illustrated in Table 7, neither Ellejoy Creek, nor the agricultural ditch showed a significant difference for any of the parameters.

The LR sites did show a significant difference in TDN ($P=0.047$) and NO_3 ($P=0.048$). The changes in nitrate were consistent from those measured in the pre-dairy operation years. However, the significant difference in TDN was a new change from that time period. Since nitrates accounted for approximately half of the TDN sampled, that means there were significant forms of other nitrogen species introduced during the dairy operations. This is likely in the form of manure fertilizer applications for the establishment of silage crops.

The lack of significant changes in water quality between the paired sites is also a reflection of the scale of the dairy operation relative to the watersheds of these sample sites as well as the influence of land use. The ditch drainage is predominately located on the dairy operation, but a small portion of the upper end of the watershed lies on adjacent crop land. Since the ditch is a consistent agriculture land use along the entire reach, little changes in constituent concentration would be expected. Both Little River and Ellejoy Creek have relatively large drainage areas at the sample sites, approximately 190 and 38 square miles, respectively. The 550-acre size of the dairy farm is likely not a large enough contributor of constituents to affect significant change in water quality between these sampling sites located down the watershed.

By taking the percent difference in concentrations between the upstream and downstream monitoring sites for the Little River (LR) and Ellejoy Creek (EJ), it was possible to see how significantly the localized land management change from crop to dairy production influenced the water quality in the streams (Table 8).

As the data indicates, there was a significant decrease in TSS in the LR ($P=0.013$). TSS load to LR was significantly lowered after the dairy operation was established, likely due to a slight decrease in total acreage farmed (due to dairy buildings) and the adoption and maintenance of some water protective conservation practices (e.g. drainage buffers, rainwater capture and reuse, and controlled drainage features). This would explain the reduction in TSS. It should be noted that, while TDN showed a significant increase ($P=0.031$ in Little River, NO_3 ($P=0.173$) did not. This is likely in the form of manure fertilizer applications for the establishment of silage

crops. It should also be noted that EJ experienced a significant decrease in BOD (P=0.030). This is likely due to a reduction in crop harvest, and dissolved organic matter.

While NPS from the farm land management may only have a localized impact on the watershed, not noticed further down in the watershed, treatment of this NPS may be indicative of BMP efficacy. If the treatment wetland can reduce NPS pollutants at the farm scale, it may be possible that wetland BMPs can reduce pollutants elsewhere in the watershed, resulting in a greater reduction in NPS, as a whole.

Table 8. Comparison of the change in pollutant concentrations (%) in the LIttle River (LR) and Ellejoy Creek (EJ) before and after dairy production

		% Change in Pollutant Concentration Between Upstream and Downstream Monitoring Sites			
		Little River (LR)		Ellejoy Creek (EJ)	
		2005-2009	2011-2016	2005-2009	2011-2016
TSS (mg/L)	Mean Difference	60.319	9.792	20.300	13.594
	P value	**0.013**		0.319	
BOD (mg/L)	Mean Difference	1.817	0.961	23.462	5.567
	P value	0.442		**0.030**	
TDN (mg/L)	Mean Difference	6.770	47.548	7.650	13.064
	P value	**0.031**		0.205	
NO_3 (mg/L)	Mean Difference	26.308	51.506	18.161	15.464
	P value	0.173		0.425	
TP (mg/L)	Mean Difference	36.604	1.080	1.080	-2.260
	P value	0.162		0.399	

Conclusion

In this study, the major findings were:

1. The need for water quality protection BMPs because of significantly higher concentrations of targeted chemical constituents in drainage ditches as compared with surrounding perennial streams.
2. Dairy farm construction did have a significant influence on nitrogen concentrations in the Little River
3. TSS and ammonia were attenuated at the event scale in both wetlands sampled during this study.
4. TSS attenuation was positively correlated with inflow pollutant load, while phosphorus attenuation was negatively correlated with inflow pollutant load.

Future Work

It would be beneficial to know how drainage area characteristics (land-use, area, surface slope, etc.) influence the ability for constructed wetlands to treat agricultural runoff. This can be accomplished by establishing additional sampling sites, or through using a large-scale computer models incorporating geographic information systems.

CHAPTER 2. EXPLORATORY ANALYSIS TO IDENTIFY FIRST FLUSH PHENOMENA IN AGRICULTURAL RUNOFF FROM A CONCENTRATED DAIRY OPERATION IN EAST TENNESSEE

Abstract

Hydraulic and chemical loading factors related to local land use often influences the efficiency of best management practices (BMPs) for water quality protection. One pollutant transport mechanism of interest is the first flush effect. A first flush effect occurs when higher pollutant concentrations are transported in the initial storm event runoff, as compared with the remainder of the storm. These higher concentrations can influence the efficiency with which BMPs are able to treat non-point source (NPS) pollution. This research sought to evaluate the runoff generated from a dairy farm in East Tennessee. The primary focus of this study was to evaluate first flush effect characteristics among targeted pollutants and metals, as well as to determine how storm event characteristics influenced the first flush effect. Storm event runoff was collected at three sampling sites from August 2012 to February 2014. Samples were analyzed for total suspended solid (TSS), ammonia (NH_4), nitrate (NO_3), phosphate (PO_4), total dissolved nitrogen (TDN), dissolved organic carbon (DOC), total phosphorus (TP), chloride (Cl), nitrite (NO_2), sulfate (SO_4), magnesium (Mg), calcium (Ca), Iron (Fe), zinc (Zn), potassium (K), and sodium (Na). First flush function and strength was identified by cumulative load curves and the pollutant adjustment coefficient, β.The results of this study indicate that: 1) Particulate pollutants, such as TSS and TP, showed a greater first flush effect, compared with other pollutants; 2) the strength of the first flush effect for TSS was positively correlated with the average rainfall event intensity; 3) there was no statistically significant correlation between first flush effect and inflow pollutant concentration, rainfall event average intensity, maximum rainfall event intensity, antecedent dry period (ADP), rainfall event duration, precipitation depth, or runoff inflow volume; and 4) TSS attenuation shows a negative trend with first flush effects.

.

Keywords

First Flush, Agricultural Runoff, Non-point Source Pollution, Stormwater Wetland, BMPs.

Introduction

Many southeastern states' 305(b) reports suggest that agricultural non-point source (NPS) pollution is the leading source of river and lake pollution, the major contributor to contaminants in estuaries and ground water, and the second largest source of impairment to wetlands ecosystem (Burkart & James, 1999; USEPA, 1998; USEPA, 2002; USEPA, 2005). Normal agricultural practices including chemical fertilization, pesticide application, concentrated livestock activities, farmland management, and site construction are considered the primary sources of various NPS pollutants (USEPA, 2012). Pollutants carried by storm runoff from these land use activities drain into surface streams and are responsible for water quality degradation and surface water eutrophication (Dierberg et al., 2002; Lee et al., 2014; Rogers et al., 2009; Sharpley & Smith, 1989). The major contaminants in agricultural runoff include total suspended solids (TSS), total dissolved nitrogen (TDN), total phosphorus (TP), metals, salts, pathogens, and other organic matter that affect biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Cooke et al., 2011; Dierberg et al., 2002; Harms et al., 1974; Knisel, 1980; Loehr, 1972; Neumann & Dudgeon, 2002) .

Unlike municipal and industrial wastewater point sources, agricultural NPS pollution is generated from large land area disturbance (Abdalla et al., 2007). This pollution is therefore most influenced by environmental parameters, such as precipitation and temporal land use activities, as well as seasonal changes in soil organic matter content and other elements (Borah & Bera, 2004; Braskerud, 2002; Carpentier et al., 1998; Diebel et al., 2009; Ritter & Shirmohammadi, 2000). In order to prevent and control agricultural NPS pollution, federal and state funded incentive programs cost-share to provide technical assistance for best management practices (BMPs) implementation on farms (USEPA, 2005). The measure of effectiveness of many BMPs at pollutant attenuation or removal is directly linked with loading rates (Barrett, 2008; Carleton et al., 2001). Therefore, it is critical to understand the chemical nature of the runoff inflow and how it is impacted by environmental parameters such as precipitation event intensity, volume, and duration.

Previous studies have sought to evaluate pollutant transport and transport mechanisms, but they often focus on the urban watersheds (Berndtsson, 2014; Davis et al., 2001; Lang et al., 2013). As a result, there is value in learning more about pollutant transport and transport

mechanisms for small drainage agricultural runoff. One pollutant transport mechanism of interest is the first flush effect. The first-flush phenomenon is described as the initial surface runoff generated from a rain event where higher pollutant concentrations could be transported as compared with the remainder of the storm (Kato et al., 2009). During the first flush, a greater quantity of pollutants are discharged into the receiving waters (Lee & Bang, 2000 The strength of the first flush effect can be influenced by certain variables, such as constituent type, particle size, concentration, dissolvent capacity, and load (Berndtsson, 2014; Su & Mitchell, 2006). At the catchment scale, surface area, slope, length of flowpath, land use, Manning's roughness coefficient, and vegetation composition can also influence chemical load transport, leading to variation in the strength of the first flush. Furthermore, previous research has indicated that hydro-meteorological components such as runoff flowrate, rainfall depth, intensity, precipitation duration, and antecedent dry periods can also cause first flush effect changes (Deletic, 1998; Lee et al., 2011; Sansalone & Cristina, 2004; Vorreiter & Hickey, 1994). Previous studies have evaluated the strength of the first-flush effect among different pollutants (Kato et al., 2009; Stutter et al., 2008; Su & Mitchell, 2006). While these previous studies looked at the strength of the first flush effect for larger drainage basins, this research is designed to quantify the first flush effects on the farm-scale, in East Tennessee.

It is known that higher initial pollutant concentrations in stormwater runoff, associate with the first flush, have an important interaction with BMP performance and NPS pollutant removal (Barco et al., 2008). It has been proven that many BMPs, including sedimentation devices and filters, show greater treatment efficiency when the inflow pollutant concentrations are higher (Barco et al., 2008; CASQA, 2003). It has also been reported that runoff transported, during the beginning of storm events, contains the highest concentration of smaller particulates (Barco et al., 2008; Li et al., 2005). Because many pollutants – including metals and organic contents – are adsorbed and found in higher concentrations on smaller particles, first flush attenuation provides a greater opportunity to remove pollutants in the particulate phase (Barco et al., 2008; Li et al., 2005). The purpose of this research is to provide a better understanding of transport properties of pollutants generated from agricultural land, particularly with regard to the first flush effect.

The objectives of this paper are 1) to detect the strength of first flush effects among potential pollutants from basins draining to constructed stormwater treatment wetlands, and 2) to

identify how environmental parameters, such as rainfall intensity, flow duration, and dry periods influence pollutant first flush effects.

Materials and Methods

Study Site

This study was carried out on a university-owned dairy farm located in the Little River watershed at the base of the Smoky Mountains near Walland, Tennessee. The operation, known as the East Tennessee Research & Education Center (ETREC) Little River Animal and Environmental Unit (LRAEU), is utilized for research and educational programming in Holstein dairy production. The total farmed area is 529 acres, which is constituted by 300 acres of crop farmland and over 200 acres land for cow milking and production management. The LRAEU was constructed in 2010, and has grown its herd size to approximately 200 head. There are two streams surrounding the dairy farm, Little River and Ellejoy Creek. The entirety of the farm discharges into these watersheds (Figure 17).

The Walland area receives on average 121.92 centimeters of annual rainfall, which is relatively high as compared with the national average 99.49 centimeters (NOAA, 2013) and equal to the East Tennessee regional average. Stormwater runoff from crop production lands and cattle travel areas were measured to carry concentrations of TDN and TP as high as 15.91mg/L and 3.28mg/L respectively (unpublished data sampled in Sep 2012), and pulses of *Escherichia coli* were measured as high as >12098 counts per 100 ml (unpublished data sampled in June 2013). Because of this pollution potential, stormwater treatment wetlands were constructed in the main drainages to treat runoff before it is discharged into the surrounding surface waters. Wetland FW (3962097.99m N, 242763.54m E) has two inlets, FW 15 and FW24, which drain agricultural runoff separately from the south and east side of a crop field, respectively. Wetland BP (3961708.01m N, 243416.44m E) has one inlet, and receives runoff from a combination of grass pasture, cattle travel lanes, and several buildings used for dairy operation (Figure 17).

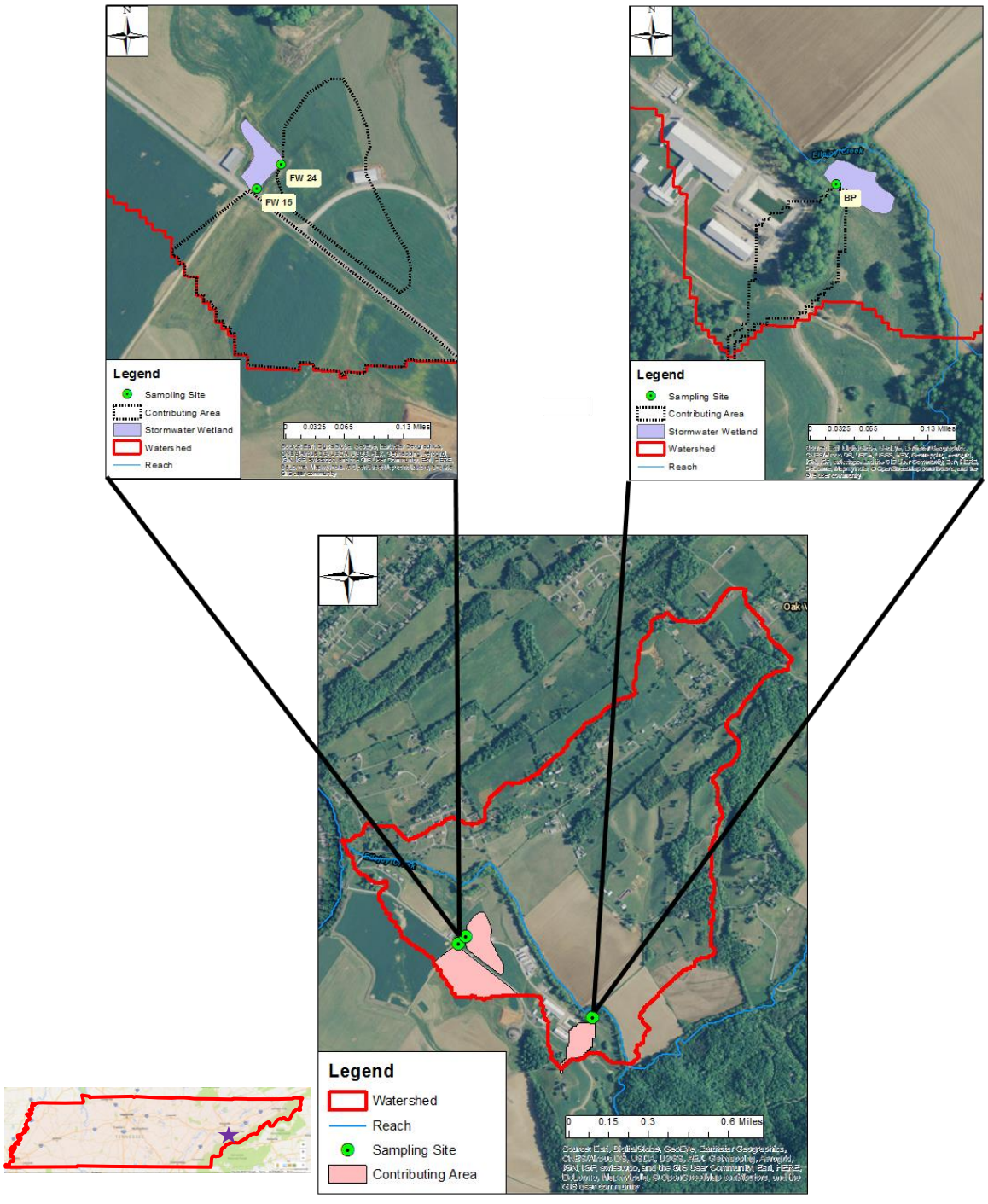


Figure 17. The location of the LRAEU and the delineation of the contributing areas for the constructed wetlands

The wetlands were designed as emergent, free water surface wetlands that intercept a seasonally high groundwater table and surface runoff. The characteristics of each wetland are described in Table 9. Wetland FW has more continuously inundated surface area as compared to the BP wetland.

Table 9. Wetlands Designing Data.

Wetland	Wetland Surface Area (Ac)	Drainage Area (Ac)		Vegetation Composition	Contributing Land Use Cover	Construction Date
FW	0.8	Inlet FW 15 Inlet FW 24	50 30	Obligate Wetland Emergents	Crop Fields (Corn/Wheat Rotation)	March 2012
BP	1.22		15	Mixed Obligate Wetland Emergents and Cool Season Grass (Fescue)	Cattle Operations Area and Wooded Buffer	April 2012

Stormwater Runoff Sampling

Three monitoring stations were installed to sample inflow at the two FW intlets and the BP inlet. Flow-weighted composite water samples were collected using an ISCO model 3700 auto-sampler (Teledyne Inc., NE) installed on the inlets of wetland FW and BP. At the FW inlet, auto samplers were triggered to begin sampling at the first detection of water level – measured by an ultrasonic sensor (Magnetrol EchoTel model 355, Cincinnati, OH). A CR800 datalogger (Campbell Scientific Inc., UT) was programmed to calculate the output flow rate and volume using Manning's Equation for flow through concrete culverts. After flow stage reached 15.25cm, the ISCO auto-sampler was triggered to collect composite samples. The smaller flume was set above the floor of the larger flume. As a result, this 15.25 cm trigger point reflects the point at which flow would pass through both flumes, and thus reflect discharge from the outlet. For wetland BP, inlet water stage was measured by a TFLI water level sensor (Yoder et al., 1999). This sensor was installed on a stainless steel 30-cm 120-degree v-notch weir. A CR800 datalogger was programmed to compute output flow rate and volume for each site, using a weir equation. Water samples were collected from August 2012 to April 2014.

Weather data was collected using a TE525MM Rain Gage (Campbell Scientific Inc., UT) and included precipitation depth and intensity with a 5-min interval, hourly, and daily frequency from September 2012 to April 2014. Water samples were collected within 24 hours after storm events and analyzed in the Water Quality Laboratory at the Biosystems Engineering & Soil Science Department, University of Tennessee. Water constituent analysis included: TSS, NH_4, NO_3, PO_4, TDN, DOC, TP, Cl, NO_2, SO_4, Mg, Ca, Fe, Zn, K, and Na. Methods are noted in Table 10.

Table 10. Water Chemistry Lab analysis.

Analysis	Methods	Standard Methods	Instrument
NO_2, Cl, NO_3, NH_4, PO_4, SO_4, Na, K, Mg, Ca	Chromatography Methods	EPA 9056A	Dionex-100 Ion
TP	Spectrophotometric methods		Skalar
DOC, TDN	Combustion method	Combustion	Shimadzu
Zn, Fe	Atomic absorption		Analyst 700 Perkin Elmer
TSS	Standard Filter Methods	EPA 160-2	TSS Filtration Apparatus

First Flush Analysis

First flush function and strength can be identified by the pollutant adjustment coefficient β and cumulative load curves (CLCs). A "first flush effect" occurs when β is less than one. The β parameter is inversely proportional to the pollutant concentration detected at the beginning of a rain event; a smaller β parameter is indicative of a higher concentration of pollutant in the first flush (Rossi et al., 2005).

For this study, CLCs of each chemical constituent were developed to examine transport during each sampled storm event. Cumulative runoff ratios were plotted on the horizontal axis, and cumulative load ratios were plotted on the vertical axis. Based on this distribution graph, the first flush characteristic of each pollutant was compared (Bertrand-Krajewski et al., 1998) (Figure 18).

Cumulative runoff ratio (CRR) were calculated by:

$$CRR=\frac{V_i}{\sum V_i}$$

Cumulative load ratio (CLR) were calculated by:

$$CLR=\frac{M_i}{\sum M_i}$$

Mi - the inlet pollutant mass at time i (M)

Vi - the inflow volume at time i (L)

The pollutant adjustment coefficient was approximated by the equation:

$$\int_0^i C_i Q_i \, dt = M_{tot} \left(\frac{\int_0^i Q_i dt}{V_{tot}}\right)^{\beta}$$

C_i- Pollutant concentration during a rain event at time i (M/L^3)

Q_i-Inflow rate during a rain event at time i (L^3/T)

M_{tot}- The total mass of nutrient during the rain event (M)

V_{tot}- The total volume of the event (L)

β - The first flush coefficient

t – time (T)

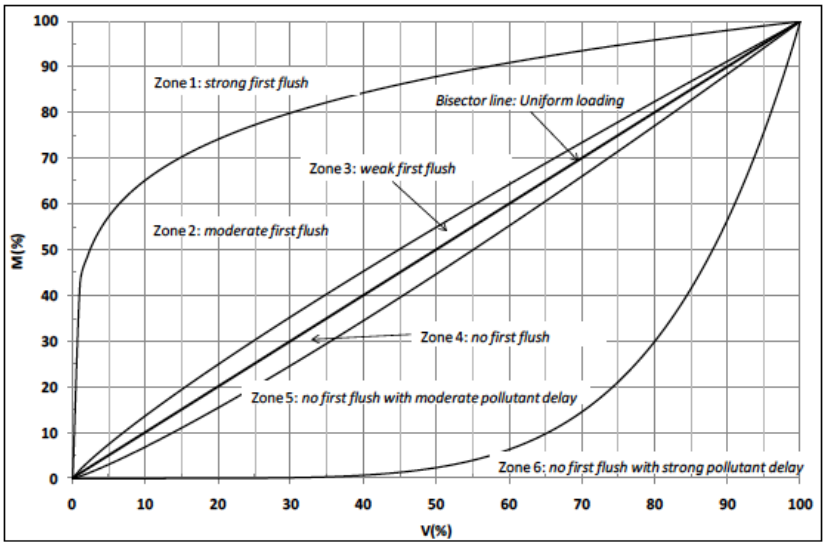


Figure 18. CLCs Curve Zone (Bertrand-Krajewski et al., 1998)

For this study, the parameters tested for their influence on the first flush effect include inflow water chemistry characteristic and storm event parameters. The inflow water chemistry

characteristic included minimum, maximum, and Event Mean Concentration (EMC), while the storm event parameters were constituted by rainfall event average intensity, rainfall event max intensity, precipitation duration, antecedent dry period (ADP), precipitation depth, and runoff inflow volumes.

Statistical Analysis

Statistical analyses were conducted using Microsoft Excel®. The Paired T-tests were used to measure for significant difference of first flush coefficient value between particulate pollutants and non-particulate nutrient. First flush effect strength of TSS comparison between sites FW and BP were also be applied with paired T-test. Simple linear regression and the Spearman Rank Correlation test were used to evaluate correlation between first flush effects and storm event characteristics. Variance of first flush indicators between the 14 sampled storms was used as an indicator of watershed condition and to explain differences between constituent transport behavior.

Results

Water samples were collected from a total of 15 storm events, from August 2012 to April 2014. Events were selected based on a duration greater than six hours, and a depth of at least 1.4 centimeters. Precipitation events with les than 1.4 centimeters of depth did not result in runoff inflow. For this paper, only 14 were used. The first storm data not used was in August 5th, 2012. This storm captured the first runoff after construction of the dairy farm operation. The significant land disturbance – and change in land management operations – caused inflow runoff characteristics to show extremely elevated pollutant concentrations, compared to runoff collected after routine land management operations were established.

Hourly precipitation data was collected for 12 of those 15 storm events, occurring from September 2012 to February 2014, shown in Table 11. Due to mechanical error in the ISCO auto-sampler, no events were detected or collected for wetland BP during spring and summer of 2013. For the purpose of this study, the antecedent dry period (ADP) refers to the number of

days with precipitation less than 0.05 centimeters rain, or no surface runoff in the previous 24 hours (WSDOT, 2009).

First flush coefficient values for each of the tested pollutants are listed in Table 12. Based on the cumulative runoff ratio and cumulative loads ratio models above, CLCs were generated to describe how constituent loads vary with stormwater discharge magnitude and dynamics, shown in Figure 19 and 20. Table 13 indicates the number of events per site, used to calculate the CLCs. Due to technical issues with laboratory testing, TP analysis could only be conducted on samples from one storm event. In cases where the storm did not yield many samples, it was not possible to test the samples for each parameter. To evaluate if the first flush effect was noticeable at each inlet, calculations for the cumulative runoff ratio and cumulative loads ratio were completed for each individual inlet (FW15, FW24, and BP). Inherent differences in the drainage areas and storm characteristics for each of the three sites may have influenced runoff inflow volume at each inlet. Because samples were flow weighted, this variation would explain the why each site collected a different number of samples per event. Table 14 provides a statistical characterization of the first flush coefficients.

It should be noted that not all samples were tested for each parameter, as noted in Table 12, 13, and 14. Due to the nature of the tests run, and the wide array of pollutants evaluated, not all storms yielded enough sample to test for each pollutant parameter. In some other cases, such as with TP, technical issues with the laboratory tests rendered some results to be invalid. As a result, the total number of samples tested – and the thus the total number of lines for each CLCs curve – varies for each pollutant. Based on the results from Table 12 and Table 13, it appears that FW had greater influence over the beta value.

Table 11. Pertinent Characteristics of Sampled Storm Events Using Data Collected by precipitation gauge (TE-525MM CSI-Texas Electronics) at the Station of Little River Dairy Farm in Walland, Tennessee.

Storm number	Date	Number of Bottles		Storm Event Begins	Precipitation (mm)	Duration (hrs)	Antecedent Dry Period (days)	Average Intensity (mm/hr)	Max Intensity (mm/hr)
1	8/5/2012	FW	Not Constructed	Rain Gauge Not Installed					
		BP	24						
2	8/9/2012	FW	Not Constructed						
		BP	9						
3	8/10/2012	FW	Not Constructed						
		BP	6						
4	9/18/2012	FW	23	9/17/2012	104.65	26	2	4.03	18.29
		BP	24						
5	12/16/2012	FW	7	12/10/2012	43.69	32	3	1.37	13.72
		BP	10						
6	12/20/2012	FW	6	12/20/2012	15.24	6	2	2.54	4.32
		BP	7						
7	12/24/2012	FW	32	12/24/2012	71.88	59	2	1.22	5.59
		BP	NC						
8	1/30/2013	FW	24	1/30/2013	39.62	10	2	3.96	9.14
		BP	24						
9	4/19/2013	FW	29	4/19/2013	23.37	6	6	3.90	7.11
		BP	8						
10	8/10/2013	FW	17	8/8/2013	33.78	9	5	3.75	18.8
		BP	NC						
11	9/26/2013	FW	11	9/25/2013	14.47	26	2	0.56	1.52
		BP	NC						
12	11/26/2013	FW	24	11/18/2013	21.34	22	1	0.97	1.524
		BP	NC						
13	12/6/2013	FW	48	12/5/2013	25.15	28	1	0.90	1.778
		BP	24						
14	12/11/2013	FW	NC	12/11/2013	63.75	54	3	1.18	3.30
		BP	13						
15	2/21/2014	FW	NC	2/21/2014	64.77	44	2	1.47	9.65
		BP	24						

Table 12. Average First Flush Coefficient Value Collected from All Sites & Zone Distribution.

Element	Number of Samples (n)	Average First Flush Coefficient	Range	Description
TSS	24	0.66	$0.185< \beta <0.862$	Moderate First Flush
NH_4	20	1.02	$1< \beta <1.159$	No First Flush
NO_3	22	1.07	$1< \beta <1.159$	No First Flush
PO_4	22	0.99	$0.862< \beta <1.00$	Weak First Flush
TDN	22	0.88	$0.862< \beta <1.00$	Weak First Flush
DOC	18	0.96	$0.862< \beta <1.00$	Weak First Flush
TP	3	0.44	$0.185< \beta <0.862$	Moderate First Flush
Cl	22	1.07	$1< \beta <1.159$	No First Flush
NO_2	13	1.40	$1.159< \beta <5.395$	No First Flush with Moderate Pollutant Delay
SO_4	22	1.02	$1< \beta <1.159$	No First Flush
Mg	19	0.95	$0.862< \beta <1.00$	Weak First Flush
Ca	19	0.92	$0.862< \beta <1.00$	Weak First Flush
Fe	19	1.17	$1.159< \beta <5.395$	No First Flush with Moderate Pollutant Delay
Zn	14	1.03	$1< \beta <1.159$	No First Flush
K	13	0.89	$0.862< \beta <1.00$	Weak First Flush
Na	13	0.92	$0.862< \beta <1.00$	Weak First Flush

Table 13. Number of storms (n) per site, used for generating CLCs (Figure 3) and calculating beta-values (Figure 4) for each pollutant.

	FW24	FW15	BP
TSS	10	6	8
NH_4	9	5	6
NO_3	10	5	7
PO_4	9	5	8
TDN	10	4	8
DOC	8	4	6
TP	1	1	1
Cl	10	5	7
NO_2	5	4	4
SO_4	10	5	7
Mg	9	4	6
Ca	9	4	6
Fe	9	4	6
Zn	6	3	5
K	6	3	4
Na	6	3	4

Table 14. First Flush Coefficient Statistical Characterization of Runoff from the Analysis of 15 storm events in Walland, Tennessee.

	TSS	**NH_4**	**NO_3**	**PO_4**	**TDN**	**DOC**	**TP**	**Cl**
Min	0.23	0.27	0.11	0.41	0.21	0.26	0.10	0.31
Med	0.62	0.99	1.00	0.95	0.97	0.98	0.50	0.98
Max	1.33	2.03	3.91	1.75	1.16	1.91	0.73	2.90
Mean	0.66	1.02	1.07	0.99	0.88	0.96	0.44	1.07
Number of Samples	24	20	22	22	22	18	3	22
	NO_2	**SO4**	**Mg**	**Ca**	**Fe**	**Zn**	**K**	**Na**
Min	0.77	0.16	0.20	0.23	0.43	0.38	0.33	0.26
Med	1.17	0.90	0.95	0.89	1.08	0.98	0.98	0.98
Max	2.77	2.67	2.06	2.16	2.02	1.87	1.16	1.13
Mean	1.40	1.02	0.95	0.92	1.17	1.03	0.89	0.92
Number of Samples	13	22	19	19	19	14	13	13

Figure 19. CLCs of Rainfall Events for Pollutants and Metals

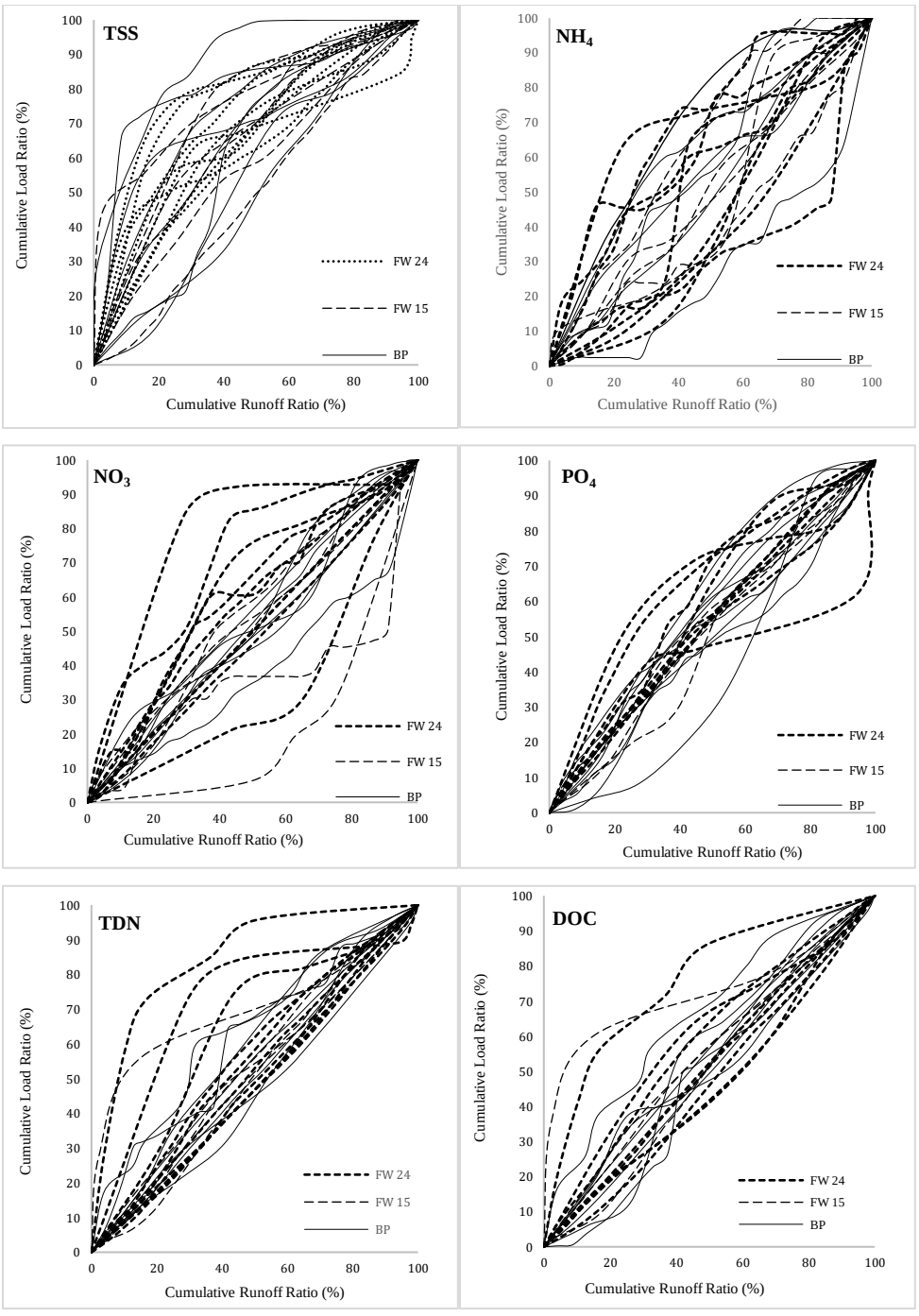


Figure 19. CLCs of Rainfall Events for Pollutants and Metals (continued)

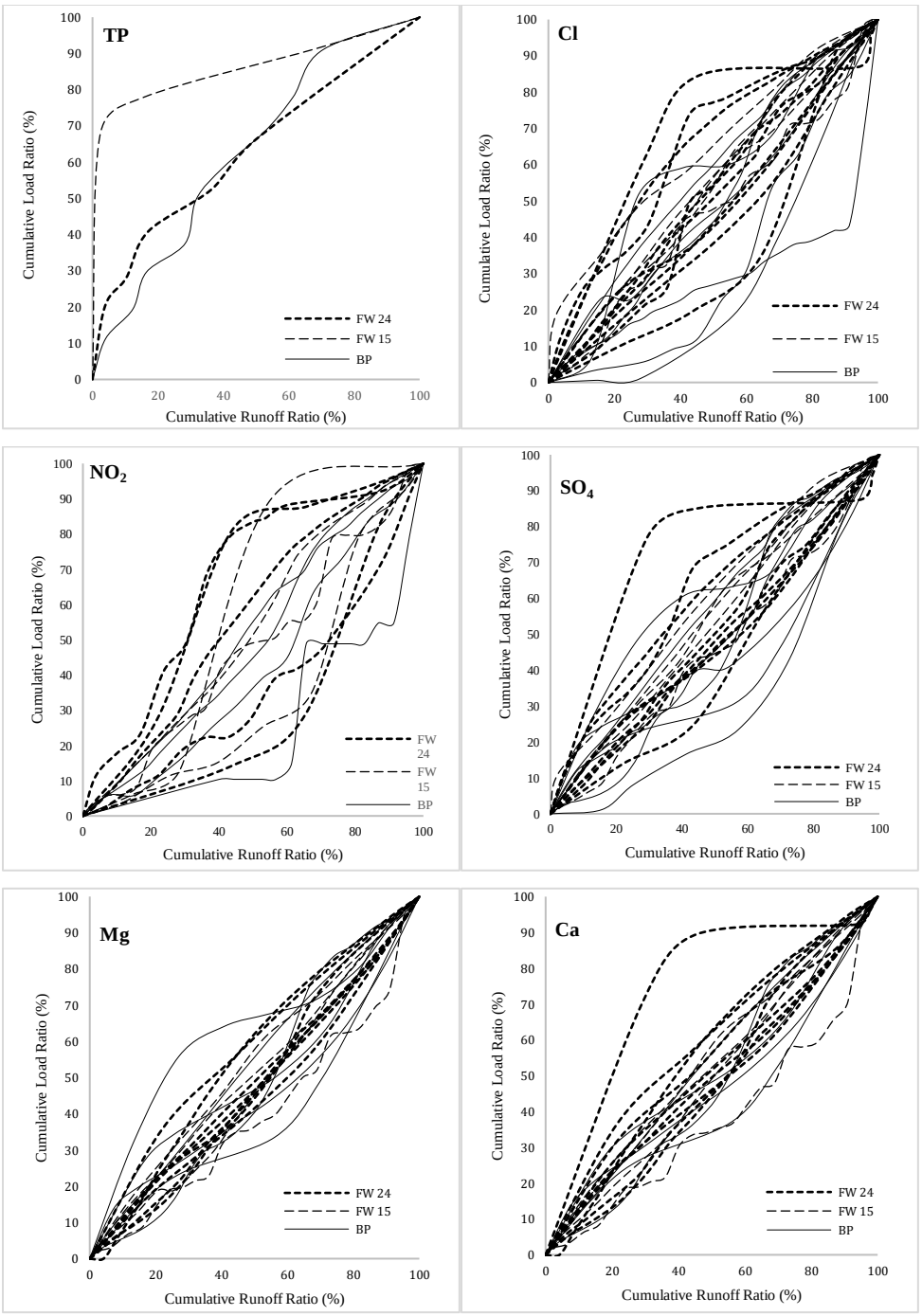


Figure 19. CLCs of Rainfall Events for Pollutants and Metals (continued)

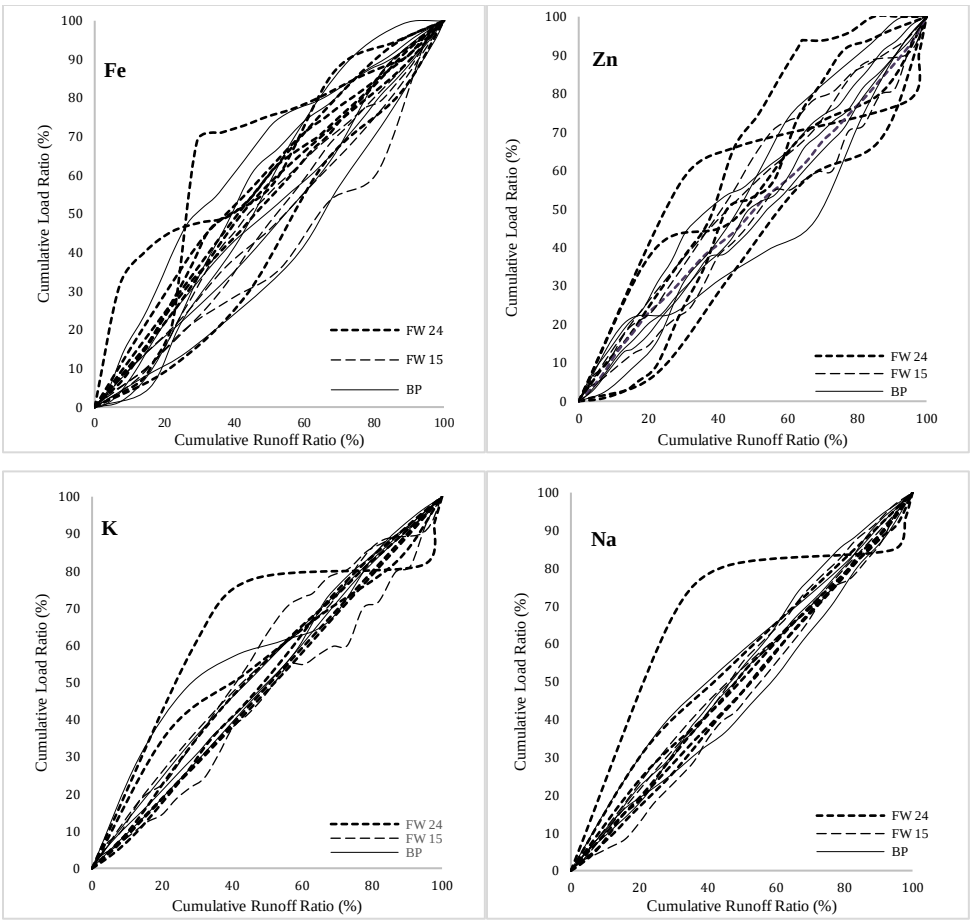


Figure 19. CLCs of Rainfall Events for Pollutants and Metals (continued)

Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP.

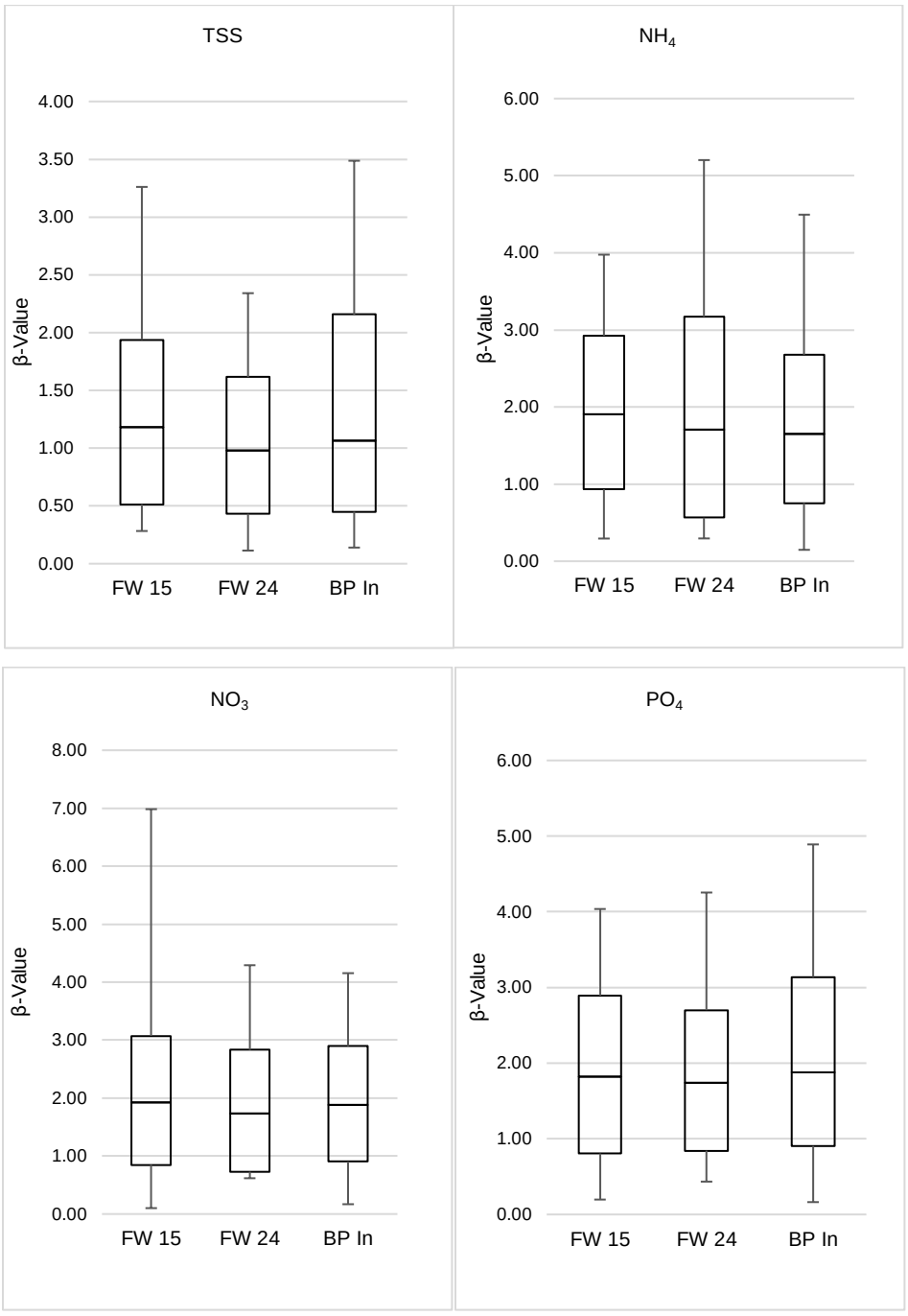


Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP (continued)

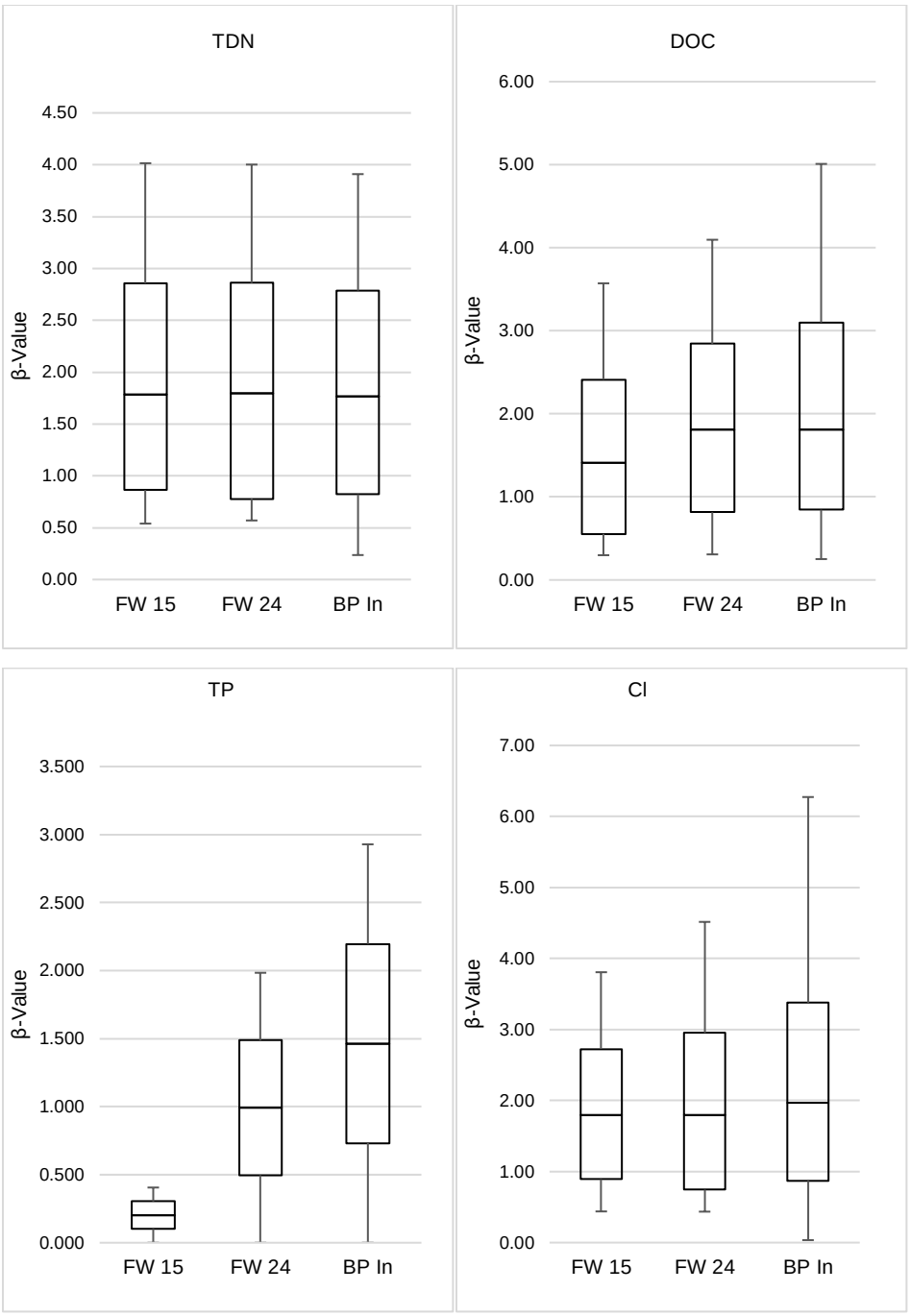


Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP (Continued).

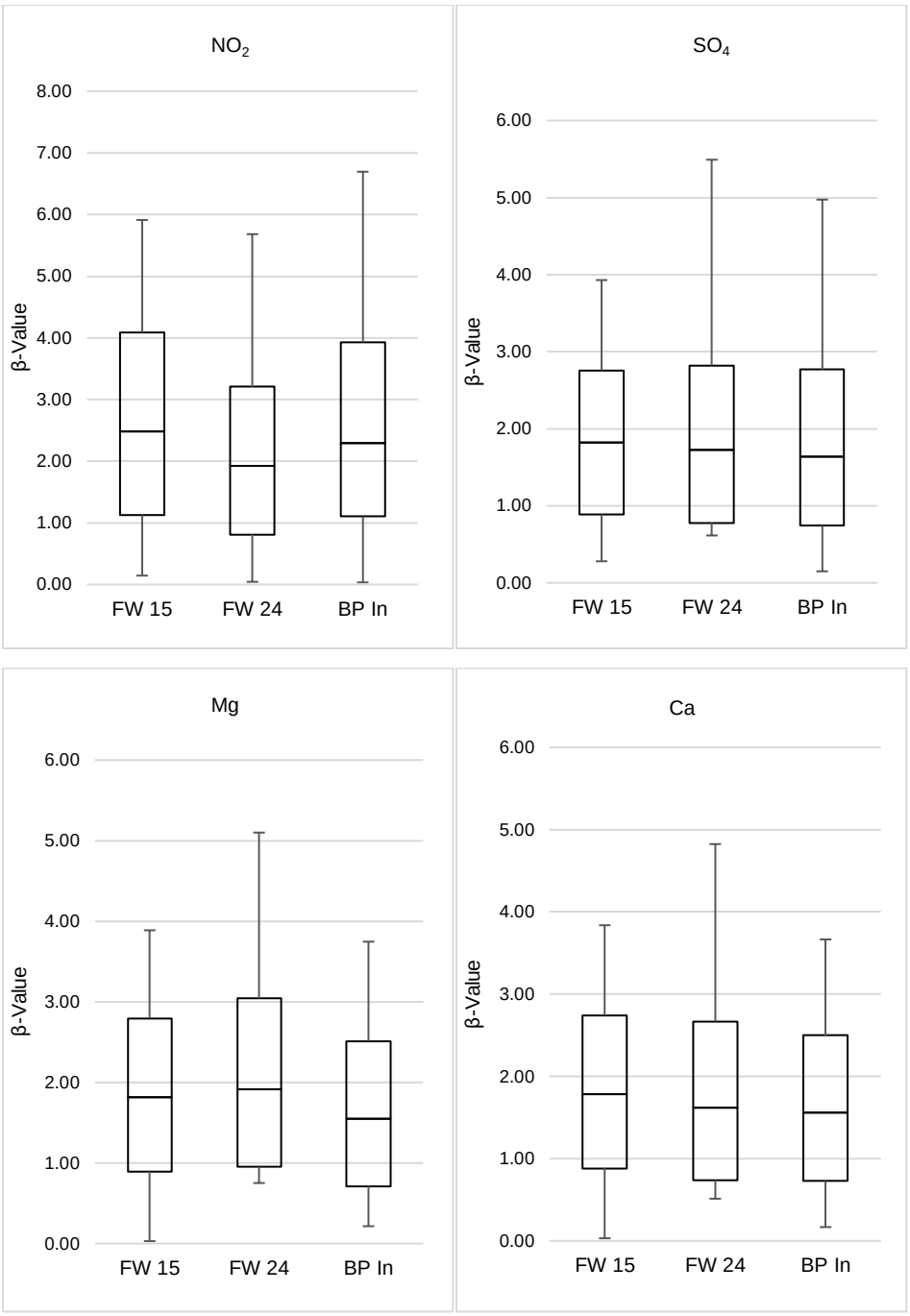


Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP (Continued).

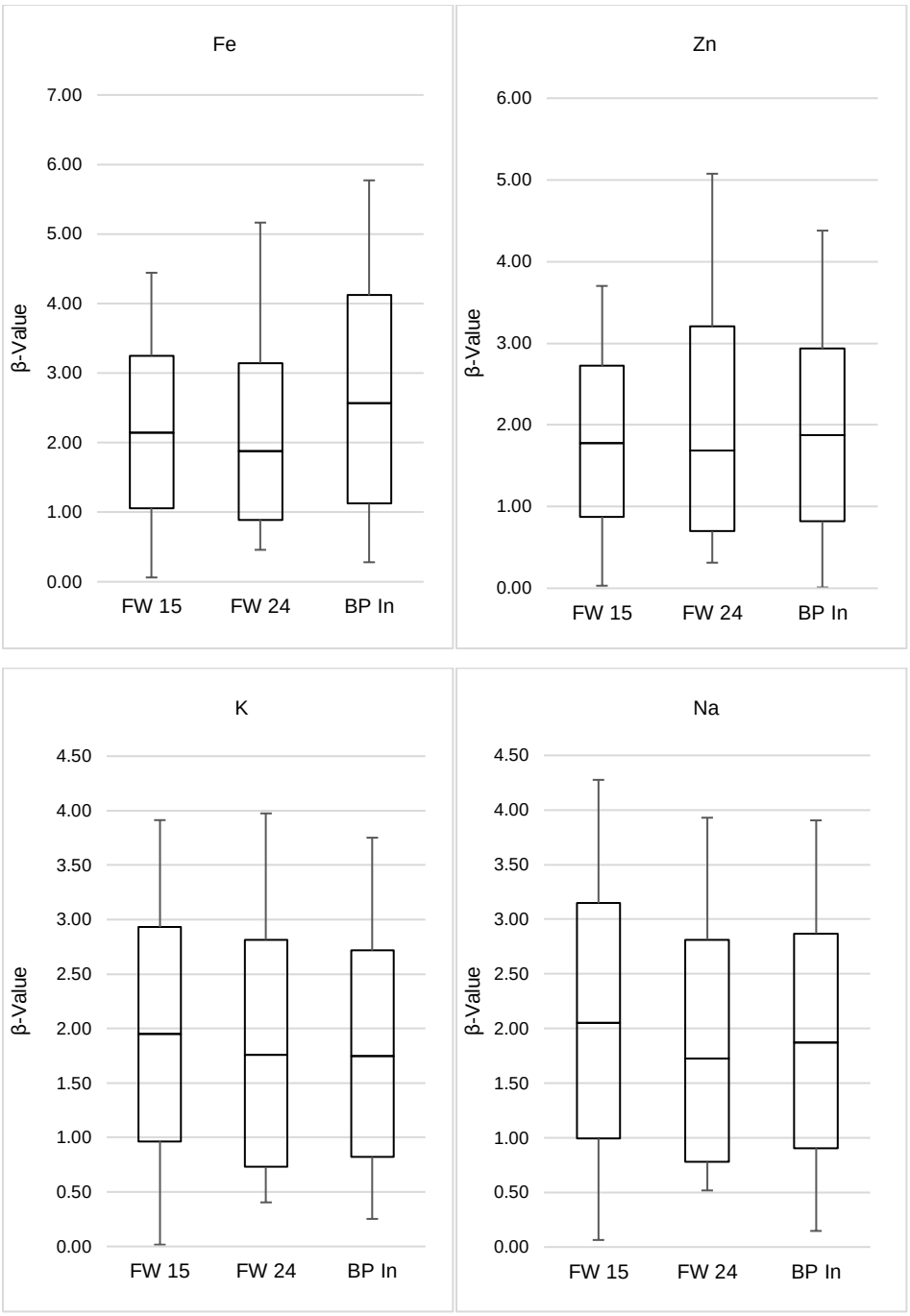


Figure 20. Box Whisker Plot of β Values for Pollutants and Metals Collected from FW15, FW24, and BP (Continued).

In the collected data set, each element exhibited different transport characteristics. The first-flush β value varies per precipitation event. By plotting each of the events on the CLC curve plot, and taking the mean of the β values, it was possible to determine the general first-flush effect for each element. The lowest β values came from TSS (range from 0.23 to 1.33, mean 0.66) and TP (range from 0.10 to 0.73, mean 0.44), suggesting the concentrations of these pollutants are substantially higher during initial runoff period of the storm event. The β values for TDN (β value range from 0.21 to 1.16, mean 0.88), PO_4 (β value range from 0.41 to 1.75, mean 0.99), and DOC (β value range from 0.26 to 1.91, mean 0.96) indicate a weak first flush effect during each storm event. NH_4 (β value range from 0.27 to 2.03, mean 1.02), NO_3 (β value range from 0.11 to 3.91, mean 1.07), Cl (β value range from 0.31 to 2.90, mean 1.07), and SO_4 (β value range from 0.16 to 2.67, mean 1.02), did not show any first flush phenomenon, indicating that nutrient load is evenly distributed with runoff discharge.

The pollutant with greatest β value, NO_2 (β value range from 0.77 to 2.77, mean 1.40), suggests that there was no first flush detected, but a moderate pollutant delay. This lag may be attributed to land management practices. Ammonia in fertilizers or animal waste could have oxidized into NO_2, leading to a peak in NO_2 production, after O_2 introduced with runoff, the β value of metals here were approximately 1, indicating a weak first flush effect. The reduced variance of the metals, especially for K and Na, compared to the non-metal pollutants, suggests that first-flush effects were not heavily influenced by variable environmental factors. Figure 21 and Table 15 show the relatively stronger first flush effect in TSS and TP and relatively less variance than other non-particulate chemical constituents. TP includes both particulate and soluble phosphorus forms, however, particulate phosphorus is the dominant form (Kato et al., 2009). These findings are consistent with the research from Kato et al., and Stutter et al, with particulate pollutants showing a stronger first flush effect than non-particulate nutrients (Kato et al., 2009; Stutter et al., 2008).

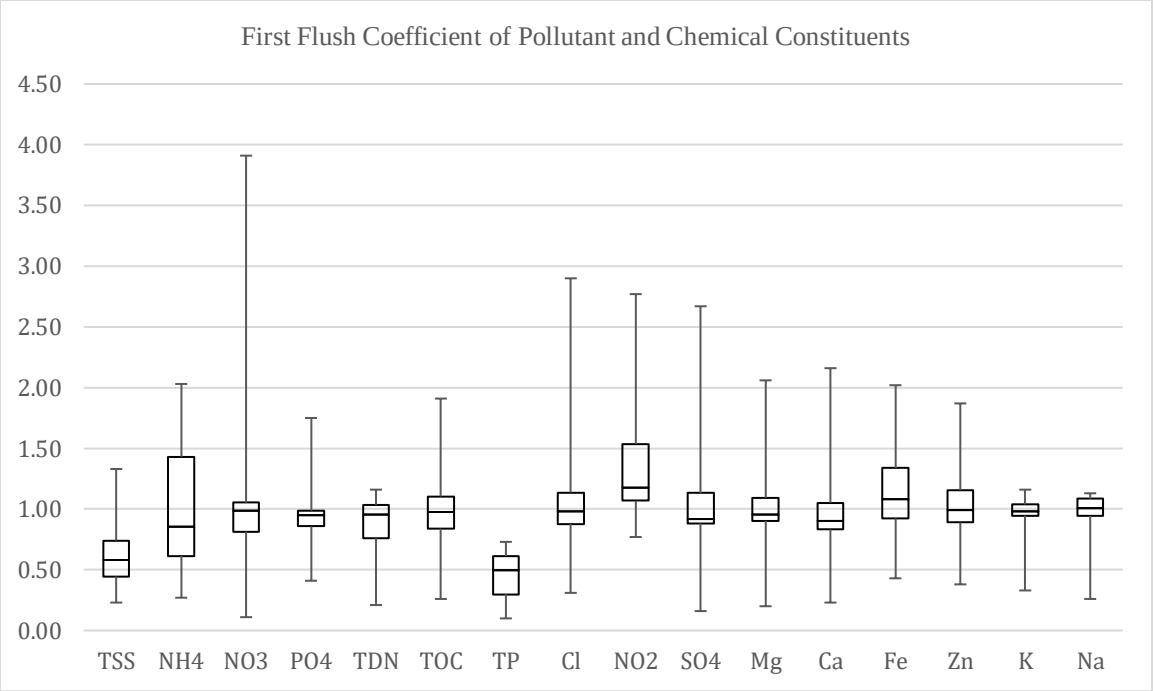


Figure 21. Box Whisker Plot of First Flush Coefficient Comparison Collected from FW15, FW24 and BP

Table 15. T-Test Statistic Results Comparing Pollutant β-value

	Mean	P value
Particulate Pollutants (TSS and TP)	0.50	<0.01
Non-Particulate Chemical Constituents (NH_4, NO_3, PO_4, TDN, TOC, CL, NO_2, SO_4, Mg, Ca, Fe, Zn, K, Na)	1.00	

Discussion

Based on the results, both TSS and TP showed less variance than other measured constituents, one possible explanation is that TSS and TP are particulate constituents. These particulates are transported by stormwater runoff and can be stored in drainage ditch substrate sediments or surface farmland soils and re-suspended during subsequent events, making the ditches act as a pollutant source. This explanation would be consistent with previous studie (Kato et al., 2009).

For all statistical analyses, FW15 and FW24 results were combined to reflect the inflow characteristics of wetland FW, in general. This allowed for a direct comparison of wetland FW, and wetland BP. For particulate pollutants like TSS, the first flush in site FW had significant greater effect than site BP, as Figure 22 and Table 16 show. The mean β values of TSS in the FW and BP sites were 0.54 and 0.76, respectively. The mean β value of another particulate pollutant, TP, showed a similar trend with TSS; TP yielded a β value of 0.30 in site FW, compared with 0.73 in site BP. This trend suggests a delay of particulate pollutant transport for site BP, comparing with FW. The discrepancy may be the result of variation in land use and composition; FW collects runoff from a crop farm, while BP collects from a dairy operation. Inflow travels through a wooded channel, before entering wetland BP, thus providing additional filtration. This may have contributed to the reduction in particulate pollutants flowing into site BP. Runoff from cropland drained into FW doesn't have any BMPs, which may have lead FW to show a stronger first flush effect, as compared to BP.

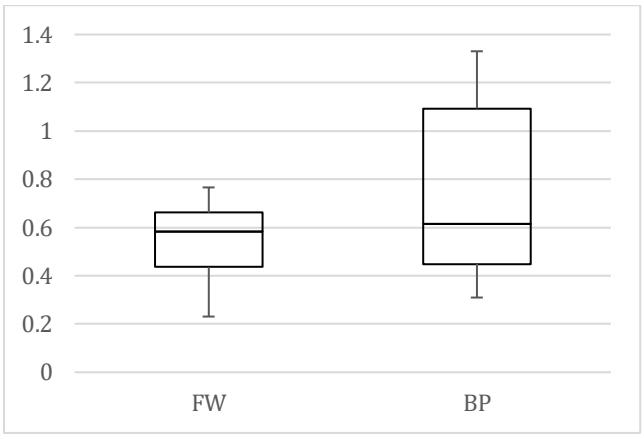


Figure 22. Box Plot of the First Flush Coefficient of TSS Site Comparison of FW and BP.

Table 16. T-Test Statistic Results of Sites Comparison of β Values.

	Mean	P value
FW	0.54	0.04
BP	0.76	

For soluble pollutants, such as NO_3, NH_4, SO_4, TDN, and DOC, there is no significant difference detected between site FW and BP. Based on previous research, the drainage system or catchment surface with higher slope may avoid deposition during dry periods; this would result in a relatively weak first flush effect (Barco et al., 2008).

Based on a Pearson correlation analysis, there was no significant correlation detected between first flush effect of TSS and minimum concentration, maximum concentration, or EMC, shown in Table 17. Only 12 events selected for TSS first flush effect analaysis because TSS concentration was not tested for event December 20th, 2012 and Feb 21st, 2014 . After completing a paired T-test analysis, there was no significant difference detected between BP and FW runoff inflow for TSS minimum, maximum, and EMC, with p-values of 0.47, 0.09, and 0.34, respectively.

Table 17. Storm Event Characteristics from Sampled for TSS at the Dairy Farm in Walland, Tennessee.

Event Date	Min. Concentration (mg/L)	Max. Concentration (mg/L)	EMC (mg/L)	β Value of TSS
8/9/12	26.00	583.00	201.83	0.31
8/10/12	79.75	294.00	181.05	1.33
9/18/12	28.00	741.25	134.13	0.39
12/16/12	5.75	615.75	252.17	0.85
12/24/12	31.17	1433.25	375.20	0.62
1/30/13	52.42	1271.50	247.14	0.45
4/19/13	5.91	167.57	48.76	0.95
8/10/13	29.65	149.00	19.46	0.37
9/26/13	9.17	36.05	17.06	0.48
11/26/13	22.42	1914.75	133.60	0.63
12/6/13	20.60	2464.00	339.74	0.57
12/11/13	78.38	1219.00	390.86	0.54

Linear regression and the Spearman Rank Correlation showed the only storm event parameter to show significant ($P<0.05$) influence on the TSS first flush coefficient was rainfall event intensity (Figure 23, Table 18). At the FW site, first flush coefficients for TSS were negatively influenced by average storm intensity. Large storms transported more particulate pollutants from the catchment surface into the sampling sites. Greater runoff velocity, resulting from larger storm events, was likely to cause this particulate first flush effect (Taebi & Droste, 2004).

Although the Spearman Rank correlation coefficient showed a strong negative correlation between ADP and TSS first flush coefficient, the p-value suggests that this correlation was not statistically significant. These results may be due to the fact that the Spearman Rank correlation coefficient is based on a ranking of the data, while the T-Test Statistic is based on the mean of the data. As a result, it is possible that individual points are relatively correlated, but that the means of the sampled data are not.

In Table 18, it can be seen that the TSS β values exhibit a statistically significant, negative correlation with average rainfall event intensity ($P<0.05$). It can also be seen that NO_3 β values have a significant negative correlation ($P<0.05$) with average event rainfall intensity, maximum event rainfall intensity, and ADP (Figure 24). A significantly negative correlation with the β value indicates a positive correlation with the actual first-flush effect.

One possible explanation for these results is that NO_3 did not infiltrate into the soil. With the ADP reflecting number of days without a large rainfall event, it is possible that there was not a sufficient amount of water for the NO_3 to infiltrate the soil. If the storm intensity was greater than the infiltration rate of the soil, then it is possible that the subsequent runoff resulted in a first flush event. While the mean β value for NO_3 indicated that there was not a first-flush, inspection of the CLC curves indicate that some storm events exhibited a first-flush and some exhibited a lag. This correlation could be investigated further, to determine if there is a threshold intensity that would result in the more noticeable first-flush effect in future research.

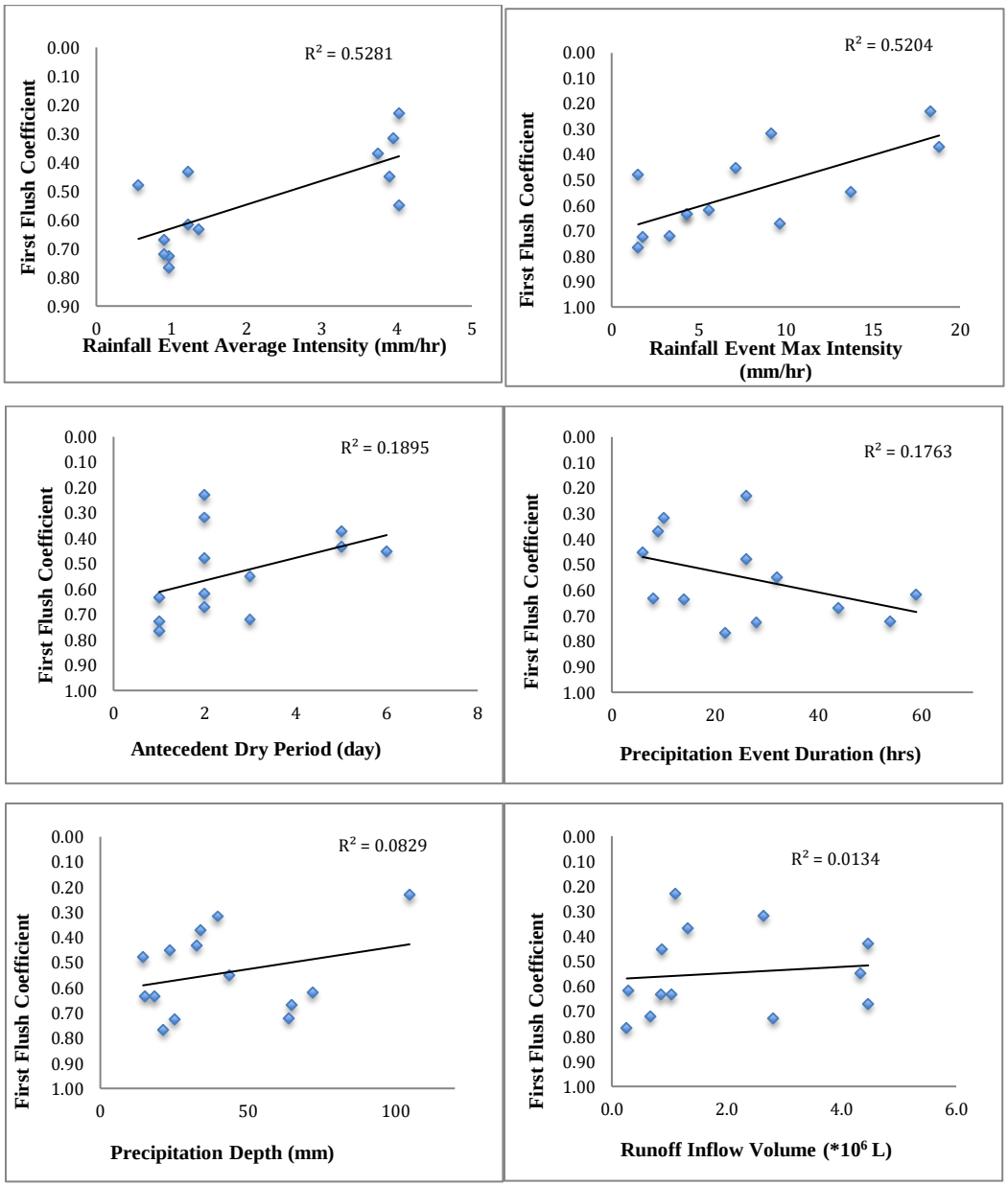


Figure 23. TSS First Flush Coefficient vs. Storm Event Parameters.

Table18. Statistical Results of Correlations Between Storm Event parameters, and TSS and NO_3, respectively

	Linear Coefficients		Spearman Rank Correlation		P Value		r^2 Value	
	TSS	NO_3	TSS	NO_3	TSS	NO_3	TSS	NO_3
Average Rainfall Event Intensity (mm/hr)	-0.73	-0.65	-0.73	-0.71	0.005	0.005	0.53	0.42
Maximum Rainfall Event Intensity (mm/hr)	-0.72	-0.67	-0.64	-0.66	0.29	0.01	0.52	0.44
Antecedent Dry Period (day)	-0.44	-0.36	-0.71	-0.58	0.13	0.03	0.19	0.25
Rainfall Event Duration (hr)	0.42	0.29	0.38	0.37	0.28	0.24	0.18	0.09
Precipitation Depth (mm)	-0.29	-0.27	-0.23	-0.28	0.32	0.26	0.08	0.07
Runoff Inflow Volume (L)	-0.12	0.03	-0.33	0.12	0.57	0.91	0.01	0.001

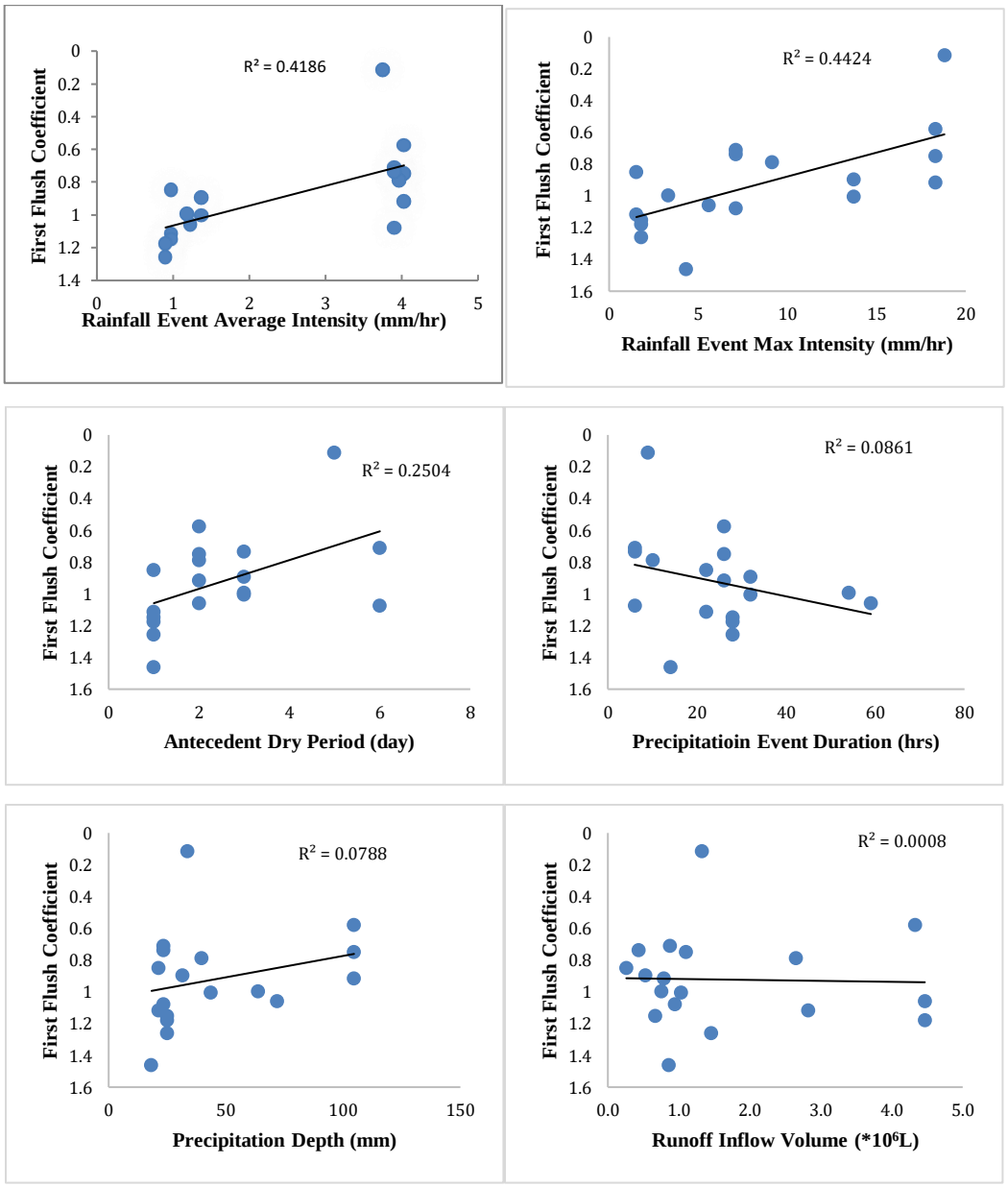


Figure 24. NO_3 First Flush Coefficient vs. Storm Event Parameters

First flush effects were evaluated against wetland performance to investigate a correlation. The first flush coefficient and percentage mass removal (PMR) were compared for wetland BP, to evaluate whether the first flush effect would influence treatment performance. Because wetland FW had two inlets, with one outlet, it was not used for this comparison. The Pearson correlation coefficients for these comparisons can be found in Table 19. The Pearson Correlation can range from -1 to 1. The magnitude of the number reflects the extent to which the parameters are correlated, while the sign indicates whether the correlation is positive or negative. A coefficient ranging from 0.0-0.3 is considered a weak correlation. A coefficient equal to 0.5 is a moderate correlation. A 0.7 correlation coefficient is considered a strong correlation. A perfect correlation has a magnitude of 1.0.

Table 19. Pearson Correlation for Pollutant Attenuation percentage vs First Flush Coefficient value TSS, TDN, NO_3, NH_4, and PO_4.

	TSS	TDN	NO_3	NH_4	PO_4
Pearson Correlation	0.49	-0.17	-0.17	-0.36	-0.74

From Figure 25, it can be seen that the first flush coefficient is positively correlated with percent attenuation for TSS. This suggests that the first flush effect is negatively correlated with attenuation for TSS. This is to be expected because the more consistent the inflow load of TSS, the greater the overall attenuation. Because the first-flush effect can deliver up to 70% of the total load at the beginning of a storm event, it is possible that the elevated concentration is causing a reduction in treatment efficiency.

For PO_4, there was a distinct negative correlation between the first flush coefficient value and pollutant attenuation percentage, indicating a positive correlation between the first flush effect and pollutant attenuation performance. NO_3, NH_4, and TDN each show a slightly negative correlation between the beta value and percent attenuation, suggesting a slightly positive correlation between the first flush effect and the pollutant attenuation performance. It should be noted, however, that the first-flush effect for PO_4, NO_3, NH_4, and TDN was negligible.

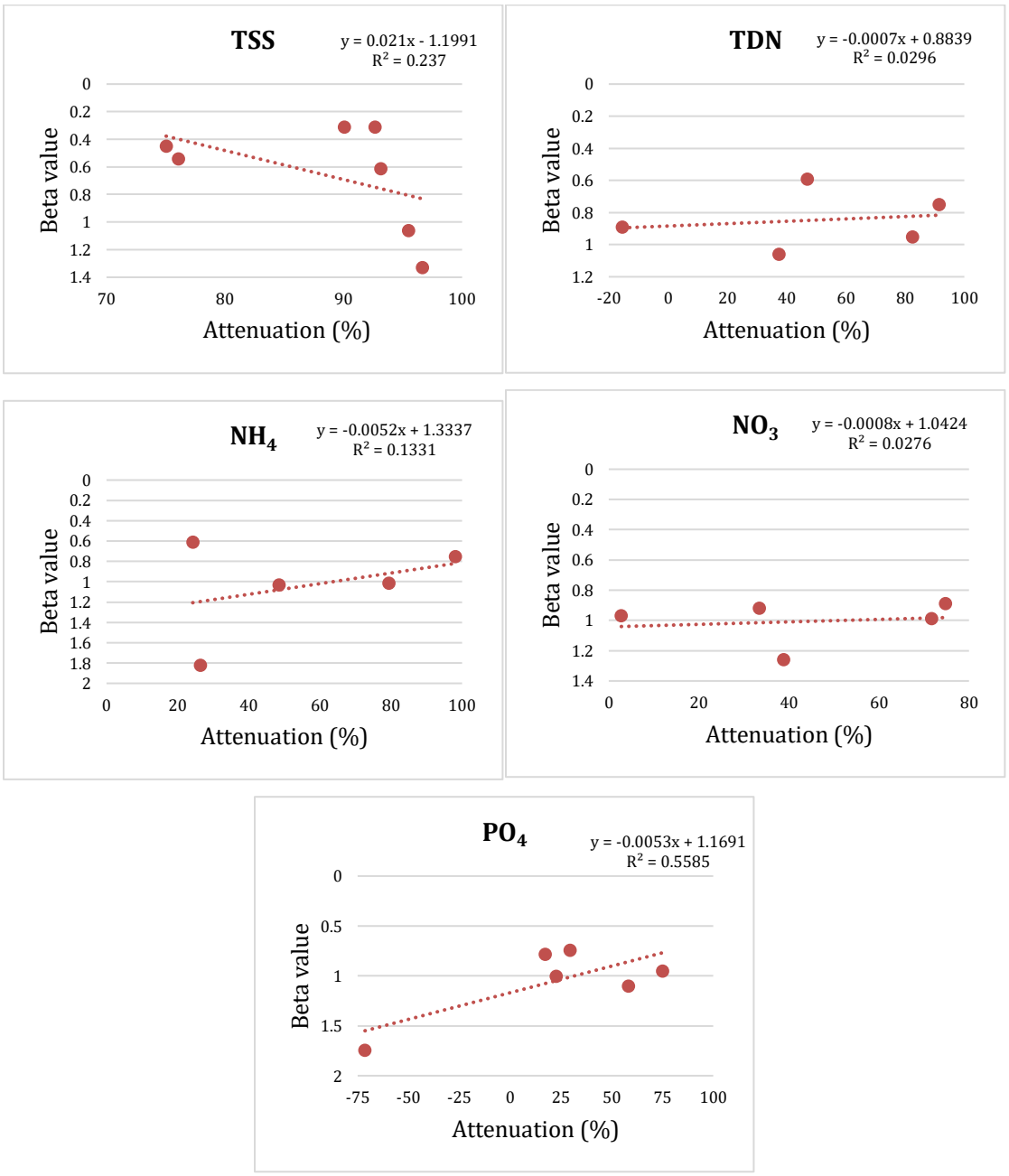


Figure 25. Correlation of Pollutant Attenuation Percentage vs. First-flush Coefficient Value

Conclusion

This research analyzed 14 rainfall events from August 2012 to February 2014; the results of this study showed that:

1) Particulate pollutants tend to have a stronger first flush effect, compared to non-particulate nutrient.
2) First flush effects for particulate pollutants showed variance between sites, which could be caused by differences in catchment land use, contributing drainage area, and/or surface slope.
3) A significant negative correlation was found between the average intensity of rainfall events and the TSS first flush coefficient.
4) The first flush coefficient for NO_3 showed a significant negative correlation with average rainfall event intensity, maximum rainfall event intensity, and ADP.
5) TSS attenuation is positively correlated with first flush coefficient, suggesting that first flush effects are negatively correlated with TSS attenuation.

Future Work

The first flush effect describes a phenomenon where initial surface runoff generated from a rain event results in higher pollutant concentrations being transported, as compared with the remainder of the storm. As a result, a greater quantity of pollutants being discharged into the receiving waters. Future work is needed to further evaluate the correlation between first flush coefficients and pollutant attenuation. With better understanding of the first flush effect on agricultural runoff, future research should also evaluate the effect to which drainage characteristics (land use, area, surface slope, etc.) influences this effect. This can be accomplished through additional field sampling, or through the use of a computer model.

FUTURE WORK

This research sought to evaluate the first flush effects on an engineered wetland, as a function of hydrologic parameters, and the wetland performance for pollutant removal. While this research would have benefitted from a larger data set, particularly with regard to stormflow data, this study was a success. Future research efforts will focus on modeling the wetland systems using AnnAGNPS. In successfully calibrating and validating a model of these study sites, it will be possible to evaluate potential wetland performance under a variety of different conditions. In particular, the calibrated/validated model would be used to evaluate which farm and land management practices may reduce pollutant runoff. Additionally, the AnnAGNPS model would be used to evaluate how wetland performance may change, based on different climate conditions.

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