STORMWATER AND NON-POINT SOURCE POLLUTANTS IN SESSOM CREEK, SAN MARCOS, TX

by

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DEDICATION

A las montañas y arroyos de mi pueblo, Boconó, que me enseñaron a amar la naturaleza.

A mi compañero de aventuras, Brent, por su amor inmensurable.

A mi mamá y hermanita, que siempre me inspiran a luchar por la justicia y la verdad.

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LIST OF ABBREVIATIONS

Abbreviation **Description**

ADD – Antecedent Dry Days

E – Event(s)

EMC – Event Mean Concentration

Escherichia coli – E. coli

ETp2 – accumulated modeled evapotranspiration in the last 2 weeks

ETp8 – accumulated modeled evapotranspiration in the last 8 weeks

LULC – Land Use/ Land Cover

Max RI – Maximum Rain Intensity

N – Nitrogen

NH_4^+-N – Ammonium nitrogen

NO_3^- N – Nitrate nitrogen

NPS – Non-point source(s)

NVSS – Non-Volatile Suspended Solids

P – Phosphorus

Peak Q – Peak Discharge

Rain – Total Event Rain

Rain 1 – accumulated rain in the previous week

Rain 2 – accumulated rain during the 2 previous weeks

Rain Dur – Rain Duration

Rain Int – average intensity of the rainfall

RO – Runoff

SLRM – Simple Linear Regression Models.

SRP – Soluble Reactive Phosphorous

SS – Suspended Solids

TN –Total Nitrogen

TP –Total Phosphorus

TSS – Total Suspended Solids

USMR – Upper San Marcos River

USMRW – Upper San Marcos River Watershed

VSS – Volatile Suspended Solids

ABSTRACT

The primary goal of this project was to evaluate and model the transport (timing and amounts) of non-point source pollutants (NPS) from the Sessom Creek watershed into the Upper San Marcos River (San Marcos, Texas) during storm events. Sessom Creek is a small and heavily urbanized tributary of the Upper San Marcos River, a spring-fed river from the Edwards Aquifer. Runoff is extremely rapid in the high-gradient Sessom Creek watershed, and there are no significant stormwater retention or detention structures in the watershed. Therefore, rapid transport and loading of contaminants from Sessom Creek into the Upper San Marcos River occurs during storm events. This is a concern due to the presence of several federally endangered or threatened species in the river, and its heavy recreational use. Twelve storm events were sampled during 2018 with an ISCO automatic water sampler. NPS pollutants, including total/volatile/non-volatile suspended solids, nutrients (dissolved and total forms of nitrogen and phosphorous), and bacteria (*E. coli*) were analyzed in all samples using standard methods. Results indicate that transport and loading of stormwater pollutants to the river are highly variable and primarily dependent on peak discharge, maximum rain intensity, and runoff volume. Dissolved and total nutrients were significantly related to volatile and non-volatile suspended solids. Increases in discharge and peak of discharge can occur within 5 minutes of rain, and most of the NPS loads are transported during the first hour of a storm event. Peak concentrations of NPS pollutants often occur before the peak flow for each event, suggesting that remediation efforts should focus on detention and retention to avoid transport during the first flush portion of the hydrograph.

I. INTRODUCTION

Description of the problem:

The process of urbanization alters the hydrological cycle by creating impermeable cover, decreasing landscape roughness, increasing runoff, and reducing infiltration and evapotranspiration. These impacts promote a higher frequency and magnitude of floods, increase soil erosion, and increase rates and loads of non-point source (NPS) pollutants inputs to water bodies (Leopold, 1968; Brabec, et al., 2002); consequences of these alterations are magnified during high intensity hydrological events (Carpenter et al., 2016). NPS are diffuse sources of contaminants that are not attributed to a single source (i.e., motor vehicles, construction, agrochemical application, erosion, and animal and human wastes). Pollutants derived from NPS are various and include suspended sediments (total suspended solids, TSS), nutrients, bacteria, agrochemicals, metals, and petroleum-derived hydrocarbons (EPA, 2012).

In urban environments, transport of NPS loads to water bodies is carried via water (e.g., stormwater runoff). Stormwater runoff (or, simply Runoff (RO)) generation in a watershed can be conceptualized using a simple water balance (Equation 1), where RO is equal to precipitation (P) minus the sum of infiltration (I) and evapotranspiration (ET) (Viessman and Lewis, 2002).

$$RO = P - (I + ET) \qquad (1)$$

Large loads of nutrients to water bodies, such as nitrogen (N) and phosphorus (P), can produce eutrophication and harmful algal blooms (Smith et al., 1998; Salameh & Harahsheh, 2010). Suspended solids (SS) are often associated with metals, nutrients, and pesticides due to their adsorption to particles (Bilotta and Brazier, 2008). Elevated SS reduce light penetration in the water column, generate changes in water temperature, and infill channels, subterranean conduits, and/or human-made surface reservoirs (Ryan, 1991; Verstraeten and Poesen, 2000). The effects of sediments deposition can affect a diversity of aquatic organisms, particularly those that are not highly mobile, through smothering benthic aquatic organisms, though the specific effects depend on the exposure time and on the species (Bilotta and Brazier, 2008). Lastly, the bacteria in runoff events can contain pathogenic species, such as *Escherichia coli*, a public health problem worldwide and one of the major causes of human gastrointestinal infection (Momba et al., 2006).

Factors that control NPS pollutants

The magnitude of runoff and associated pollutants transported during storm events depends primarily on their point and non-point sources, watershed properties, antecedent conditions, and rainfall event characteristics, (Nowlin and Schwartz, 2012; Gellis, 2013). Watershed properties include topography, soil types, and land use/land cover (LULC) such as amount of impervious cover. These properties contribute to NPS pollutants export via different mechanisms. For example, watersheds with higher gradients and lower rugosity result in high velocity flows, which is capable of more intense soil erosion (Nowlin and Schwartz, 2012; Paul and Meyer, 2001; Morisawa and La Flure 1979).

Impervious surfaces generate stormwater pollutants differently, depending on material composition, use type, degree of utilization, age, and exposure. Moreover, specific land use like heavily urbanized areas, airports, parking lots, and industrial surfaces can contribute to specialized pollutant loadings such as sediments, heavy metals, and polycyclic aromatic hydrocarbons (Göbel et al., 2007).

Antecedent and environmental conditions such as soil moisture, evapotranspiration, construction activity, biological processes (e.g., pollen production), characteristics of the previous storm events, antecedent dry days, and dry atmospheric deposition (transfer of dust, aerosols, and gas from the atmosphere to the surface) also contribute to the availability of NPS pollutants. For example, more organic material will be available during periods of high biological activity, more time between storms will allow accumulation of materials on surfaces, and construction activities can significantly increase the amount of inorganic sediment accumulated in the watershed (Förster, 1999, Gellis, 2012; Göbel et al., 2007). After large storm-events, accumulated NPS pollutants may be flushed from hillslopes and waterways, and their concentrations in subsequent event may be reduced (Walling and Webb, 1982). Thus, contaminant concentrations can be reduced with a sequence of storms, while the occurrence of small storms may transport pollutants from hillslope to downslopes, making those sediments available for later transportation (Gellis, 2013).

The effects of a given precipitation event on runoff not only depends on the physical and chemical properties of the precipitation (i.e., intensity, magnitude, frequency, pH, and wet atmospheric deposition), but also on interactions between all the factors that control NPS pollutants. (Sharif et al., 2010; Boulomytis, et al., 2017). For example, a high intensity storm event in a small high gradient urban watershed will likely have different pollutant loads and event concentrations of contaminants than a low intensity storm in a large low gradient watershed dominated by agricultural land uses.

One approach to studying mechanisms controlling pollutant transportation during storm events is through hysteresis analysis (McDiffett et al., 1989). Hysteresis is a time-series plot of two variables that are related to each other (e.g., stormwater TSS and discharge), which can used to characterize watershed processes and better understand mechanisms controlling stormwater and sediment transport (Gellis, 2013)

The Upper San Marcos River

This study took place in Sessom Creek; the smallest of four sub-watersheds in the Upper San Marcos River watershed (USMRW, Figure 1), in San Marcos, TX. The USMR originates at San Marcos Springs in Spring Lake before flowing 7.2 km to the confluence with the Blanco River (GBRA, 2013). San Marcos Springs is a large karst spring complex that provides an average of 5m^3/s of high-quality water from the Edwards Aquifer (USGS, 2019). The headwater regions of the USMR (Sink and Purgatory Creeks) are typically dry because they lie on the Edwards Aquifer Recharge Zone; an intensely karstified region with exceptional recharge capacity. As a result, the springs are the only source of water in the river during baseflow conditions. The USMR watershed has experienced significant LULC changes over the last 30 years, including a decline of natural or permeable landscapes (i.e., forest and agriculture) (Nowlin and Schwartz, 2012). NPS pollutant loads during storm events are the primary concern in the USMR due to the presence of several federally endangered or threatened species, the intense recreational use of the river, and the impairment of high-quality and stable water (Meadows Center for Water and the Environment, 2018). Stormwater runoff is of particular concern in the Sessom and Willow Creek watersheds (Figure 1) because they have higher proportions of impervious cover and are located over the transition and artesian zones of the Edwards Aquifer, where karst infiltration is minimal or non-existent (Table 1).

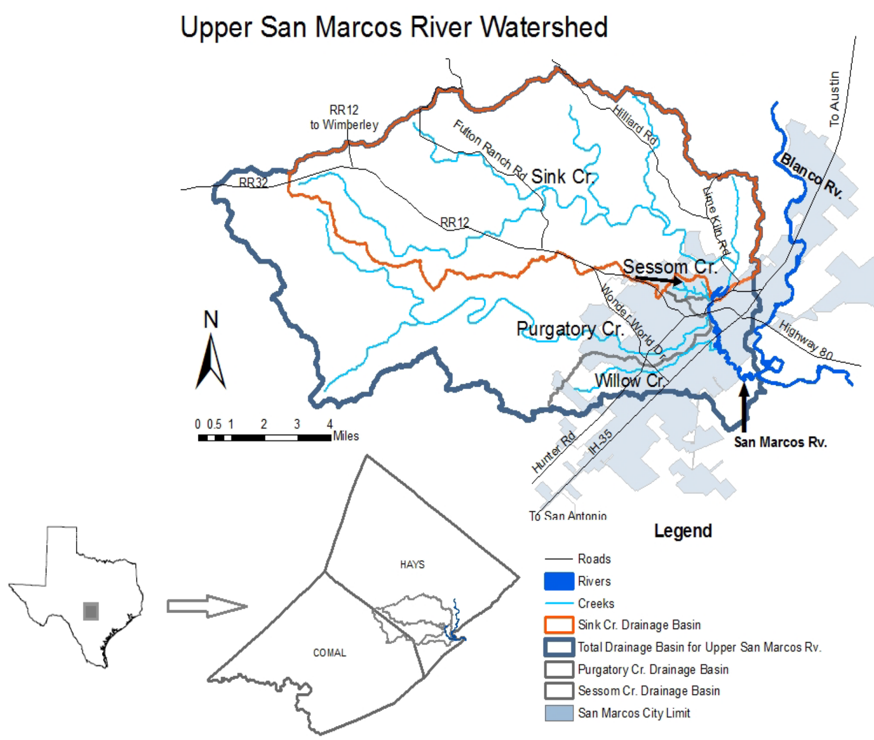


Figure 1: The Upper San Marcos River Watershed and its four sub-watersheds: Sink Creek, Sessom Creek, Purgatory Creek, and Willow Creek in Texas (Nowlin and Schwartz, 2012).

Table 1: Physical characteristics of the sub-watersheds in the Upper San Marcos River watershed.

Sub-Watershed	Area (km^2)	Impervious cover (%) [b]	Channel slope (%) [b]	Proportion of Erodible soils (%) [b]
Sessom Creek	1.6	48	3	44
Willow Creek	10.5	24	<1	8
Purgatory Creek	88[a]	3	<1	4
Sink Creek	100[c]	1	<1	4

[a]Andersen, 2017, [b]Gleason, 2017, [c]Nowlin and Schwartz, 2012.

Study area

Sessom Creek is the smallest (~1.6 km^2) and most highly urbanized (48% of impervious cover) of the four tributaries in the USMRW. Except for a short spring-fed reach at the downstream terminus, Sessom Creek is typically dry (Figure 1 and Figure 2). The lower reach of Sessom Creek is narrow and mainly encased by a concrete channel before its confluence with the USMR. The watershed also has minimal stormwater management, highly erodible soils, and steep slopes, (Table 1) (Gleason, 2017), and storm-related discharge can increase from no-flow to 10's of m^3*s^{-1} in <10 minutes from onset of intense precipitation. Maximum elevation of the Sessom Creek Watershed is ~248 m, and the minimum is ~171 m (Figure 3).

Climate in San Marcos, TX is semi-arid, with mean annual precipitation of 838 mm/yr (2007 to 2017). May, September, and October are on average the wettest months, while February and August are the driest period (National Oceanic and Atmospheric Administration, NOAA, 2017). The maximum mean temperature is 37°C during the hottest months (July and August), and coldest months are December and January (NOAA, 2017).

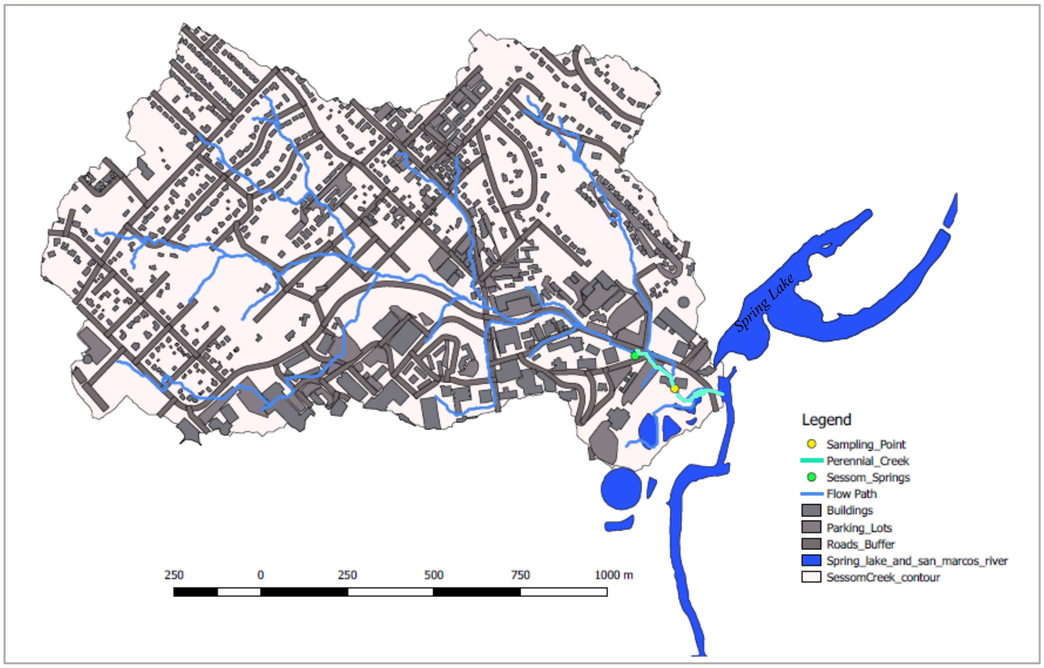


Figure 2: The Sessom Creek Watershed. Impervious cover is shown in grey (buildings, parking lots, and roads), and areas without features indicate permeable land. Flow paths illustrated are normally dry and only carry water during storm events.

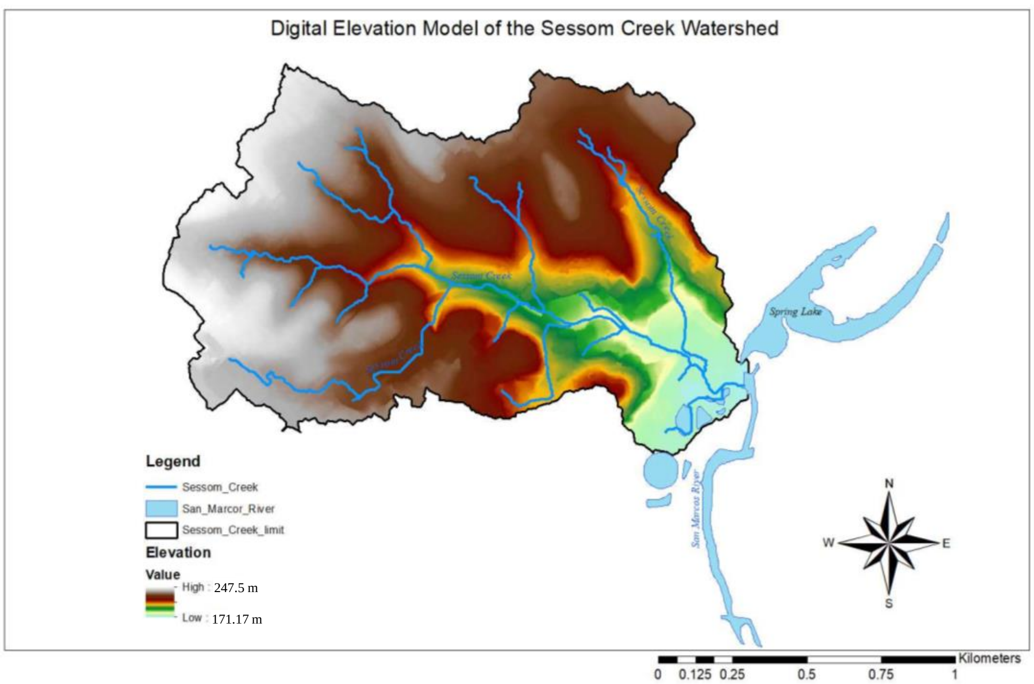


Figure 3: Digital Elevation Model of the Sessom Creek Watershed, San Marcos, Texas.

The Sessom Creek Watershed has six soil types (Figure 4), with three comprising 78% of the area: 1) Comfort-Rock outcrop complex (CrD) = 28%; 2) Doss silty clay (DoC) = 26.2%; 3) Eckrant-Rock outcrop association (ErG) = 24%. CrD has 1-8 % convex slopes, low to medium runoff, low permeability, and low available water capacity. DoC has 1 to 5% slopes and are well-drained. ErG soils have convex slopes from 8 to 30 percent. ErG are typically well drained, and their surface runoff is rapid (Batte, 1984). A full description of the soil units in Sessom Creek is provided in Appendix A.

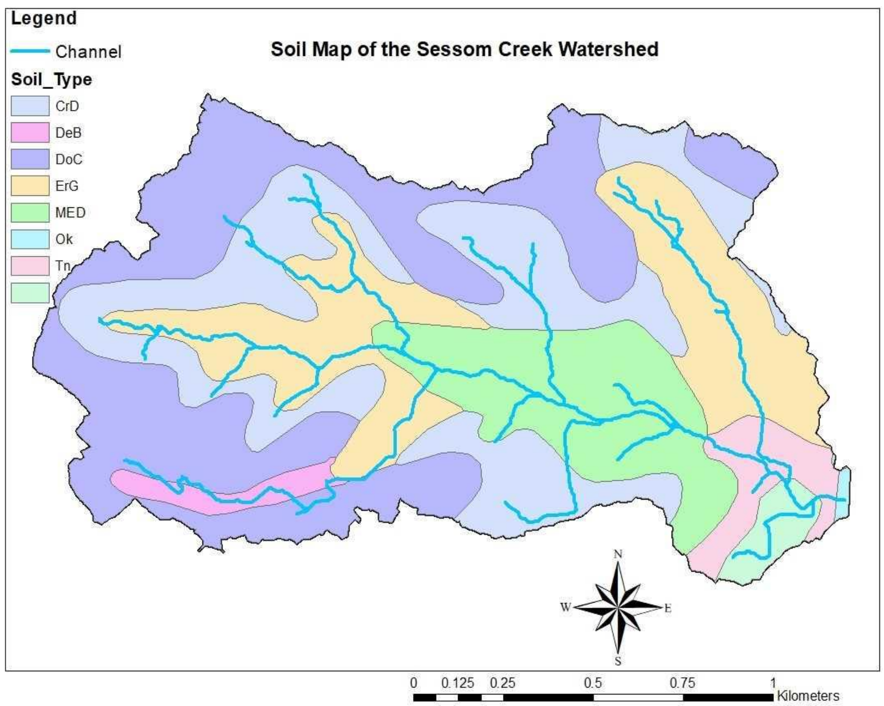


Figure 4: Soil units of the Sessom Creek Watershed (Data from USDA): Comfort-Rock outcrop complex (CrD), Denton silty clay (DeB), Doss silty clay (DoC), Eckrant-Rock outcrop association (ErG), Medlin-Eckrant association (MED), and Tn (Tinn clay).

There is no published water quality data for Sessom Creek, and most previous monitoring efforts have focused on baseflow conditions of the USMR itself. In 2010 and 2012, the USMR was classified as impaired for total dissolved solids (TDS) (TCEQ, 2011; TCEQ, 2013). More recently, the 2014 Texas Integrated Report of EPA—where impaired water bodies of Texas are shown in the 303(d) List—did not include the USMR as impaired by any parameter (TCEQ, 2014). A reason for this improvement could be related to existing structural and non-structural watershed-based management efforts from different stakeholders in the USMRW, including Best Management Practices (BMPs), regulations, ordinances and educational efforts. On the other hand, the Guadalupe Blanco River Authority (GBRA, 2013) analyzed nutrients concentrations approximately once every two months for a period of 10 years and found a rising trend of nitrate- nitrogen (NO_3^--N) from an average of 0.8 to 1.4 mg/L from 2002 to 2012. Increments of NO_3^--N during baseflow are possible correlated with NPS pollutant transportation via groundwater recharge (Meadow Center for Water and the Environment, 2018).

Study Objectives

The primary goal of this study was to quantify and statistically model factors controlling transport, loads, and concentrations of stormwater-associated NPS pollutants from the Sessom Creek watershed to the Upper San Marcos River during 12 storm events, with the goal of providing information that can be used to develop better management practices (BMPs). Specifically, I hypothesized that:

1) The magnitude of NPS contaminant loads and concentrations during storms will depend on environmental factors (i.e., rainfall amount and rainfall intensity), and antecedent conditions (i.e., antecedent rain and evapotranspiration).

2) The relationship between NPS pollutants and discharge during storm events will follow a type one hysteresis (Gellis, 2013), where the peak concentrations of contaminants are reached before peak discharge.

II. METHODS

Hydrological and water quality data

An ISCO automatic water sampler was used to collect 24 1-L samples per storm event (event), during 12 events between March and September, 2018. Samples were collected beneath the Freeman Aquatic Building of Texas State University, San Marcos, TX (29º 53’ 23” N 97º 56’ 09” W) located near the confluence of Sessom Creek with the USMR (Figure 2). The sampler was triggered by a liquid-level sensor set ~5 cm above the creek’s non-storm water level. Sampling was non-linear and targeted high concentrations of contaminants in the rapidly rising and falling stormwater hydrograph, with fewer samples monitoring the receding limb: 6 bottles at 3-minute intervals, 6 bottles at 5-minute intervals, 6 bottles at 10-minute intervals, and 6 bottles at 30-minute intervals. In addition, 3 samples were collected to determine background levels of all analytes during baseflow conditions. During each event, two field duplicate samples of 1L were randomly taken during one of the twenty-four ISCO samples. After sampling, bottles were placed on ice and/or refrigerated for no more than 48 hours until appropriate processing/preservation.

Continuous discharge (*Q*) was calculated using the cross-sectional area of the channel, and water level and velocity data collected by the Sessom Creek NOAA gauge (NOAA National Severe Storms Laboratory, 2019). Turbidity was obtained from two different sources: 1) measured continuously during storm events with a YSI 6920-V2 sonde with a 6136 turbidity probe (Edwards Aquifer Research and data center, unpublished.), and 2) continuous measurement using Eureka brand water quality (Edwards Aquifer Authority, unpublished).

Samples were analyzed in the Nowlin-Schwartz Lab at Texas State University for the following parameters: total nitrogen (TN), total phosphorus (TP), soluble reactive phosphate (SRP), ammonium-nitrogen (NH_4^+-N), nitrate-nitrogen (NO_3^--N), total suspended solids (TSS), non-volatile suspended solids (NVSS), volatile suspended sediments (VSS), Total Coliforms (TC), and *E. coli.*

Samples were processed and analyzed within 24 hours of collection for bacteria and preserved within 48 hours for all other parameters. For analysis of TSS, NVSS, and VSS, a known volume of the homogenized sample was filtered using Pall A/E (1µm nominal pore size) pre-ashed filters. After filtration, filters were dried at 60 °C for 48 h, weighed, combusted at 500 °C for 4 hours, and re-weighed. Mass loss was used to quantify TSS, NVSS, and VSS (Eaton *et al.*, 1995). Filtered samples were used to analyze dissolved nutrients, while total nutrients were measured on unfiltered sample. Both filtered and unfiltered samples were preserved with sulfuric acid (H_2SO_4) for dissolved and total nutrients respectively, while unfiltered samples were preserved with nitric acid (HNO_3) for total Cu. All samples were stored in clean 125 mL HDPE bottles (Eaton *et al.*, 1995).

TP and SRP analyses used the ascorbic acid method (Eaton *et al.*, 1995). TN was quantified using second-derivative spectroscopy on a Varian 50S UV/VIS Spectrophotometer (Crumpton et al., 1992). NH_4^+-N was measured using methods modified from Wetzel and Likens (2000).

TC and *E. coli* were determined using the Enzyme Substrate Coliform Test (9223 A and B procedures) by doing the multiple-well procedure. Chromogenic substrate (ortho-nitrophenyl-β-D-galactopyranoside (ONPG)-based) was inoculated and mixed into 100 mL of diluted sample (dilutions varied from 1/10 to 1/50), then incubated at 35±0.5 ºC for 24. If the β-D-galactosidase enzyme hydrolyzes the substrate, the medium turns yellow indicating a positive test for TC. The presence of *E. coli* is determined if fluorescence occurs (Eaton et al., 2005).

Finally, total Cu was determined with the direct air-acetylene flame method on an atomic absorption spectrometer (Eaton et al., 2005). This procedure was only used to analyze samples from event 1, the largest event. However, because total Cu was below the Minimum Detection Limit (MDL) in all samples, no additional analyses were performed.

During baseflow conditions, TSS, VSS, and NVSS were measured 3 times. TN, TP, NO_3^--N, were monitored twice, and SRP and NH_4^+-N only once.

Loads, Event Mean Concentrations (EMC), and hysteresis determination.

Total loads for each storm event were calculated by multiplying *Q* by the concentration (mass/L) of each variable at a given sampling time, and then integrating these estimates across the hydrograph of a storm event. EMC was determined by dividing the total load by total *Q* for each storm event. Hysteresis curves were obtained by plotting TSS and *Q* concentrations in the rising and falling limb of the hydrograph.

Meteorological Data

Precipitation, temperature, dew point, and barometric pressure data were obtained from Weather Underground (Sessom Creek KTXSANMA24 Station). Potential evapotranspiration was calculated using the Penman-Monteith equation (Allen, 2005) through the Daily Reference Evapotranspiration Calculator program (Synder & Eching, 2000). Daily solar radiation was obtained from the University of Texas Pan-American Solar Radiation Lab at Austin, TX (Ramos and Andreas, 2011).

Geospatial analysis

A Digital Elevation Model (DEM) was developed using Light Detection and Ranging (LIDAR) elevation data obtained from the Texas Natural Resources Information System (TNRIS) [http://tnris.org]. LIDAR data were processed in ArcMap 10.6 into a raster layer using the LAS dataset to Raster tool. Hydrology tools from ArcMap were used to compute flow direction, flow accumulation, channels, and delineate the watershed. The LULC map was created using shapefiles from the city of San Marcos and TNRIS. Road centerlines were buffered with a 7.62m-width to estimate road area. Parking lots were digitized in ArcMap using the editor tool and a base satellite image map. Data to create the soil map were downloaded from USDA and clipped to the watershed boundary.

Statistical analyses

Response variables were EMC and total event loads of each of the twelve events, while proposed independent/explanatory variables were: Total rain (Rain), total runoff (RO), duration of the rainfall (Rain dur.), average intensity of the rainfall (Rain Int.), antecedent dry days (ADD), maximum rain intensity (Max RI), maximum discharge rate (Peak Q), accumulated evapotranspiration in the last 8 weeks (ETp8) and in the last 2 weeks

(ETp2), accumulated rain in the previous week (Rain 1), and accumulated rain during the 2 previous weeks (Rain 2). Instantaneous discharge is Q in m^3/s, and runoff (RO) is the total volume of water transported from Sessom Creek into the USMR during an event.

Prior to regression modeling, Pearson correlation matrices were used to test for correlation between NPS loads, EMCs, and explanatory variables. Principal Component Analysis (PCA) was performed to reduce data dimensionality. Both, correlation matrices and PCAs, were performed to understand the degree and significance of correlation between variables and find variables that are most representative of EMCs, loads, and the explanatory variables. Those variables were then prioritized as response variables and predictors in the linear regression models. Additionally, PCA was performed to visualize the spatial distribution of the data, and to find main loading variables (principal components) that could summarize the variance of the variables (Balzarine et al., 2008). Thus, key variables selected through the PCA can be used for management purposes to represent NPS pollutants in Sessom Creek. The Pearson coefficient assumes data normality, but data for event loads were skewed left. To correct for this, two outliers were removed for analysis, and permutation tests with 9,999 permutations were used to test the correlation matrix of the response variables. The function used in R was per.relation(x), where “x” would be the correlation between each set of variables. Statistical analyses were performed using R program (R Core Team, 2017).

As statistical outliers, E1 and E10 were not included in the PCA analyses or correlation tables for loads and environmental variables, because they were about one order of magnitude larger than the other events. E1 and 10 caused a deflation of the standard error around the mean, and inflation of the Pearson coefficient; therefore, only the small and medium events were used when predicting loads. Conversely, all 12 events were included for the EMC analysis, because the mentioned effects were attenuated since loads are divided by discharge.

Simple Linear Regression Models (SLRM) were run to find predictors that best estimated EMCs and loads. Also, surrogate models (those models that predict certain response variables using other response variables) were built by predicting total and dissolved nutrients with suspended solids (TSS, VSS, and NVSS) as predictor variables. These surrogate models can be used for management purposes, and to reduced costs of the direct measurement of nutrients. Some relationships found with SLRM were exponential, and in those cases, the response variable was transformed with natural log (ln).

Despite the identification of key response variables from the correlation matrices and the PCAs (which were the variables recommended for management purposes), in this study, all the response variables were explained by SLRM, with the objective of exploring the main environmental controls on each dependent variable.

III. RESULTS

Baseflow Concentrations

Estimated and measured parameters during baseflow showed that TSS, VSS, and NVSS are essentially 0 mg/L when there is no runoff influence. The very low amount of TSS is mainly in the form of VSS, suggesting that during baseflow conditions, suspended solids were primarily organic matter, such as algae or detritus. TN, NO_3^--N, and NH_4^+-N had an average of 1923 µg/L, 1845 µg/L, and 136 µg/L respectively, which are similar to groundwater concentrations in the region. TP was ~19 µg/L and SRP ~11 µg/L.

Storm Events and Environmental Conditions

Over the sampling period (03/28/2018 to 09/07/2018), twelve storm events (E_i) of different magnitude and intensity were recorded and sampled (Table 2). Figure 5 shows the total daily precipitation (mm/day) and response in discharge in Sessom Creek (Q) (m^3/s) during the monitored time. Events 1 (03/28/2018) and 10 (07/09/2018) had the highest total rainfall (Rain) (132.6 mm and 81.1 mm respectively), Q, and pollutant loads (Figure 5, Table 4). Fifty percent of the events (E3, E4, E6, E7, E11, and E12) had rainfall totals < 27 mm, with the smallest event, E3, taking place on 4/7/2018 with only 5.6 mm of rainfall and a total runoff (*RO*) of 1274 m^3. Four of the twelve events (E2, E5, E8, E9) were ranked as medium magnitude; ranging from 27 mm to 65 mm.

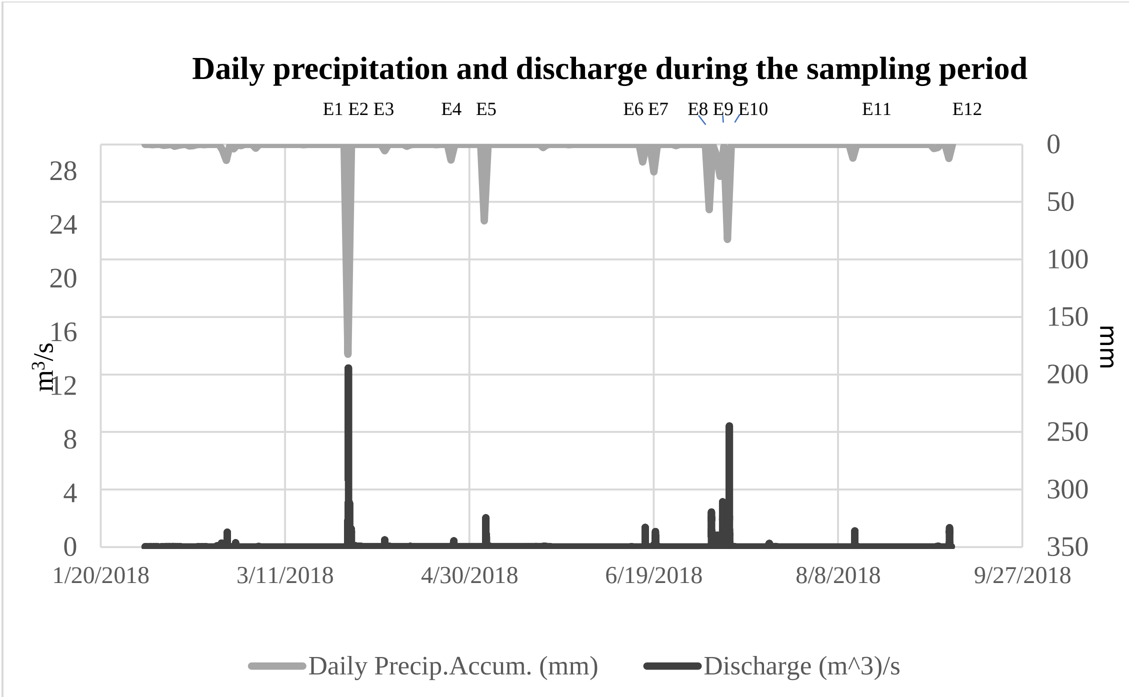


Figure 5: Accumulated daily precipitation (mm) (right axis) and discharge (m^3/s) (left axis) from 02/01/2018 to 09/07/2018. Note that precipitation axis is plotted upside down.

Table 2: **Summary of environmental variables per storm event**: Day (mm/dd) of 2018, Total rain (Rain), total runoff (RO), duration of the rainfall (Rain Dur.), average intensity of the rainfall (Rain Int.), Antecedent dry days (ADD), maximum rain intensity (Max RI), peak discharge (PQ), accumulated evapotranspiration in the last 8 weeks (ETp8), accumulated rain in the previous week (Rain 1), and accumulated rain during the 2 previous weeks (Rain 2).

E	Day (mm/dd/yy)	Rain (mm)	RO (m^3)	PQ (m^3/s)	Rain Dur (min)	Rain Int. (mm/hr)	Max RI (mm/hr)	ETp8 (mm)	ETp2 (mm)	Rain1 (mm)	Rain2 (mm)	ADD
1	03/28/18	132.6	66472	13.3	412	19.3	118.9	147.9	56.32	0.0	0.3	8
2	03/28/18	33.0	14985	3.3	158	12.5	76.2	147.9	56.32	132.6	132.8	0
3	04/0718	5.6	1274	0.9	15	22.4	27.4	167.1	52.1	0.0	182.9	8
4	04/25/18	13.5	2597	0.3	215	3.8	9.1	201.2	58.6	0.3	2.0	3
5	05/04/18	64.8	14667	2.0	318	12.2	125.0	206.7	50.77	0.0	13.7	8
6	06/16/18	15.2	23257	1.2	35	26.1	67.1	291.2	86.5	0.0	0.0	19
7	06/19/18	21.3	4502	1.2	185	6.9	12.2	294.4	81.88	15.8	15.8	0
8	07/04/18	56.6	11268	2.6	160	21.2	82.3	317.4	80.29	0.0	25.4	8
9	07/07/18	27.7	8621	3.4	60	27.7	125.0	315.9	92.35	66.6	67.6	0
10	07/09/18	81.8	28095	9.0	290	16.9	173.7	312.6	81.2	96.0	97.0	0
11	08/12/18	11.9	1844	1.2	145	4.9	42.7	309.5	76.8	0.0	0.0	31
12	09/07/18	12.2	2823	1.4	90	8.1	33.5	315.0	71.18	6.4	6.4	2

Table 3: **Correlation Matrix between environmental and antecedent conditions** (E1 and E2 were excluded). P values were obtained through permutations.

	Rain	**RO**	**Peak Q**	**Rain Dur**	**Rain Int.**	**Max RI**	**ETp8**	**ETp2**	**Rain1**	**Rain2**	**ADD**
Rain	**1.00**	0.47	0.57	0.65*	0.14	0.72*	-0.03	-0.12	0.11	-0.14	-0.18
RO	0.47	**1.00**	0.42	0.04	0.51	0.60*	-0.04	0.16	0.26	-0.11	0.08
Peak Q	0.57	0.42	**1.00**	0.00	0.45	0.78**	0.06	0.22	0.74*	0.29	-0.33
Rain Dur	0.65*	0.04	0.00	**1.00**	-0.60*	0.16	-0.21	-0.4	-0.06	-0.41	-0.12
Rain Int.	0.14	0.51	0.45	-0.60*	**1.00**	0.55*	0.12	0.36	0.12	0.38	-0.04
Max. RI	0.72*	0.60*	0.78**	0.16	0.55	**1.00**	0.07	0.13	0.33	0.04	-0.05
ETp8	-0.03	-0.04	0.06	-0.21	0.12	0.07	**1.00**	0.87**	-0.35	-0.64	0.26
ETp2	-0.12	0.16	0.22	-0.4	0.36	0.13	0.87**	**1.00**	-0.05	-0.42	0.16
Rain1	0.11	0.26	0.74*	-0.06	0.12	0.33	-0.35	-0.05	**1.00**	0.49	-0.44
Rain2	-0.14	-0.11	0.29	-0.41	0.38	0.04	-0.64	-0.42	0.49	**1.00**	-0.30
ADD	-0.18	0.08	-0.33	-0.12	-0.04	-0.05	0.26	0.16	-0.44	-0.30	**1.00**

* indicates p value <0.05
** indicates p value <0.01
Absence of asterisk implies non-significant correlation

Principal Component Analysis (PCA) for the environmental and antecedent conditions

The first three components of the PCA of the environmental and antecedent conditions explained almost 76% of the variance (Appendix B). The variables that most explained the variance in the dataset were Peak Q (Peak_Flow in the bi-plot, Figure 6), Max RI, and ETp2. The strong relation between them suggests that those variables are redundant, and therefore, Peak Q should be the key variable in this group (also strongly negative correlated with principal component 1 (PC1 or Dim1). Total rain and prior rain in the last week (Rain 1) are also positively associated (Figure 6, table 3), but total rain explains more variance, and therefore this should be another key variable. ETp2 and rain duration were strongly negative associated with PC2 (Dim2). These key variables have been prioritized to explain EMCs and total event loads in the SLRM shown on tables 7 and 8.

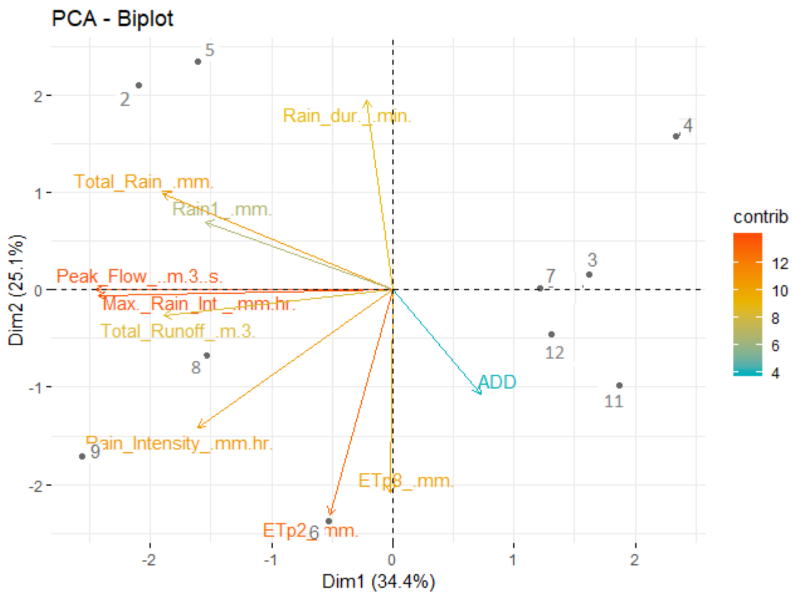


Figure 6: Principal component analysis of environmental and antecedent conditions. Eigenvalues or components are shown as Dim1 and Dim2. Eigenvectors correspond to the loads (vectors); longer vectors indicate that more variance is explained by those variables in the PCA. Numbered circles represent storm events. Events 1 and 10 were excluded from the analysis because their magnitude was much greater than other events.

Load Analyses

Description & Correlations

Total event loads are displayed in Table 4. The largest event loads of SS and nutrients primarily occurred during the largest storms (E1 and E10), although NH_4^+-N loads were highest in E1 and E5 (Figure 7). The largest loads of *E. coli* were during E1, E2, and E6, and their concentrations were higher than the maximum detectable limit (>2419 MPN/100mL, where 100mL corresponded to a diluted sampled with dilution factors between 1/10 to 1/50). Values of *E. coli* could have been inflated due to bacterial growth after sample collection by the ISCO automatic sampler. Samples collection last approximately 5 hours during each event in non-refrigerated conditions. All load variables were positively and significantly correlated with each other, except for the relationship between NO_3^--N and NH_4^+-N with TSS and NVSS, which were positive but non-significant after permutations (Table 5). The strongest correlations were observed between TSS and its two constituent parts: VSS and NVSS. Correlations also existed between TSS and TN, TP, and SRP (Pearson > 0.7). Finally, inorganic dissolved nutrients (SRP, NO_3^--N, and NH_4^+-N) had strong correlations with VSS and TN.

Table 4: Summary of accumulated sediment and nutrient loads per storm, and summarized statistics: mean (x̄), standard deviation (SD), first quantile (1q), second quantile or median (2q), third quantile (3q)

E	TSS [kg]	VSS [kg]	NVSS [kg]	TN [kg]	TP [kg]	NH_4^+-N [kg]	NO_3^- -N [kg]	SRP [kg]	*E. coli* (MPN)
1	36,197.02	6319.83	29877.19	155.73	103.89	11.11	54.49	11.89	>1.52x10^{+15*}
2	2357.85	526.74	1831.11	31.95	6.05	2.01	16.85	2.17	>2.67 x10^{+14*}
3	171.72	83.02	88.7	4.01	0.42	0.25	1.06	0.01	>4.06 x10^{+13*}
4	274.18	101.44	172.74	5.26	0.66	0.44	1.98	0.21	4.26 x10^{+11}
5	2,001.29	529.78	1471.51	24.84	4.63	3.02	7.46	1.41	3.47 x10^{+12}
6	876.2	350.24	525.96	9.81	1.87	0.32	2.81	0.37	>2.88 x10^{+14*}
7	177.72	76.44	101.28	3.9	0.62	0.14	1.59	0.21	9.67 x10^{+11}
8	1878.1	404.24	1473.87	17.22	4.15	0.74	6.55	1.06	1.01 x10^{+12}
9	3410.5	481.62	2928.87	14.41	7.41	0.53	3.75	0.64	1.38 x10^{+12}
10	17,166.74	2749.63	14417.1	58.66	23.38	1.65	17.82	2.71	1.53 x10^{+13}
11	547.52	116.27	431.25	4.84	1.28	0.13	1.76	0.18	1.19 x10^{+12}
12	538.86	123.76	415.1	5.09	1.15	0.29	1.93	0.23	4.57 x10^{+13}
x̄	5466.48	988.58	4477.89	27.98	12.96	1.72	9.84	1.76	3.39E+12
SD	10755.76	1831.57	8928.16	43.32	29.33	3.09	15.21	3.31	5.34E+12
1q	472.69	112.56	354.51	5.03	1.03	0.28	1.89	0.21	9.89E+11
2q	1377.15	377.24	998.74	12.11	3.01	0.49	3.28	0.51	1.19E+12
3q	2621.01	527.50	2105.55	26.62	6.39	1.74	9.81	1.60	2.43E+12

"*": MPN (Most Probable Number) was greater than the maximum detectable.

Table 5: **Correlation matrix between loads.** *P*-values were obtained by performing permutation to test each correlation.

	TSS	VSS	NVSS	TN	TP	NH_4^+ -N	SRP	NO_3^- -N
TSS	1	0.900***	0.996***	0.755**	0.994***	0.522	0.689*	0.603
VSS	0.900***	1	0.856**	0.906***	0.913***	0.738***	0.840***	0.743***
NVSS	0.996***	0.856**	1	0.705*	0.986***	0.464	0.641*	0.559
TN	0.755**	0.906***	0.705*	1	0.808**	0.860**	0.987***	0.940***
TP	0.994***	0.913***	0.986***	0.808**	1	0.569	0.753*	0.679*
NH_4^+ N	0.522	0.738***	0.464	0.860**	0.569	1	0.829*	0.727*
SRP	0.689*	0.840***	0.641*	0.987***	0.753*	0.829*	1	0.973***
NO_3^- -N	0.603	0.743***	0.559	0.940***	0.679*	0.727*	0.973***	1

* indicates p value <0.05; ** indicates p value <0.01; *** indicates p value <0.001
Absence of asterisk implies p values > 0.05.

Load composition

Load composition and magnitudes of TSS, TN and TP (Figures 7 and 8) were variable across the 12 events. Higher percentages of NVSS in TSS (~80%) occurred during higher magnitude storm events (E1, E10, E8 and E9), and conversely, proportions of VSS were higher in smaller events (E3, E4, and E7). In events of high and medium magnitude, VSS was usually between 10-20% of TSS, while in small-magnitude storms, VSS was between 20-45%. Most TP and TN was in particulate, with NH_4^+-N usually comprising less than 10% of TN, and NO_3^--N being the most variable, with the highest % NO_3^--N occurring during E2, E7, and E12. Lastly, SRP varied from ~40% (E2 and E7) to less than 10% (E3 and E9) of TP.

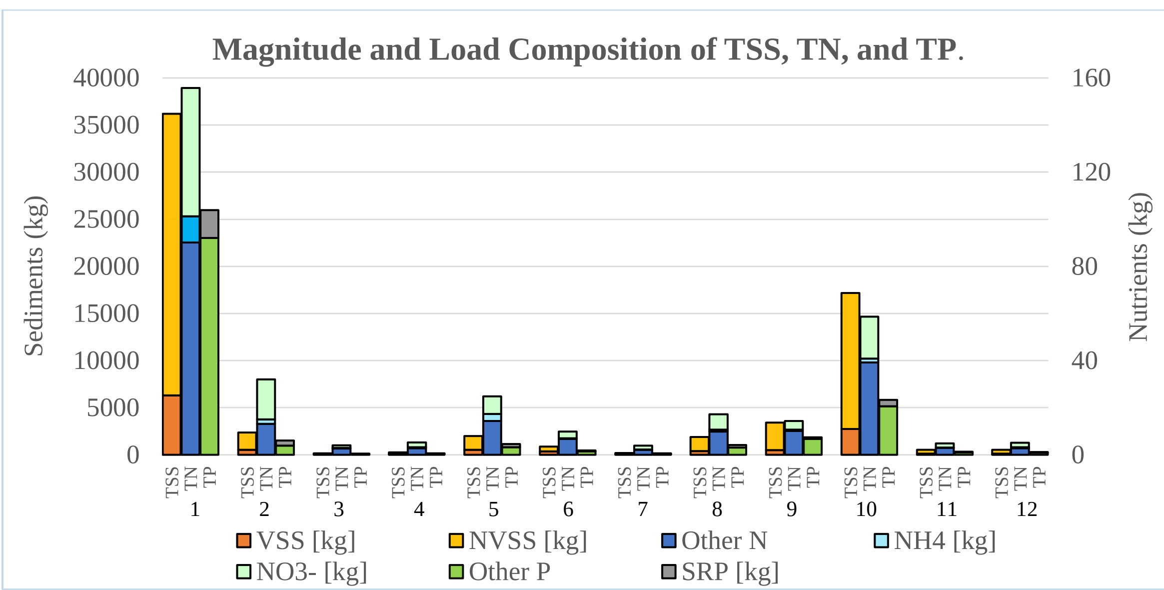


Figure 7: Load compositions. "Other N" and "Other P" correspond to parts of TN and TP that are particulate.

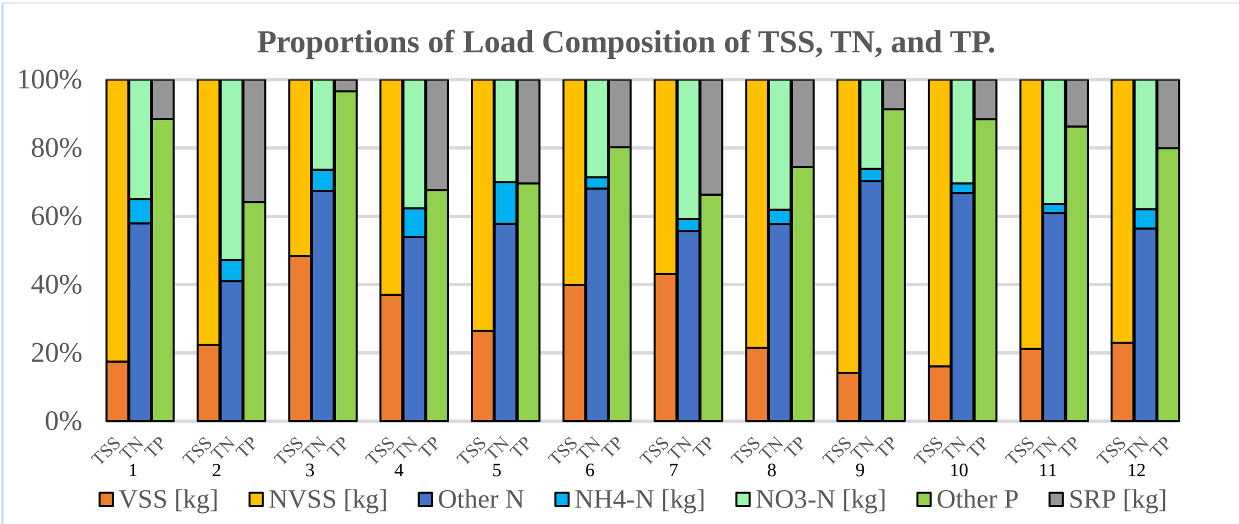


Figure 8: Percentage of the composition of the TSS, TN and TP loads. "Other N" and "Other P" correspond to the part of TN and TP that are particulate .

Principal Components Analysis – Loads

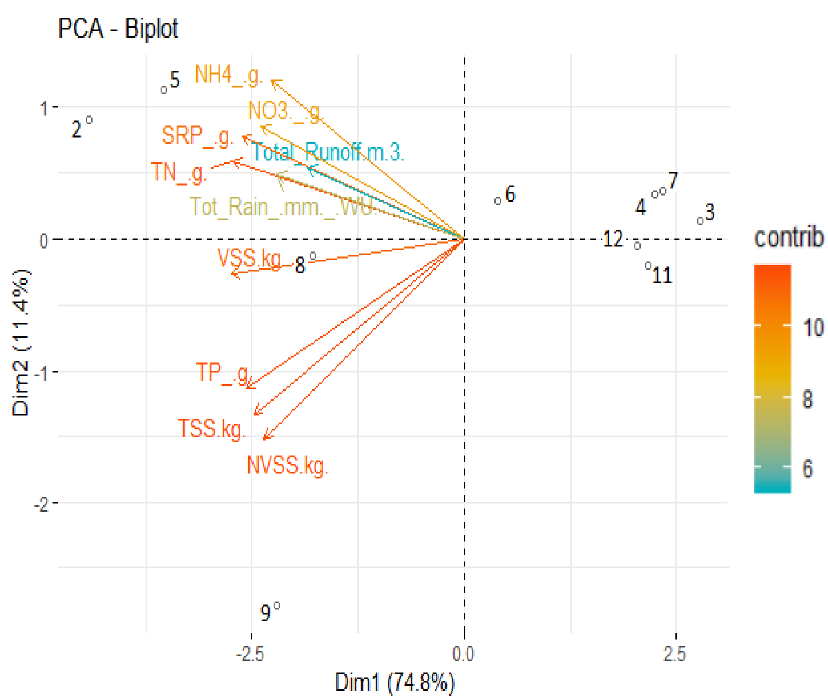


Figure 9: Principal component analysis of total event loads. Eigenvalues or components are shown as Dim1 and Dim2. While eigenvectors correspond to the loads (vectors); longer vectors indicate that more variance of those variable are explained by the PCA. Numbered circles represent storm events, with events 1 and 10 excluded from the analysis because their magnitude was much greater than other events.

Storm events of smaller magnitude were positively associated with PC1, while events of medium magnitude (>27 mm) were negatively associated with PC1 (Appendix D). VSS was more strongly associated with nutrients than was NVSS, except that TP was strongly associated with NVSS and TSS. PC1 explained 75% of the variance, and the first 3 components together explained 93% (Appendix C). Also, the bi-plot shows that event 9, despite being the smaller of the medium events (27 mm <E9< 60 mm), was associated with higher loads magnitude of TSS, NVSS, TP, and VSS in comparison with all the small and medium events. All the other load variables were larger and similar during events 2 and 5, despite those events being very different in magnitude (33 mm and 65 mm respectively).

The PCA and correlation matrix of total event loads (Table 5 and Figure 9) show that TSS, VSS and TN are the key response variable for loads, and they can be used to represent the other variables.

Event Mean Concentrations (EMC) Analyses

Description and correlations

The highest TSS EMCs occurred during E1 and E10, followed by E9, E11, and E12 (Table 6 and Figure 10), and the lowest EMCs were observed in E2 to E8, where RO had different magnitudes. In contrast with SS, the highest TN EMCs were during small magnitude events (E3 and E11) with 3148.92 µg/L and 2623.27 µg/L respectively. The highest EMC of NH_4^+-N was observed in E5 (206.13 µg/L), while NO_3^--N reached its maximum in E2 (1124.41 µg/L), followed by E3 and E1 (Table 6 and Figure 11). E1, E9, and E10 showed the highest EMC of TP, and E1 and E2 had higher mean concentrations of SRP. In general, EMCs of nutrients and sediments were lower for E6 and E7. EMCs of TN, NO_3^--N, and NH_4^+-N were comparable with those observations made during baseflow conditions. Contrarily, EMCs of SS, TP and SRP were orders of magnitude higher in comparison with concentrations during baseflow; the only exception was the EMC of SRP for E3, which was similar to SRP concentration during baseflow conditions, probably because this event was the smallest event.

Table 6: **Event Mean Concentration of SS and nutrients for each storm event.** Summary statistics are shown below: mean, ±1 SD, first quantile, second quantile (median), and third quantile.

Event	Date [mm/dd/yr]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [μg/L]	TP [μg/L]	NH_4^+-N [μg/L]	NO_3^--N [μg/L]	SRP [μg/L]
1	3/28/2018	544.54	95.07	449.47	2342.80	826.23	167.14	819.68	178.88
2	3/28/2018	157.35	35.15	122.2	2132.02	403.67	134.25	1124.41	144.94
3	4/7/2018	134.78	65.16	69.62	3148.92	325.84	196.26	829.87	11.28
4	4/25/2018	105.59	39.06	66.53	2027.26	254.09	171.06	764.07	82.28
5	5/4/2018	136.45	36.12	100.33	1693.49	315.44	206.13	508.31	95.86
6	6/16/2018	37.68	15.06	22.62	421.74	80.58	13.77	120.63	15.98
7	6/19/2018	39.48	16.98	22.5	865.43	136.65	30.88	352.84	45.95
8	7/4/2018	166.67	35.87	130.8	1527.78	367.88	65.35	581.26	93.88
9	7/7/2018	395.59	55.86	339.73	1671.03	859.12	60.98	435.48	74.15
10	7/9/2018	611.02	97.87	513.15	2087.73	832.17	58.56	634.43	96.54
11	8/12/2018	296.86	63.04	233.82	2623.27	693.96	70.79	954.51	95.03
12	9/7/2018	190.85	43.83	147.02	1804.43	408.58	101.79	685.21	82.27
Mean		234.74	234.74	49.92	1862.16	458.68	106.41	650.89	84.75
±1 SD		189.05	189.05	26.69	730.22	274.82	66.25	275.15	47.38
1st Quantile		127.48	127.48	35.69	1635.22	300.10	60.37	490.11	67.10
Median		162.01	162.01	41.45	1833.29	385.77	86.29	642.66	83.52
3rd Quantile		250.27	250.27	57.66	2042.38	517.50	122.58	704.92	94.17

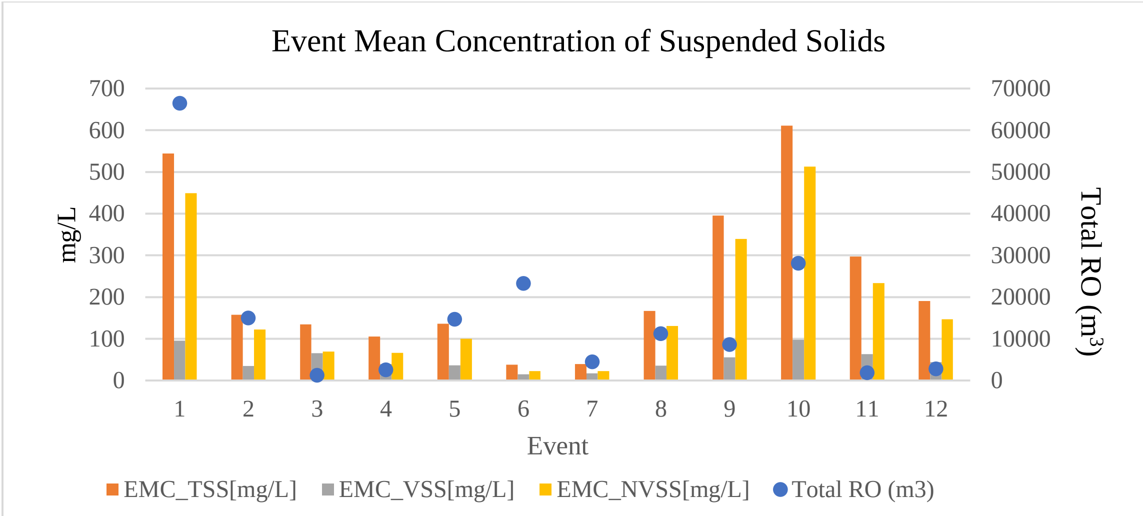


Figure 10: Event Mean Concentrations of total/volatile/and non-volatile suspended solids (bar graphs and left axis), and total runoff (RO) (blue dots and right axis).

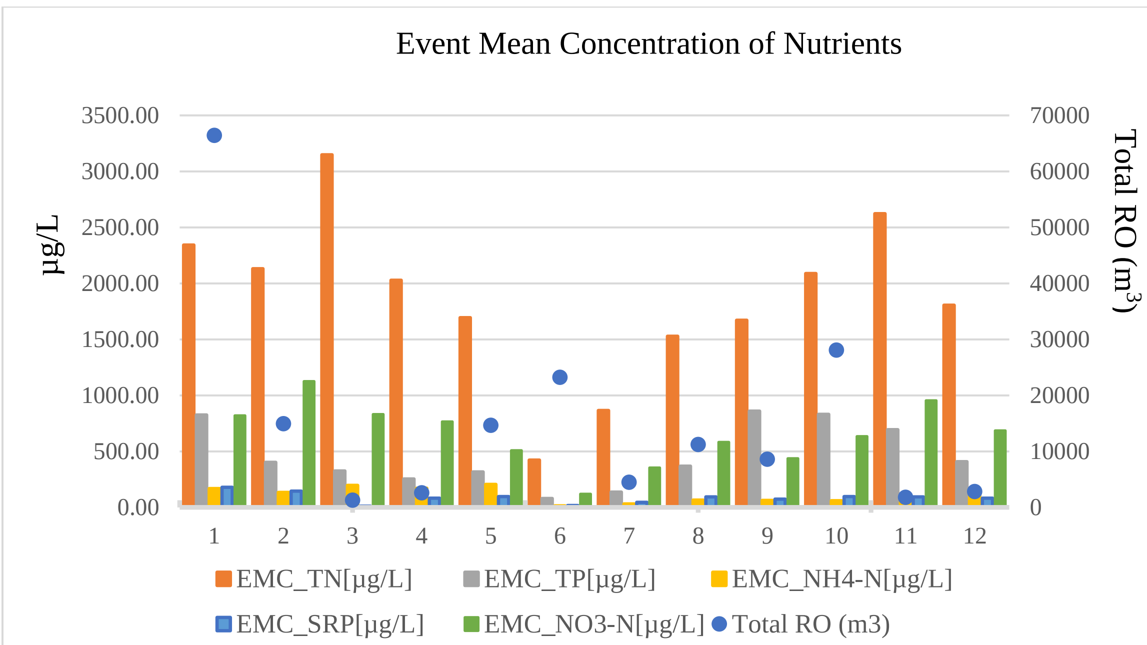


Figure 11: Event Mean Concentrations of Nutrients. Total Nitrogen (TN), Total Phosphorous (TP), ammonium (NH_4^+-N), Soluble Reactive Phosphorous (SRP), and nitrate (NO_3^--N) (bar graph and left axis), and total runoff (RO) (blue dots and right axis).

Correlations between EMCs (Table 7, Figure 12) are positively strong between TSS, NVSS, VSS, and TP (Pearson >0.7; p <0.001). TN was positively strongly correlated with VSS, NO_3^--N, and NH_4^+-N. Finally, SRP was weakly positive correlated with most of the variables, and it was better correlated with TSS (Pearson= 0.61, p value <0.05)

Table 7: Correlation matrix of EMCs. P values were obtained by performing permutation for each correlation. All events were included in this table.

	TSS	VSS	NVSS	TN	TP	NH_4^+-N	SRP	NO_3^--N	Rain	RO
TSS	1	0.76***	0.99***	0.42	0.96***	0.03*	0.61*	0.31	0.44*	0.30*
VSS	0.76***	1	0.76***	0.72**	0.74***	0.31	0.29	0.45	0.09*	-0.04
NVSS	0.99***	0.76***	1	0.41	0.96***	0.02	0.60*	0.31	0.43*	0.34*
TN	0.42	0.72**	0.41	1	0.45	0.59*	0.40	0.91***	-0.17	-0.24
TP	0.96***	0.74***	0.96***	0.45	1	0.02	0.50*	0.35	0.31*	0.19
NH_4^+-N	0.03*	0.31	0.02	0.59*	0.02	1	0.33	0.58*	0.01	-0.20
SRP	0.61*	0.29	0.60*	0.40	0.50*	0.33	1	0.49*	0.64**	0.51
NO_3^--N	0.31	0.45	0.31	0.91***	0.35	0.58*	0.49*	1	-0.20	-0.25
Rain	0.44*	0.09*	0.43*	-0.17	0.31*	0.01	0.64**	-0.20	1	0.87**
RO	0.30*	-0.04	0.34*	-0.24	0.19	-0.20	0.51	-0.25	0.87**	1

* indicates p value <0.05
** indicates p value <0.01
*** indicates p value <0.001
Absence of asterisk implies non-significant correlation

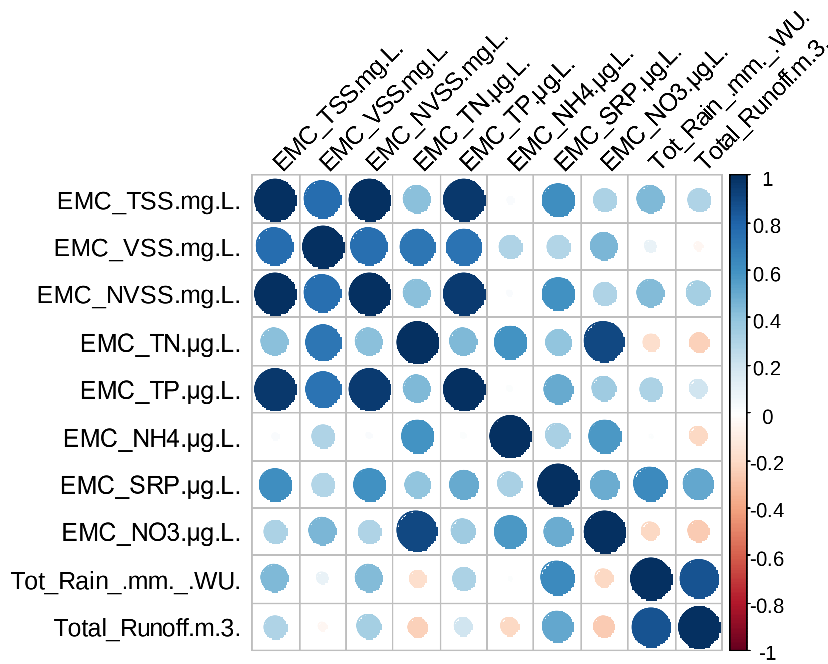


Figure 12: Circle graph of the correlation matrix of EMCs, total rain and total runoff.

Principal Component Analysis of Event Mean Concentrations

The PCA using EMCs indicates that the first three components explain 90% of the variance (Appendix E). PC1 was negative correlated with E1 and E10 (large magnitude events), and positively correlated with most of the small-magnitude events (Figure 13), suggesting that total runoff and rain still play an important role in the explanation of EMCs. The PCA shows a strong association between suspended solids (TSS, VSS, NVSS), TP, SRP, Total Rain, and RO. These variables were usually positively associated with PC2 (except for VSS and SRP), and negatively associated with PC1. TN, NO_3^-, and NH_4^+ were grouped together and negatively correlated with PC1 and PC2. For environmental management purposes, according to this PCA and the correlation matrix (Table 7) EMCs of TSS, VSS and TN are the most representative variables of this dataset.

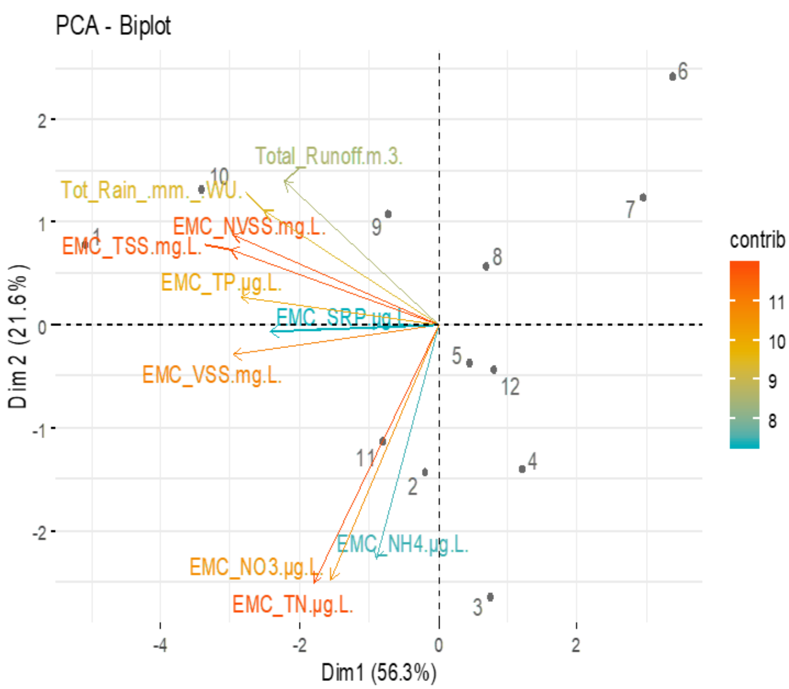


Figure 13: Principal Component Analysis of EMCs. Eigenvalues or components are shown as Dim1 and Dim2. Eigenvectors correspond to the EMCs variables vectors; longer vectors indicate that more of the variance in a variable is explained by the PCA. Circles describe events.

Linear Regression Models

Selection of the best predictors explaining EMCs and loads was based on the R^2, p values, and the key variables derived from PCA of the environmental and antecedent conditions.

Simple Linear Regressions (SLR) to estimate EMCs.

The best predictor to estimate EMCs of TSS were Peak Q ($R^2 = 0.83$, p value < 0.0001***). TP was strongly correlated with TSS ($R^2 = 0.88$, p value < 0.0001***), and TN with VSS ($R^2 = 0.46$, p value = 0.01*). For dissolved nutrients, the more significant predictor for SRP was rain duration, while ETp2 was significant for NH_4^--N and NO_3^-N. Notice that it is not possible to build multiple linear regression models that include RO, Peak Q, Max RI, and SS because those variables are highly correlated with each other (Appendix G) and the assumption of non-collinearity would be violated (Hoffmann, 2016). Table 7 shows the summary of SLR models performed for EMCs and a scatter plot of the main variables is provided in Appendix H. The intercept was forced through the origin when RO and Peak Q were used as predictors because it can be assumed that any concentration of NPS pollutant will be “0” when there is not runoff or discharge. However, this inflated the R^2, p value, and residual standard error of the models.

Table 8: **Best regression models to estimate EMCs.** All storm events are included.

Y	Predictor	Equation	ε	F	R^2	p value
TSS	Rain	TSS = 98.54 + (3.43*Rain)	143.9	8.996	0.4736	0.01 *
	Peak Q	TSS = (54.26* Peak Q)	126.8	54.58	0.83	1.38e-05 ***
TP	Peak Q	TP= (88.17* Peak Q)	306	25	0.66	0.0004***
	TSS	TP = 138 + (1.36*TSS)	98.29	76	0.8837	5.51e-06 ***
TN	VSS	TN=934.73+(18.58*VSS)	562.2	8.56	0.4612	0.0151 *
SRP	Rain	SRP =49.26 + (0.89*Rain)	34.7	10.5	0.5123	0.00885 **
	Rain Dur	SRP= 34 + (0.29*Rain Dur)	33.59	11.88	0.5429	0.00626 **
	Peak Q	SRP= (15.9* Peak Q)	56.65	23.56	0.68	0.000508 **
NH_4^+-N	ETp2	NH4 = 405 + (-4.25*ETp2)	23.05	7.45	0.8899	4.18e-06 ***
NO_3^--N	ETp2	NO3=1430 + (-11.09*ETp8)	232.3	5.432	0.352	0.04201 *

DF = 10, for all models, except for RO and Peak Q, which was 11.
ε= residual standard error
Note: Intercept was forced to the origin when using RO and Peak Q as predictors.

Simple Linear Regressions (SLR) to estimate Loads

TSS was the best explanatory variable for TP (p value < 0.001***, R^2 = 0.99), while VSS was the key predictor for dissolved nutrients (SRP, NO_3^--N, and NH_4^+-N). Environmental conditions that were significant in the prediction of total event loads were Max. RI (p value < 0.001***, R^2 = 0.82) and Peak Q (p value < 0.001***, R^2 = 0.91) for TSS; Max. RI (p value < 0.001***, R^2 = 0.78), Peak Q (p value < 0.001***, R^2 = 0.90); amount of accumulated rain since the previous week (Rain1) (p value = 0.03*, R^2 = 0.46) for TP; and, total rain (p value = 0.02*, R^2 = 0.54), Max. RI (p value = 0.02*, R^2 = 0.51), Peak Q (p value = 0.0009**, R^2 = 0.9), and Rain1 (p value = 0.04*, R^2 = 0.44) for TN. Only the best of those predictors is shown in Table 9. A scatter plot of the main load and explanatory variables is available in Appendix I.

Table 9: **Best regression models for NPS pollutant loads**. Other possible models are shown to illustrate, for comparison purposes, how well they predicted the loads.

Y	Predictor	Equation	ε	F	R^2	p value
TSS	Peak Q	TSS= 774.63* Peak Q	493.7	98.56	0.91	3.8e-06 ***
TN	Total Rain	ln(TN)= 1.39+(0.03*Rain)	0.52	12.84	0.6162	0.00715 **
	Peak Q	ln(TN)=1.11* Peak Q	0.75	88.33	0.9	5.98e-06 ***
	VSS	ln(TN)=1.11+(0.0039*VSS)	0.1887	150.3	0.9495	1.82e-06 ***
TP	Total Rain	ln(TP) = -0.35+(0.036*Rain)	0.7802	7.836	0.4948	0.0232 *
	Peak Q	TP=-1.78* Peak Q	1.04	117.1	0.92	1.85e-06 ***
	TSS	TP=0.07 +(2.255^{-3}*TSS)	0.2879	690.4	0.9903	2.43e-09 ***
SRP	Total Rain	ln(SRP)=-2.55+(0.05505*Rain)	1.102	8.974	0.5287	0.01719 *
	Peak Q	SRP=0.4* Peak Q	0.48	28.88	0.7624	0.000448 ***
	VSS	SRP=-0.17+(0.003*VSS)	0.3987	19.23	0.7063	0.00233 **
NO_3^--N	Peak Q	log(NO3)=0.65* Peak Q	0.53	60.26	0.87	2.8e-05 ***
	Rain1	NO3 = 2.65 +(0.09*Rain1)	3.138	13.28	0.6241	0.00654 **
	VSS	NO3 = 0.06 +(0.0038*VSS)	0.4025	32.64	0.8031	0.000448***
NH_4^+-N	Total Rain	NH4=-1.82+(0.04*Rain)	0.6951	12.06	0.6012	0.00841 **
	Rain Dur	NH4=0.16+(0.007*Rain_Dur)	0.7644	6.162	0.4351	0.038 *
	VSS	ln(NH4)=2+(0.004445*VSS)	0.5941	19.46	0.7087	0.002251 **

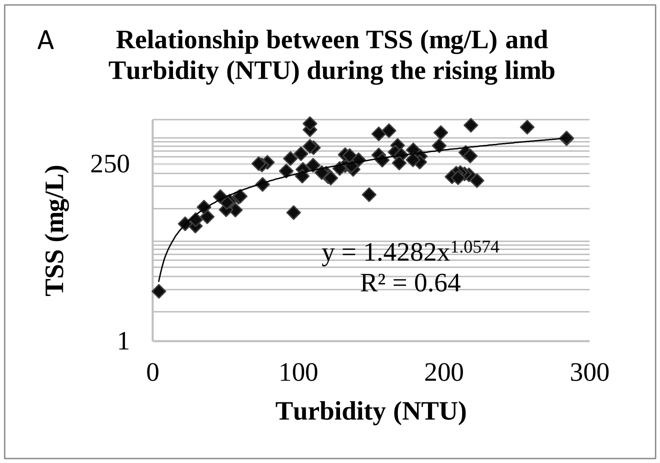
DF = 8, for all models, except for RO and Peak Q, which was 9.
ε= residual standard error
Note: Intercept was forced through the origin when using RO and Peak Q as predictors.

Hysteresis characteristics

Time series of TSS *vs Q* were plotted, and eight of the twelve storm events were characterized as a Type 1 hysteresis, in which peak TSS occurs during the rising limb of the hydrograph, and before peak discharge; resulting in a clockwise loop. Hysteresis type 4 (a figure-eight loop) characterized E2 and the second rising limb of E1. Hysteresis type 3 was observed in E9 and E10 (a counterclockwise loop). Finally, E11 was not characterized, due to a lack of data during the rising limb (see Appendix J)

Relationships between TSS and Turbidity

The dynamic between TSS and turbidity was different on the rising and falling limb of hydrographs in Sessom Creek (Figure 14). For the rising limb, TSS vs turbidity data were more scattered with increasing variability at higher concentrations; likely due to variable antecedent conditions, storm intensities, and percentages of organic detritus during the rising limbs. In contrast, the falling limb relationship had a clear positive linear relationship. Higher levels during the receding limb may be associated with small particles dominating TSS, which are usually inorganic (NVSS) during the receding limb. Figure 15 describes the relationship between the ratio of NVSS/VSS and Turbidity; higher turbidity is associated with higher NVSS/VSS.



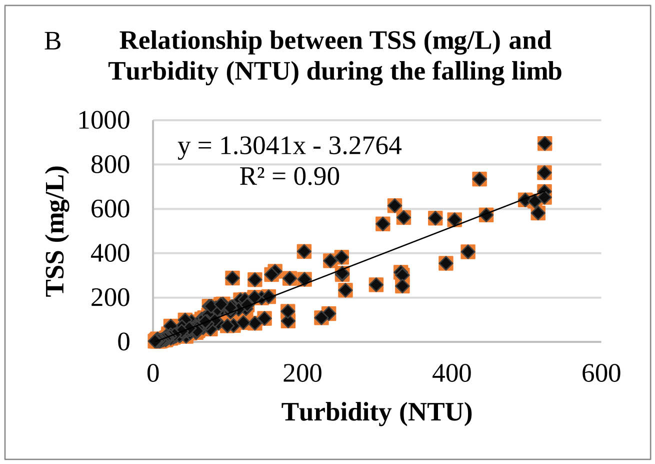


Figure 14: Relationship between TSS and Turbidity during the rising (A) and falling limb (B) of the hydrograph. This graph includes data from storm event 4 to 12. Events 1-3 are not included because turbidity data were not collected or due to instrument failure.

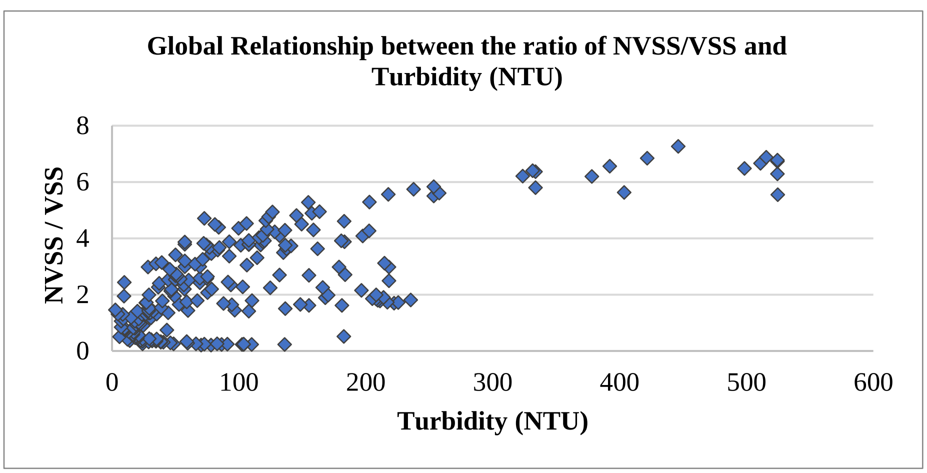


Figure 15: Global Relationship between the ratio of NVSS/VSS and Turbidity (NTU) for events 4 to 12.

IV. DISCUSSION

Storm events, NPS Loads and EMCs

The amount of precipitation during storms was highly variable (Figure 5), with the largest events (E1: 132.6 mm, E10: 81.8 mm) causing overbank flow in the lower reaches of the Sessom Creek watershed. Despite the fact that the larger rainfall events also produce more total runoff, the amount of runoff in an event is not strongly correlated with the total amount of rain; it is more associated with the intensity of the rain (Figure 6). For example, E4 and E6 had similar total rain (13.5 mm and 15.2 mm respectively), but the runoff generated in each event was different by an order of magnitude (RO for E4 was 2596 m^3, while RO for E6 was 23257 m^3). Differences between these events were that E4 had a Rain Int. of 3.8 mm/hr and a Max RI of 15.24 mm/hr, while E6 had Rain Int. of 26.1 mm/hr and Max RI of 67.1 mm/hr. In addition, E6 was a complex event, where the discharge hydrograph had three peaks (Figure 16, a and b). This suggests that, even though the watershed has a high percentage of impervious cover, there is still significant capacity for infiltration, storage, and evapotranspiration during less intense events.

Another example that illustrates how rainfall characteristics affect runoff generation in Sessom Creek is a comparison between E6 and E5 (Figure 16, b and c). Event 5 had ~65 mm of rain (vs 15.2 mm for E6), but RO in event 5 was 14667 m^3 *vs.* 23257 m^3 in E6. The lower RO of E5 in comparison with E6 can be attributed to the differences in average Rain Int. (12.2 mm/hr *vs.* 125 mm/h). Lastly, E6 had relatively low EMCs of SS and nutrients, and it is possible that dilution may have been a factor.

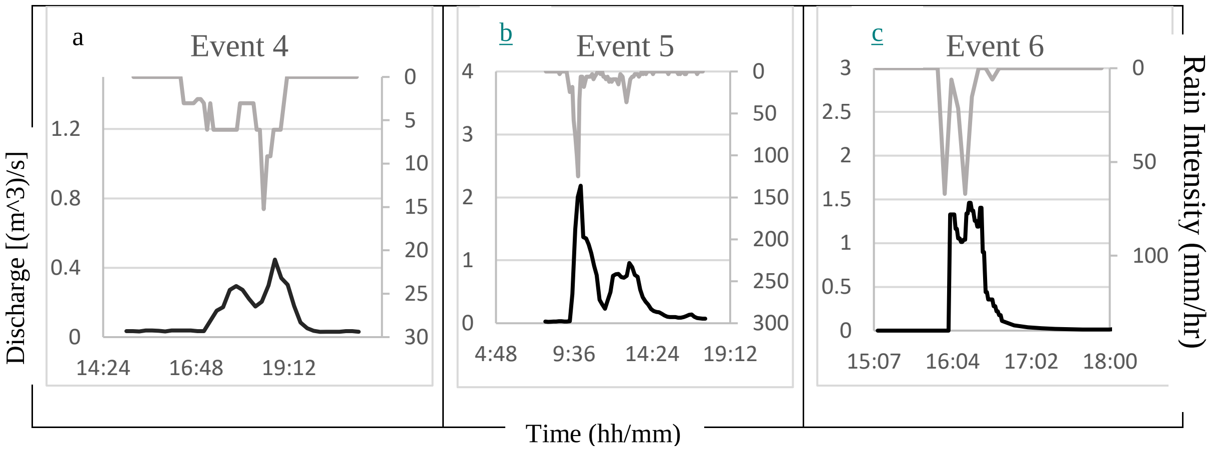


Figure 16: Comparisons of rain intensity (grey line: mm/hr) and response in discharge (black line: m^3/s) for E4, E5, and E6. Note that Runoff (RO) is the area under the discharge curve.

One hundred percent of the measured loads in Sessom Creek were NPS pollutants because there are no point sources in the Sessom Creek Watershed. The magnitude of loads and EMCs in a watershed can be variable (Maniquiz, et al., 2010; Gellis, 2013), and different studies in small urban watersheds have shown different values for the measured parameters, with data often being skewed for certain variables (Griffin, et al., 1980), which produces challenges for statistical analyses. For example, Appel and Hudack (2001) reported EMCs from 4 storm events of different magnitudes in an urban watershed (35% urbanized) of North Texas (City of Denton, TX). Their estimations suggested average values of 291 mg/L for TSS, and 950 µg/L for TP in events with less than 25 mm of precipitation, compared with EMCs of this study for TSS (234 ± 189 mg/L) and TP (459 ± 275 µg/L). Comparison of loads or EMCs with other studies can be complicated and lead erroneous conclusions because load calculations are not corrected by the discharge volume, and total loads are likely to be dependent on watershed size. In this sense, when Drewry, et al. (2008) evaluated pollutant loads for sediments and nutrients in a large forested watershed (1810km^2- 85% forest), they found loads of up to 10 times larger during moderate rainfall (~50mm) than those found in this study. This is expected because the watershed area is much larger than Sessom Creek's. On the other hand, Wang, et al. (2011) studied a smaller and more heavily urbanized watershed than the Sessom Creek Watershed (3.6 ha or 0.036 km^2 with >75% impervious cover), and found much higher load values for TSS than values measured in Sessom Creek.

Regression Models

Peak Q and Max. RI were the environmental factors of most importance for total event loads and EMCs of TSS, TN, and TP. Antecedent rain was a weak predictor of TN and TP loads, but not for TN and TP EMCs. These results coincide with results found by Gellis (2013) where Peak Q was a significant predictor for both loads and EMCs. However, that study sampled >100 storm events and found that the magnitude of loads and EMCs of sediments in an urban watershed in Puerto Rico was dependent on both antecedent conditions (previous rain) and total rainfall, while in this study these predictors were either weak or non-significant as predictor variables (Gellis 2013). This could be the result of differences in processes operating in the watershed, or it could be due to a relatively low number of events included in my data.

In addition, my results suggest that total and dissolved N are highly dependent on VSS, and TP can be predicted using TSS, which explains the high values or particulate P and N. Models developed by Wang, et al. (2011) showed that total runoff and ADD were significant predictors for TSS and other NPS in a small urban watershed. Although this study hypothesized that antecedent conditions would play a significant role in the generation of loads and concentrations of sediments and nutrients, results support this idea only with some predictors in a few response variables. For example, accumulated potential evapotranspiration during the two weeks prior each event (ETp2) was only significant when explaining NH_4^+-N and NO_3^--N. The relationship between NH_4^+-N and ETp2 can be explained by the cycle of nitrogen. NH_4^+ (and less so for NO_3^-) is the form of N consumed by plants and microorganism in the soil. While actual evapotranspiration (ETa) is a process that include evaporation and plant transpiration, ETp is more related to atmospheric demands. Once NH_4^+ or NO_3^- are taken by plants, transformation to N_2 occurs (atmospheric nitrogen), and this is released to the atmosphere through transpiration (Kalf, 2002). This process likely explains the strong negative relation between the EMCs of NH_4^+-N and ETp2 (Figure 17). ETp can be very different from ETa in dry times or regions, because plants limit their transpiration in dry conditions when demand and potential for evapotranspiration are still high. However, the sampling period occurred generally during wet conditions (10 of the 12 storm events had ADD of 8 or less days). Therefore, it is possible that the vegetation in Sessom Creek was not water-limited, and active evapotranspiration and nutrient uptake played an important role in nitrogen forms and availability during storm events.

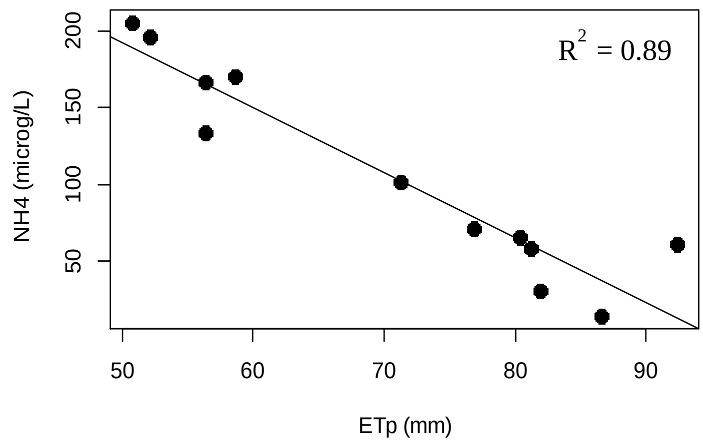


Figure 17: Simple Regression model between EMCs of NH_4^+-N and accumulated precipitation in the previous 2 weeks to each storm event (ETp2).

Hysteresis

Hysteresis curves between TSS and *Q* provide information about the source, supply, and potential mobilization of material that is transported into a channel **(**Moatar, et al., 2017; Aguilera & Melack, 2018; Gellis, 2013**)**. Clockwise hysteresis type 1 is the most common response in streams and, in this study, eight of the twelve events were characterized by this type of hysteresis, where the peak in TSS concentrations occurred before the peak in discharge in the hydrograph. Type 1 hysteresis is explained by first flush processes; sediments that are available in the channel, and on the areas immediately adjacent to it, are first “washed off” by the first flush in discharge. As a result, there is a decrease in sediment availability followed by smaller concentrations during the falling limb of the hydrograph (Gellis, 2013). Hysteresis type 3 (observed in E9 and E10), can be explained when sediments are transported from further areas of the watershed into the channel **(**Aguilera & Melack, 2018**).** E9 and E10 occurred with “0” antecedent dry days, which suggests that sediment in or near the channel washed off during antecedent rain, and was not available for immediate transport, resulting in erosion and peak sediment concentrations being delayed by transport from sources farther up in the watershed. The other type of hysteresis observed in this study was type 4 (eight loop) during event 2 and the second rising limb of E1. Antecedent conditions prior to E2 were characterized by wet soil. This is different from the results found by Seeger et al. (2004) where type 4 hysteresis occurred in antecedent dry soil conditions.

Non-structural Initiatives to protect the Upper San Marcos River and Recommendations

Findings from this study can directly support management actions that seek to reduce NPS pollutant loads from entering the headwaters of the San Marcos River. Actions and efforts include those being implemented by the Edwards Aquifer Conservation Plan (EAHCP). These plans identify stormflow from urban areas as the main water quality concern for the river and recognize that expected urban growth in the region will likely produce water quality impacts in the future (The Meadows Center for Water and the Environment, 2018; Guley, 2012).

This work has identified the main environmental factor controlling transport of NPS pollutants from Sessom Creek into the USMR as peak discharge, which usually occurs within the first minutes of the storm events. In light of this, recommendations for management purposes in the watershed include: 1) Identification and regulation of the sources (i.e. construction in the watershed, agrochemical applications, impervious surfaces with no stormwater management, etc.). 2) Remediation efforts should be focus on the detention of the initial first flush, and 3) Channel modifications may not be a suitable solution for Sessom Creek. Instead, remediation efforts should focus on small-scale retention throughout the watershed, where capture/retention of the first flush can both reduce NPS loads and EMCs, and reduce peak discharges.

Recommendations for future studies

Future efforts to understand the dynamic of NPS pollutants in Sessom Creek should include seasonal factors such as pollen generation or school related activities in the watershed. Most of the year, the Sessom Creek Watershed is very populated with more than 42,000 students attending Texas State University, but this number drops dramatically in the summer season (vacation time). Authors like Maniqui, et al. 2010 and Gellis, 2013 have concluded that season of the year affects the magnitudes of loads and EMCs of NPS pollutants.

A better method for studying hydrographs could be incorporated to achieve more precision. Complex storm events with multiple hydrograph peaks are difficult to sample consistently. For example, E1 (the largest monitored event) had multiple hydrograph peaks, but the event was treated as one, and loads were calculated under the assumption of only one rain event (Figure 18).

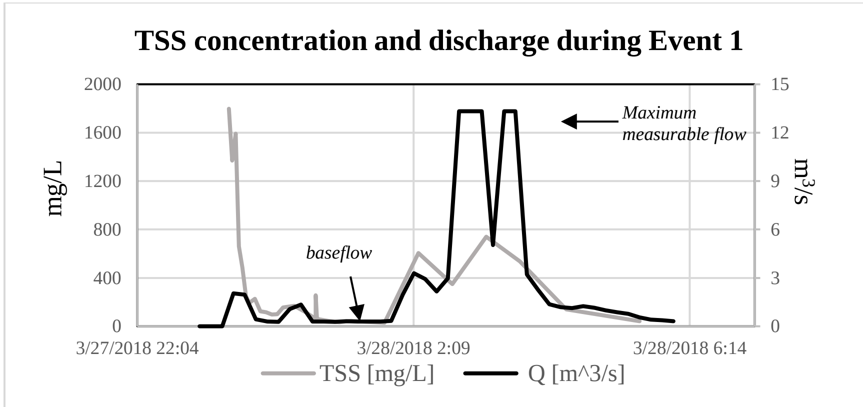


Figure 18: Hydrograph of storm event 1 and TSS concentrations.

V. CONCLUSIONS

Despite the limited number of events (n=12), this study has shown that key NPS pollutants (those pollutants that can be used to estimate others pollutants) are TSS, VSS and TN. These can be predicted with simple regressions with only a few variables (Peak Q, ETp, TSS, and VSS). This is primarily important for management purposes in the watershed, and easy estimation of EMCs and loads in future storm events.

The volatile suspended solids (VSS) portion of total suspended solids (TSS) was larger in smaller events (20 to 45%), while a greater proportion of NVSS was observed in events of medium and high magnitude (>80%). This suggests that soil erosion is more important to TSS during large events, and detrital and accumulated organic matter is more important during small events.

Large loads of pollutants are transported during storm events from Sessom Creek into the Upper San Marcos River, and SS have been identified as main concern for its mass volumes and association with particulate N and particulate P. Most of the loads are transported in the first flush of the storms, and management remediation efforts should focus in this first flush. The detention of first-flush water, using local management practices/structures distributed along the watershed, is more likely to be successful than BMPs in the channel. This is because the high gradient channel is extremely narrow in the lower area of the watershed, and physical space is very limited to make significant modifications.

APPENDIX SECTION

Appendix A: Soil complex in the Sessom Creek Watershed (Source: USDA)

Map unit symbol	Map unit name	Component name (percent)	Acres	Percent
CrD	Comfort-Rock outcrop complex, 1 to 8 percent slopes	Comfort (70%)	107.2	27.9%
		Rock outcrop (15%)		
		Unnamed (15%)		
DeB	Denton silty clay, 1 to 3 percent slopes	Denton (88%)	8.3	2.2%
		Krum (6%)		
		Doss (4%)		
		Anhalt (2%)		
DoC	Doss silty clay, moist, 1 to 5 percent slopes	Doss (85%)	100.6	26.2%
		Brackett (7%)		
		Bolar (5%)		
		Denton (1%)		
		Eckrant (1%)		
		Purves (1%)		
ErG	Eckrant-Rock outcrop association, 8 to 30 percent slopes	Eckrant (65%)	91.6	23.9%
		Rock outcrop (27%)		
		Brackett (4%)		
		Kerrville (2%)		
		Krum (1%)		
		Tarpley (1%)		
MED	Medlin-Eckrant association, 8 to 30 percent slopes	Medlin (50%)	59.2	15.4%
		Eckrant (45%)		
		Unnamed (5%)		
Tn	Tinn clay, 0 to 1 percent slopes, frequently flooded	Tinn (85%)	11.3	2.9%
		Whitesboro (10%)		
		Gladewater (5%)		
W	Water	Water (100%)	5.5	1.4%
		Total	383.7	100%

Appendix B: Importance of components in the PCA environmental and antecedent conditions.

	PC1	PC2	PC3	PC4
Standard deviation	1.86	1.58	1.27	1.06
Proportion of Variance	0.34	0.25	0.16	0.11
Cumulative Proportion	0.34	0.60	0.76	0.87

Appendix C: Importance of components in the PCA of the 2018 loads.

	PC1	PC2	PC3	PC4
Standard deviation	2.74	1.07	0.81	0.74
Proportion of Variance	0.75	0.11	0.07	0.05
Cumulative Proportion	0.75	0.86	0.93	0.98

Appendix D: Factor scores of the PCA for load variables.

Event	PC1	PC2	PC3	PC4
2	-4.42	0.90	-0.51	-1.53
3	2.78	0.14	-0.37	-0.18
4	2.24	0.34	-0.38	-0.02
5	-3.54	1.13	-0.15	1.36
6	0.39	0.29	2.26	-0.32
7	2.34	0.36	-0.11	0.22
8	-1.78	-0.13	0.02	0.69
9	-2.21	-2.79	-0.03	0.02
11	2.16	-0.20	-0.40	-0.13
12	2.04	-0.05	-0.33	-0.11

Appendix E: Importance of components in the PCA of the 2018 EMCs

	PC 1	**PC 2**	**PC3**	**PC4**
Standard deviation	2.3 7	1.47	1.12	0.78
Proportion of Variance	0.5 6	0.22	0.12	0.06
Cumulative Proportion	0.5 6	0.78	0.90	0.97

Appendix F: Factor scores in the PCA of EMCs.

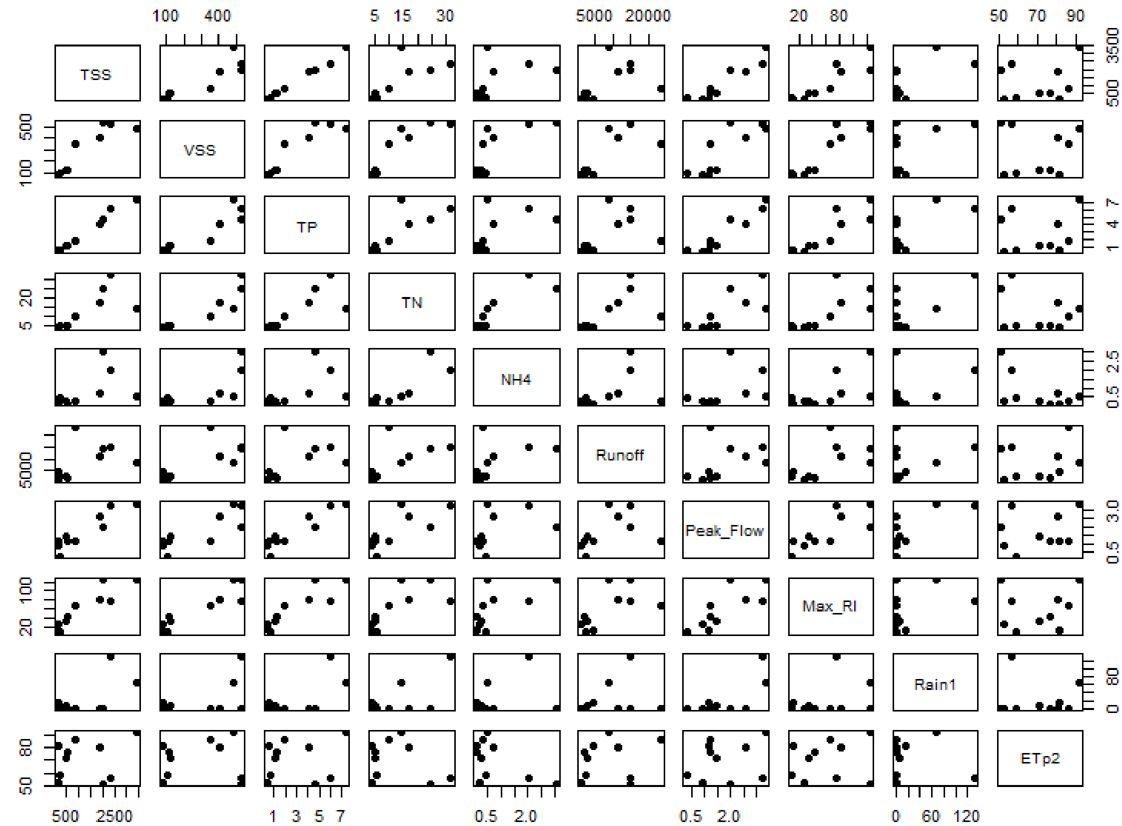
Event	**PC1**	**PC2**	**PC3**
1 (L)	-5.09	0.77	1.69
2 (M)	-0.19	-1.43	0.90
3 (S)	0.74	-2.64	-0.68
4 (S)	1.20	-1.40	0.44
5 (M)	0.46	-0.37	1.61
6 (S)	3.37	2.41	0.30
7 (S)	2.94	1.24	0.13
8 (M)	0.70	0.58	0.37
9 (M)	-0.72	1.08	-1.66
10 (L)	-3.41	1.32	-1.28
11(S)	-0.80	-1.13	-1.41
12 (S)	0.80	-0.42	-0.43

B= Large storm, M= medium storm, S= small storm

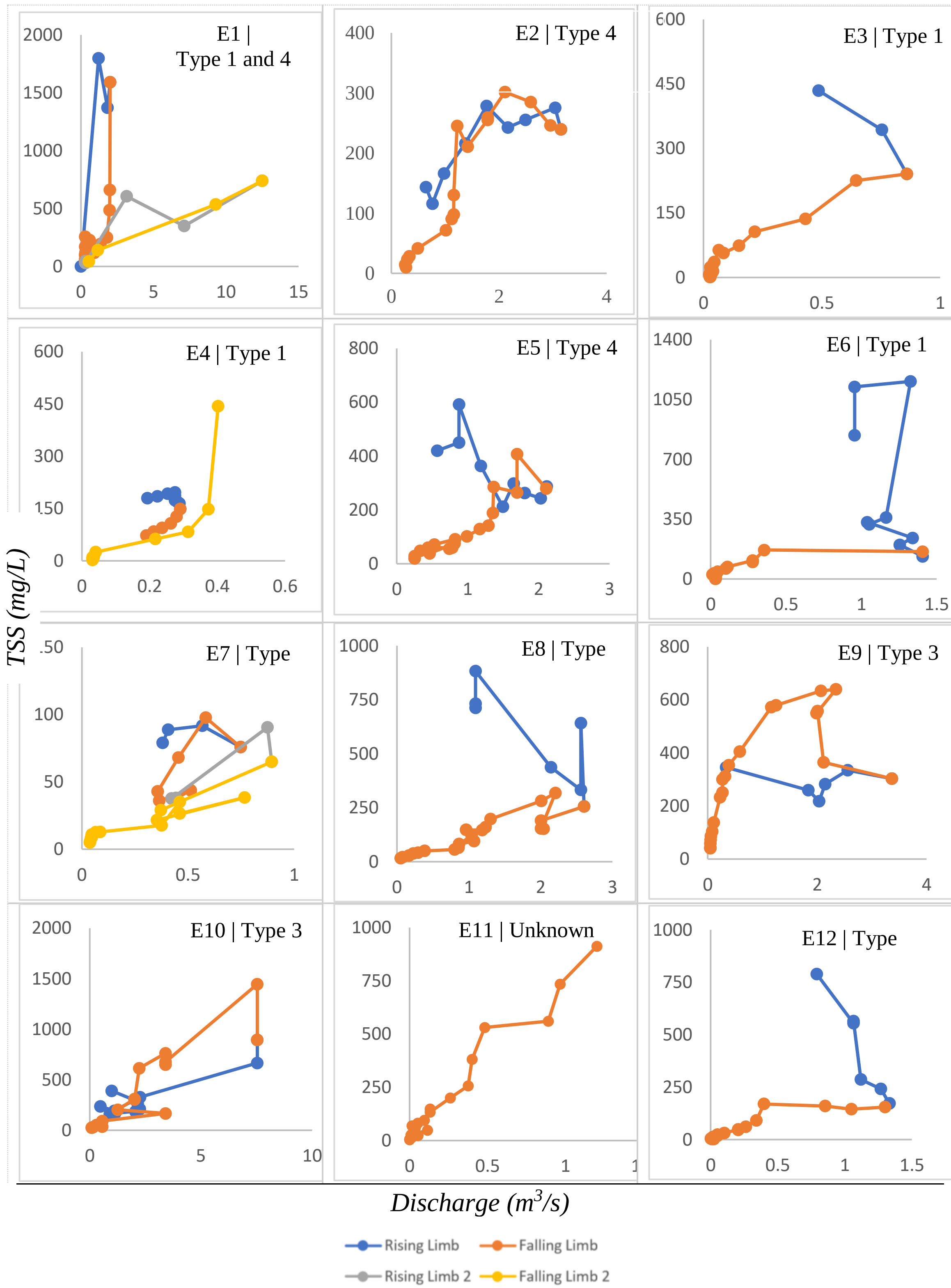
a) **Appendix G: Correlation Matrix between environmental and antecedent conditions (all events included):**

	Rain	RO	Peak Q	Rain Dur	Rain Int.	Max Intensity	ETp8	Rain1	Rain2	ADD
Rain	1.00	0.89	0.92	0.85	0.22	0.72	-0.27	0.10	-0.14	-0.17
RO	0.89	1.00	0.91	0.67	0.34	0.58	-0.35	0.06	-0.16	-0.02
Peak Q	0.92	0.91	1.00	0.70	0.28	0.69	-0.24	0.26	0.01	-0.19
Rain Dur	0.85	0.67	0.70	1.00	-0.28	0.48	-0.33	0.02	-0.32	-0.15
Rain Int.	0.22	0.34	0.28	-0.28	1.00	0.49	0.04	0.11	0.34	-0.05
Max. RI	0.72	0.58	0.69	0.48	0.49	1.00	0.06	0.45	0.12	-0.18
ETp8	-0.27	-0.35	-0.24	-0.33	0.04	0.06	1.00	-0.08	-0.36	0.15
Rain1	0.10	0.06	0.26	0.02	0.11	0.45	-0.08	1.00	0.56	-0.49
Rain2	-0.14	-0.16	0.01	-0.32	0.34	0.12	-0.36	0.56	1.00	-0.34
ADD	-0.17	-0.02	-0.19	-0.15	-0.05	-0.18	0.15	-0.49	-0.34	1.00

Appendix H: Scatter plot of the EMCs of main NPS pollutants and environmental variables.



Appendix I: Scatter plot of the loads of main NPS pollutants and environmental variables (E1 and E10 are not included)



Appendix J: Hysteresis curves between TSS and Discharge by storm event

Appendix K: Summary of water quality variables measured during storm event 1.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m^3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	*E. coli* (MPN/ 100mL)
3/27/2018 23:26	1	1.22	1797.69	402.68	1395.02	9652.92	2644.84	172.56	98.84	762.88	>24192
3/27/2018 23:26	1LD	1.22									>24192
3/27/2018 23:29	2	1.83	1369.87	381.18	988.69	6877.37	2059.59	149.83	43.82	857.62	>24192
3/27/2018 23:32	3	2.01	1590.46	364.33	1226.13	5382.24	1929.62	144.84	80.22	621.64	>24192
3/27/2018 23:35	4	1.99	660.59	161.68	498.91	4962.70	1464.46	168.67	161.99	425.10	24191.7
3/27/2018 23:38	5	1.97	484.53	135.45	349.09	3960.00	883.94	201.69	192.29	472.49	19862.8
3/27/2018 23:41	6	1.80	249.77	74.59	175.19	3753.50	737.12	188.60	170.11	462.08	15530.7
3/27/2018 23:44	7	1.35	191.80	80.97	110.83	3669.35	609.00	171.16	186.03	550.02	14136
3/27/2018 23:49	8	0.59	227.35	81.17	146.18	3593.75	569.31	151.70	147.26	823.48	>24192
3/27/2018 23:54	9	0.41	123.33	49.99	73.34	3909.66	563.35	131.61	133.54	658.51	>24192
3/27/2018 23:59	10	0.31	116.67	46.40	70.27	3908.24	516.67	103.11	104.09	949.35	>24192
3/27/2018 23:59	10LD	0.31									>24192
3/28/2018 0:04	11	0.29	96.41	49.29	47.12	3737.88	475.75	65.73	106.46	906.63	>24192
3/28/2018 0:09	12	0.28	99.10	44.39	54.72	3580.89	520.58	78.19	101.38	1036.96	>24192
3/28/2018 0:14	13	0.59	154.47	52.07	102.40	3928.05	595.84	124.44	59.56	1161.05	3724
3/28/2018 0:24	14	0.30	169.92	59.59	110.33	2932.61	383.83	119.46	93.42	537.77	19862.8
3/28/2018 0:34	15	0.93	116.59	53.62	62.97	2657.97	412.00	109.34	99.18	521.95	24191.7
3/28/2018 0:43	16FD	0.30	59.70	31.40	28.30	2249.23	311.44	104.82	103.24	535.71	24191.7
3/28/2018 0:43	16FD-SSC	0.30	255.18	50.53	204.65						
3/28/2018 0:44	16	0.30	61.15	31.69	29.46	2164.44	218.90	61.37	66.16	542.61	>24192
3/28/2018 0:54	17	0.29	44.98	25.21	19.78	2571.38	292.11	104.51	115.09	939.77	>24192
3/28/2018 1:04	18	0.29	34.55	10.71	23.84	2538.21	349.90	124.29	117.29	1045.09	>24192
3/28/2018 1:14	19	0.30	44.75	21.97	22.78	2389.25	288.41	140.64	112.21	948.52	>24192

Appendix K. Continued.

3/28/2018 1:44	20	0.31	29.05	18.24	10.81	2159.61	232.06	192.50	98.33	866.48	24191.7
3/28/2018 1:44	20LD	0.31									17328.7
3/28/2018 2:14	21	3.15	604.73	111.46	493.28	2367.46	646.22	269.27	102.73	562.55	24191.7
3/28/2018 2:44	22	7.12	349.02	65.31	283.72	1769.84	469.37	157.30	126.43	480.68	17328.7
3/28/2018 3:14	23	12.49	738.85	113.53	625.32	2151.19	1231.89	145.47	178.92	643.92	>24192
3/28/2018 3:44	24	9.28	536.20	92.38	443.82	2394.46	708.33	135.50	233.60	1066.09	>24192
3/28/2018 4:25	25	1.15	139.27	29.02	110.25	2128.82	307.94	244.51	266.78	1852.05	>24193
3/28/2018 4:25	25LD	1.15									24191.7
3/28/2018 5:30	26	0.54	42.80	32.18	10.62	2765.14	305.27	293.57	209.39	1994.69	19862.8

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.

Appendix L: Summary of water quality variables measured during storm event 2.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m^3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	*E. coli* (MPN/ 100mL)
3/28/2018 9:45	1	0.64	143.32	45.05	98.27	2234.46	292.18	122.89	74.86	1214.93	9804
3/28/2018 9:48	2	0.76	115.93	37.22	78.70	2231.69	269.02	134.00	65.76	1249.72	6867
3/28/2018 9:51	3	0.98	166.29	62.92	103.37	2372.04	287.99	142.97	66.27	1003.16	9208
3/28/2018 9:54	4	1.37	215.96	50.02	165.94	2272.07	343.91	138.03	56.31	767.21	4884
3/28/2018 9:57	5	1.77	278.58	64.79	213.79	1714.49	365.88	89.36	51.68	465.20	7270
3/28/2018 10:00	6	2.16	242.65	74.63	168.02	1778.43	319.95	71.98	50.48	385.61	8664
3/28/2018 10:03	7	2.49	255.30	49.94	205.36	1228.63	437.59	73.55	88.43	461.19	15530.7
3/28/2018 10:08	8	3.05	275.35	53.39	221.96	1865.99	556.83	87.68	139.09	663.55	24191.7

Appendix L. Continued.

3/28/2018 10:13	9	3.15	239.69	46.84	192.86	1911.65	568.01	94.64	140.81	724.67	24191.7
3/28/2018 10:18	10	2.95	246.18	50.54	195.64	2123.27	595.97	94.75	138.74	751.00	>24192
3/28/2018 10:18	10LD	2.95									>14192
3/28/2018 10:23	11	2.59	284.81	51.58	233.23	1875.36	640.71	89.25	155.92	768.75	>24192
3/28/2018 10:28	12	2.11	301.55	53.64	247.90	2210.24	692.24	119.53	180.99	813.21	>24192
3/28/2018 10:33	13	1.79	259.43	45.15	214.28	2118.72	675.27	122.67	199.19	849.71	>24192
3/28/2018 10:33	13FD	1.79	258.39	43.07	215.32	2131.92	690.25	111.12	204.69	943.64	>24192
3/28/2018 10:33	13FD - SSC	1.79	255.18	50.53	204.65						
3/28/2018 10:43	14	1.42	210.62	38.05	172.57	2263.76	612.35	123.46	230.62	1118.63	24191.7
3/28/2018 10:53	15	1.22	245.33	51.57	193.76	2249.11	616.55	119.53	232.85	1111.71	24191.7
3/28/2018 11:03	16	1.16	130.25	27.93	102.32	2210.51	466.15	136.24	232.34	1217.67	19862.8
3/28/2018 11:13	17	1.16	98.13	25.00	73.13	2501.50	424.01	141.51	234.40	1511.39	24191.7
3/28/2018 11:23	18	1.12	90.50	26.24	64.26	2288.30	419.41	163.15	245.05	1627.69	19996.5
3/28/2018 11:33	19	1.01	71.55	22.50	49.04	2443.37	395.05	195.45	235.43	1715.08	>24192
3/28/2018 12:03	20	0.49	41.49	16.90	24.59	2785.05	317.55	294.36	203.49	1974.66	15530.7
3/28/2018 12:03	20LD	0.49									14136
3/28/2018 12:33	21	0.33	28.49	17.07	11.42	3133.32	266.02	305.91	178.93	2334.71	15530.7
3/28/2018 13:03	22	0.29	23.13	13.28	9.85	3105.01	230.47	330.91	154.37	2610.23	14136
3/28/2018 13:33	23	0.26	14.50	11.23	3.27	3597.27	209.10	312.19	130.84	2679.48	9804
3/28/2018 14:03	24	0.27	10.10	12.84	0	3504.29	166.95	179.30	121.23	2872.73	9804

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.

Appendix M: Summary of water quality variables measured during storm event 3.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m^3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	*E. coli* (MPN/ 100mL)
4/7/2018 0:25	1	0.49	434.48	186.41	248.08	4377.00	734.17	210.14	10.50	452.11	>48384
4/7/2018 0:28	2	0.75	343.54	147.22	196.32	5270.20	742.73	107.08	13.79	447.03	>48384
4/7/2018 0:31	3	0.86	240.64	112.94	127.70	4792.86	497.35	107.98	17.76	415.52	>48384
4/7/2018 0:34	4	0.65	225.49	119.71	105.79	4452.50	605.02	81.85	20.01	375.58	>48384
4/7/2018 0:37	5	0.43	136.23	71.59	64.64	3923.88	486.21	98.56	15.51	429.90	>48384
4/7/2018 0:40	6	0.22	105.94	59.16	46.77	3906.96	451.18	100.13	17.76	455.68	>48384
4/7/2018 0:45	7	0.15	73.58	50.04	23.54	3385.84	391.08	110.22	13.79	687.85	>48384
4/7/2018 0:50	8	0.08	56.86	39.09	17.78	3448.88	339.14	130.86	8.25	605.44	>48384
4/7/2018 0:55	9	0.07	63.60	51.50	12.10	3101.97	337.95	131.19	10.16	867.01	>48384
4/7/2018 1:00	10	0.05	35.99	29.59	6.40	3014.51	304.91	61.55	12.58	938.95	>48384
4/7/2018 1:00	10LD										>48384
4/7/2018 1:05	11	0.04	28.16	24.32	3.84	2825.46	254.16	159.90	4.10	1045.15	>48384
4/7/2018 1:10	12	0.03	23.91	21.30	2.61	2600.98	197.24	163.04	7.04	1240.36	>48384
4/7/2018 1:20	13	0.03	16.03	12.96	3.07	2708.06	144.31	275.97	17.07	1446.37	8748
4/7/2018 1:30	14	0.04	14.63	10.32	4.31	2359.07	100.33	229.43	17.42	1614.13	>48384
4/7/2018 1:40	15	0.04	10.19	8.17	2.02	2322.70	69.48	341.12	13.61	1718.22	>48384
4/7/2018 1:50	16	0.03	9.27	8.49	0.78	2281.81	71.47	275.63	8.43	1845.01	>48384
4/7/2018 2:00	17	0.03	6.43	6.84	0	2338.43	69.88	232.90	6.70	1821.07	>48384
4/7/2018 2:10	18	0.02	6.65	7.12	0	2195.68	33.66	389.23	10.67	1939.26	15402
4/7/2018 2:40	19	0.03	6.15	6.35	0	2503.84	60.72	378.01	7.04	1898.95	>48384
4/7/2018 3:10	20	0.03	2.03	4.20	0	2417.01	22.91	460.55	9.64	2032.55	1401
4/7/2018 3:10	20LD										1119
4/7/2018 3:40	21	0.03	1.28	4.43	0	2131.69	20.33	652.08	12.23	2041.95	789

Appendix M. Continued.											
4/7/2018 4:10	22	0.03	2.10	3.48	0	2120.81	20.92	687.97	9.46	2140.91	669
4/7/2018 4:40	23	0.03	0.86	3.45	0	2415.19	20.92	651.19	7.39	2177.44	384
4/7/2018 5:10	24	0.03	0.99	4.16	0	2274.13	15.75	268.34	7.22	2180.47	1017

LD = Lab duplicate
FD = Field duplicate
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Appendix N: Summary of water quality variables measured during storm event 4.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m^3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	*E. coli* (MPN/ 100mL)
4/25/2018 16:32	1	0.19	179.72	65.64	114.08	4881.86	608.17	348.07	147.23	2190.95	217.05	8290
4/25/2018 16:32	1LD	0.19										27375
4/25/2018 16:35	2	0.22	185.13	63.73	121.40	5095.41	607.57	309.88	145.19	2229.39	214.13	40820
4/25/2018 16:38	3	0.25	191.98	68.89	123.09	4605.60	645.03	261.47	132.75	2019.65	211.21	120958.5
4/25/2018 16:41	4	0.28	173.31	60.90	112.40	3965.14	585.50	225.11	142.63	1701.75	208.29	77653.5
4/25/2018 16:41	4FD	0.28	187.42	66.75	120.67	4146.04	680.87	370.54	204.14	1623.89	208.29	5270
4/25/2018 16:41	4FD -SES	0.28	195.80	65.23	130.58							
4/25/2018 16:44	5	0.28	169.22	59.06	110.16	3964.42	589.55	207.75	155.07	1562.27	205.37	64982.5
4/25/2018 16:47	6	0.29	164.24	58.44	105.80	3463.23	521.31	194.05	154.73	1263.10	209.57	64982.5
4/25/2018 16:52	7	0.29	148.81	54.99	93.82	3510.65	514.56	177.42	151.32	1199.03	222.51	23055
4/25/2018 16:57	8	0.28	126.36	44.84	81.52	3074.31	427.16	161.34	148.08	1234.98	235.44	32440
4/25/2018 17:02	9	0.26	107.48	39.37	68.11	2534.74	442.74	184.73	154.73	940.53	225.59	27375
4/25/2018 17:07	10	0.24	94.05	35.90	58.15	2682.00	432.01	164.45	153.36	971.59	181.19	17240
4/25/2018 17:07	10LD	0.24										19865
4/25/2018 17:12	11	0.21	83.46	33.24	50.22	2615.46	341.70	223.83	162.05	964.70	136.79	36350
4/25/2018 17:17	12	0.19	72.66	30.10	42.55	2507.16	360.93	215.06	152.51	979.95	107.84	49020

Appendix N. Continued.

4/25/2018 17:27	13	0.20	54.75	22.33	32.42	2417.19	335.62	228.58	146.72	1025.89	96.76	24420
4/25/2018 17:37	14	0.27	96.19	36.27	59.92	2540.40	345.75	210.86	149.44	943.90	148.58	10230
4/25/2018 17:47	15	0.40	443.47	140.59	302.88	2851.71	561.80	122.06	118.95	575.73	196.67	9675
4/25/2018 17:57	16	0.37	147.91	45.59	102.32	2296.08	408.72	107.44	124.91	548.80	124.80	10490
4/25/2018 18:07	17	0.31	82.67	30.74	51.94	2010.12	308.69	99.04	112.30	531.10	87.89	9300
4/25/2018 18:17	18	0.22	62.47	22.41	40.06	1706.55	285.00	124.62	109.06	589.52	67.42	5890
4/25/2018 18:47	19	0.04	24.69	10.47	14.23	1811.79	175.45	197.52	92.88	1020.62	44.49	8080
4/25/2018 19:17	20	0.03	9.76	6.91	2.85	1673.11	100.94	162.62	66.98	1441.03	12.32	2955
4/25/2018 19:17	20LD	0.03										3190
4/25/2018 19:47	21	0.03	11.05	7.29	3.76	1850.37	61.86	328.34	37.16	1713.64	6.11	1250
4/25/2018 20:17	22	0.03	6.51	7.49	0	1948.85	34.32	755.33	32.05	1836.19	4.68	935
4/25/2018 20:47	23	0.03	3.83	4.55	0	2049.09	35.33	948.64	25.23	1936.04	5.66	2020
4/25/2018 21:17	24	0.03	2.48	4.07	0	2069.12	29.86	920.87	22.33	1998.15	5.78	1565

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.

Appendix O: Summary of water quality variables measured during storm event 5.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
5/4/2018 9:31	1	0.57	420.24	150.22	270.02	6278.29	931.99	502.18	291.33	1974.52	104.21	110.37	30655
5/4/2018 9:31	1LD	0.57											25860
5/4/2018 9:34	2	0.88	449.89	155.20	294.69	5316.02	1008.69	873.01	253.66	1918.89	103.30	168.18	13615

Appendix O. Continued.

5/4/2018 9:34	2LD	0.88	592.08	233.69	358.39								
5/4/2018 9:37	3	1.19	363.26	111.60	251.66	4764.57	683.91	740.93	179.49	1306.80	102.39	166.30	13615
5/4/2018 9:40	4	1.50	212.08	64.59	147.49	4042.63	606.40	756.64	152.41	852.54	101.49	103.02	9250
5/4/2018 9:43	5	1.65	298.02	112.74	185.27	3282.19	475.60	502.30	132.23	577.35	100.58	94.51	9520
5/4/2018 9:46	6	1.80	263.10	82.03	181.08	3456.78	467.33	312.78	112.55	460.00	105.07	78.72	10715
5/4/2018 9:51	7	2.03	243.74	68.17	175.58	2326.27	405.16	225.87	90.68	363.33	130.55	75.00	15380
5/4/2018 9:56	8	2.11	287.30	70.86	216.44	1884.66	496.39	208.56	100.61	328.65	156.03	106.50	30655
5/4/2018 10:01	9	2.10	279.15	58.59	220.56	2055.86	538.38	202.18	102.46	397.39	176.98	136.65	32440
5/4/2018 10:06	10	1.70	406.92	77.26	329.66	2555.75	728.92	220.59	124.99	503.15	179.88	202.74	36350
5/4/2018 10:06	10LD	1.70	264.84	64.74	200.10								40820
5/4/2018 10:11	11	1.36	285.13	58.40	226.74	2368.89	597.12	250.05	124.32	660.65	182.78	183.35	30655
5/4/2018 10:16	12	1.35	188.45	39.48	148.97	1820.11	457.23	227.34	116.92	502.76	181.23	117.31	34335
5/4/2018 10:26	13	1.29	142.25	30.37	111.88	1610.14	382.35	246.74	117.43	489.27	142.57	84.70	46040
5/4/2018 10:36	14	1.17	129.22	28.15	101.07	2282.67	334.71	260.36	116.92	751.69	115.04	83.39	36350
5/4/2018 10:46	15	0.99	101.77	24.90	76.87	1675.35	363.17	266.13	119.95	740.65	95.56	65.67	24420
5/4/2018 10:56	16	0.82	91.22	24.79	66.42	1840.54	310.69	259.87	116.25	650.78	80.62	51.65	20530
5/4/2018 11:06	17	0.53	71.60	20.29	51.32	1632.40	276.58	251.03	108.85	682.28	70.07	44.40	20530
5/4/2018 11:16	18	0.33	47.92	14.05	33.87	1577.25	246.10	250.17	116.92	819.37	63.26	37.28	24420
5/4/2018 11:46	19	0.44	59.43	17.76	41.68	1635.60	284.65	264.66	116.58	761.83	91.34	56.75	18270
5/4/2018 12:16	20	0.78	60.11	17.02	43.09	1239.48	260.43	188.80	105.48	564.98	80.55	50.27	8320
5/4/2018 12:16	20LD	0.78											12405
5/4/2018 12:46	21	0.74	55.64	17.42	38.22	1247.05	237.42	172.23	98.76	484.53	67.66	46.86	12405
5/4/2018 13:16	22	0.82	75.45	19.31	56.15	1474.12	261.64	161.30	107.67	528.29	74.93	45.55	21760
5/4/2018 13:46	23	0.46	38.40	12.83	25.57	1434.24	222.69	164.13	103.30	631.93	48.34	29.34	13775
5/4/2018 14:16	24	0.25	28.95	10.69	18.26	1614.97	278.40	156.88	100.77	694.60	42.36	26.80	20530
5/4/2018 14:16	24FD	0.25	21.92	9.44	12.48	1200.91	171.82	139.58	99.93	698.89	42.36	26.80	11795
5/4/2018 14:16	24FD - SSC	0.25	20.15	6.67	13.48								

Appendix O. Continued.

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

Appendix P: Summary of water quality variables measured during storm event 6.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^-N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
6/16/2018 15:01	1	0.96	841.97	211.34	630.64	6472.34	1701.92	77.01	135.90	1268.56	274.50	218.50	
6/16/2018 15:01	1LD	0.96	1123.77	320.89	802.88	5367.37	1667.52	83.24	141.70	1270.06	274.50	218.50	>120950
6/16/2018 15:04	2	1.33	1155.87	759.77	396.10	5219.83	1354.32	115.99	142.55	1380.84	327.00	182.85	>120950
6/16/2018 15:07	3	1.17	359.58	87.25	272.33	4958.45	962.20	76.91	145.45	1107.92	326.73	214.94	>120950
6/16/2018 15:10	4	1.05	320.02	86.07	233.95	5414.62	971.31	71.81	156.01	1255.56	299.55	183.73	>120950
6/16/2018 15:13	5	1.04	332.81	111.35	221.46	4577.49	855.57	69.77	162.32	1159.27	269.67	170.53	>120950
6/16/2018 15:16	6	1.34	239.91	64.83	175.07	3820.18	765.33	100.99	191.47	988.23	229.15	132.12	>120950
6/16/2018 15:21	7	1.26	200.85	58.23	142.62	3211.47	583.24	109.15	168.12	768.71	142.16	91.61	>120950
6/16/2018 15:26	8	1.41	132.92	36.45	96.47	2945.48	489.56	123.33	160.28	787.74	124.28	75.40	>120950
6/16/2018 15:26	8LD	1.41	160.10	52.02	108.08	2819.33	490.16	102.42	163.68	792.72	124.28	75.39	>120950
6/16/2018 15:31	9	0.36	169.99	50.70	119.28	2960.15	551.27	89.36	152.61	803.62	133.36	93.92	>120950
6/16/2018 15:36	10	0.28	101.06	29.50	71.56	2980.68	490.77	62.02	153.97	864.05	116.74	69.30	>120950
6/16/2018 15:36	10LD	0.28											5530
6/16/2018 15:36	10FD	0.28	107.31	26.86	80.45	2909.35	479.85	194.44	226.58	967.37	116.74	69.30	7105
6/16/2018 15:36	10FD – SSC	0.28	107.79	30.05	77.74						116.74	69.30	
6/16/2018 15:41	11	0.11	71.75	22.43	49.32	2734.63	445.65	110.27	156.36	827.86	97.98	57.15	>120950
6/16/2018 15:46	12	0.10	62.04	21.03	41.01	2719.76	417.73	116.39	160.79	991.22	79.15	49.42	>120950

Appendix P. Continued.

6/16/2018 15:56	13	0.05	43.84	15.76	28.08	2856.90	378.48	135.78	158.57	1104.38	62.14	39.84	>120950
6/16/2018 16:06	14	0.03	32.06	13.27	18.79	2932.45	342.46	162.51	146.13	1233.87	48.94	32.43	>120950
6/16/2018 16:16	15	0.02	33.48	17.59	15.89	2861.57	302.20	181.79	145.28	1286.44	35.16	24.74	>120950
6/16/2018 16:26	16	0.02	31.15	15.76	15.39	2863.02	286.89	193.84	135.33	1317.52	32.30	21.39	
6/16/2018 16:36	17	0.02	28.82	13.92	14.89	2864.47	271.58	205.89	125.39	1348.61	29.43	18.14	
6/16/2018 16:46	18	0.01	26.48	12.09	14.39	2865.92	256.27	217.94	115.45	1379.70	26.56	15.11	
6/16/2018 17:16	19	0.03	19.49	6.60	12.89	2870.26	210.34	254.09	85.62	1472.96	17.96	9.65	
6/16/2018 17:46	20	0.03	12.50	1.11	11.39	2874.60	164.41	290.24	55.80	1566.22	9.35	6.59	34335
6/16/2018 18:16	21	0.03	6.44	1.11	5.33	2793.73	156.12	360.12	70.97	1869.85	14.25	10.00	55992.5
6/16/2018 18:46	22	0.03	3.81	1.11	2.70	2535.30	132.24	321.45	60.23	1715.79	14.58	9.82	28970
6/16/2018 19:16	23	0.03	2.37	1.11	1.27	2335.97	111.81	326.86	60.91	1705.44	13.11	9.14	14545
6/16/2018 19:46	24	0.03	2.55	1.11	1.44	2162.51	109.78	330.53	54.26	1572.97	12.51	8.53	13065
6/16/2018 19:46	24LD	0.03											16275

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

Appendix Q: Summary of water quality variables measured during storm event 7.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
6/19/2018 10:13	1	0.38	78.93	29.69	49.24	2192.30	333.96	32.99	72.69	1087.30	94.64	52.83	25860
6/19/2018 10:13	1LD	0.38											25860
6/19/2018 10:16	2	0.41	88.82	32.37	56.45	2111.25	470.94	28.29	84.11	887.50	112.41	58.90	18270
6/19/2018 10:19	3	0.57	91.73	37.57	54.16	1657.47	323.09	24.49	83.59	887.50	88.53	60.01	32440
6/19/2018 10:22	4	0.75	75.91	20.34	55.57	1590.46	294.80	27.29	83.42	484.41	75.43	50.79	24420
6/19/2018 10:25	5	0.58	97.73	56.02	41.71	1414.91	280.65	17.99	89.39	432.04	67.87	43.43	30655
6/19/2018 10:28	6	0.45	68.08	26.78	41.30	1448.54	268.35	18.29	79.16	399.03	62.13	38.87	38505
6/19/2018 10:28	6LD	0.45				1411.51	289.26	28.89	78.31	419.43	62.13	38.87	
6/19/2018 10:33	7	0.36	42.83	19.66	23.17	1035.72	238.20	25.99	77.80	363.73	51.75	30.77	28970
6/19/2018 10:33	7LD	0.36	42.88	19.67	23.21						51.75	30.77	
6/19/2018 10:38	8	0.36	36.02	15.30	20.72	1047.80	219.13	25.09	79.16	358.55	46.23	29.26	32440
6/19/2018 10:43	9	0.51	43.70	17.33	26.37	951.53	205.60	20.29	78.31	344.85	46.84	29.46	21760
6/19/2018 10:48	10	0.44	37.99	15.67	22.32	1029.05	212.37	22.69	75.24	289.96	44.77	29.11	30655
6/19/2018 10:48	10LD	0.44											24420
6/19/2018 10:53	11	0.42	37.51	15.86	21.64	1380.95	201.50	22.49	74.90	320.52	45.67	30.23	23055
6/19/2018 10:58	12	0.87	90.50	28.87	61.63	981.18	276.34	17.19	73.54	318.77	66.19	46.37	24420
6/19/2018 11:08	13	0.89	64.93	28.02	36.90	1202.19	205.19	14.49	59.40	294.88	52.65	35.22	20530
6/19/2018 11:18	14	0.37	28.97	12.56	16.41	743.78	147.98	24.69	60.76	363.18	37.29	23.58	21760
6/19/2018 11:28	15	0.35	21.53	10.66	10.87	762.46	161.51	23.49	61.78	335.58	34.03	21.28	23055
6/19/2018 11:38	16	0.77	38.39	19.40	19.00	883.22	158.44	22.09	56.84	362.64	35.19	22.32	27375
6/19/2018 11:38	16LD					899.41	166.85	22.79	60.93	324.56	35.19	22.32	
6/19/2018 11:48	17	0.46	26.53	12.34	14.19	720.85	139.57	27.99	60.59	368.97	313.10	21.13	28970
6/19/2018 11:48	17LD	0.46	35.10	22.36	12.74						313.10	21.13	

Appendix Q. Continued.

6/19/2018 11:58	18	0.37	17.75	9.14	8.62	648.68	143.27	19.79	58.89	365.80	613.40	19.18	24420
6/19/2018 12:28	19	0.09	12.87	7.08	5.79	943.50	117.84	46.08	63.32	700.63	168.12	18.03	30655
6/19/2018 12:58	20	0.06	12.64	6.95	5.68	1306.17	109.43	118.68	56.84	1034.43	33.36	18.05	21760
6/19/2018 12:58	20LD	0.06											19365
6/19/2018 13:28	21	0.05	10.87	6.97	3.90	1500.92	110.66	180.58	51.05	1122.82	29.21	16.92	15380
6/19/2018 13:28	21FD	0.05	8.88	5.72	3.17	1504.25	104.72	191.18	57.18	1160.19	29.21	16.92	18270
6/19/2018 13:28	21FD- SSC	0.05	8.70	4.77	3.93						29.21	16.92	18270
6/19/2018 13:58	22	0.04	8.16	5.95	2.20	1516.60	77.65	235.78	44.91	1238.92	24.21	14.08	13775
6/19/2018 14:28	23	0.04	5.85	4.89	0.96	1431.11	65.96	220.38	39.29	1317.16	20.92	11.62	10065
6/19/2018 14:58	24	0.04	4.95	4.52	0.42	1451.03	62.89	222.38	36.39	1208.80	18.01	9.78	7250

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b)= Edwards Aquifer Research and Data Center, unpublished.

Appendix R: Summary of water quality variables measured during storm event 8.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
7/4/2018 14:07	Base line	Baseflow	4.27	3.65	0.62	1933.63	19.27	136.61	10.94	1918.61	11.30	4.16	<50
7/4/2018 14:31	1	1.09	711.70	153.50	558.20	4925.69	1333.03	228.90	128.40	1270.95	70.43	162.25	<120960
7/4/2018 14:31	1FD	1.09	731.23	148.32	582.91	4910.95	1453.78	301.85	215.11	1717.25	70.43	162.25	38505
7/4/2018 14:31	1FD-SSC	1.09	882.36	184.02	698.34						70.43	162.25	
7/4/2018 14:34	2	2.14	437.45	91.53	345.92	3396.71	955.56	213.66	141.53	981.72	264.84	107.90	38505
7/4/2018 14:37	3	2.56	332.12	90.09	242.03	2402.19	644.21	149.90	128.75	580.54	284.18	155.22	5230

Appendix R. Continued.

7/4/2018 14:37	3LD	2.56	641.74	244.15	397.59	2485.25	614.44	112.72	128.23	543.58	284.18	155.22	
7/4/2018 14:40	4	2.61	255.06	44.68	210.38	2037.04	542.15	62.04	113.20	510.63	216.18	72.85	4925
7/4/2018 14:43	5	2.00	189.92	32.92	156.99	1739.64	478.89	51.56	114.93	388.38	193.02	123.47	4025
7/4/2018 14:46	6	2.04	152.17	27.67	124.50	1282.50	395.72	51.99	104.05	375.93	171.20	81.09	3120
7/4/2018 14:51	7	2.00	152.91	28.35	124.56	1207.99	372.51	40.86	106.29	360.01	171.32	84.30	4800
7/4/2018 14:56	8	2.21	317.94	53.41	264.53	1836.09	599.65	64.74	127.71	539.89	284.02	163.60	9675
7/4/2018 15:01	9	2.01	281.09	44.68	236.41	1834.82	632.10	57.61	109.75	610.62	302.08	203.08	14545
7/4/2018 15:06	10	1.30	197.51	33.95	163.56	1863.91	539.07	52.10	120.45	719.87	234.80	145.55	10710
7/4/2018 15:11	11	1.23	158.99	28.72	130.27	1780.98	470.68	47.12	119.42	820.52	186.98	106.12	11410
7/4/2018 15:16	12	1.19	146.33	33.89	112.45	1833.80	420.77	53.28	125.81	911.48	142.06	114.58	12445
7/4/2018 15:26	13	0.96	147.08	30.12	116.97	1824.29	408.66	60.63	123.74	890.71	141.34	92.49	12405
7/4/2018 15:26	13LD	0.96	146.88	33.58	113.30	2067.72	429.60	61.07	123.05	932.69	141.34	92.49	
7/4/2018 15:36	14	1.07	94.71	21.22	73.50	1671.38	338.01	59.44	115.62	890.32	124.50	78.46	9590
7/4/2018 15:46	15	0.86	81.36	19.11	62.24	1458.00	326.92	58.15	111.30	749.40	112.78	71.55	5215
7/4/2018 15:56	16	1.04	119.51	25.05	94.45	1516.69	389.76	44.42	106.46	500.16	113.66	74.48	4275
7/4/2018 16:06	17	0.86	64.93	15.43	49.50	1067.78	278.25	18.27	98.52	516.97	95.23	57.47	4180
7/4/2018 16:16	18	0.80	56.18	15.75	40.43	1198.62	280.30	30.05	105.77	574.76	94.38	54.01	4065
7/4/2018 16:46	19	0.38	49.99	14.20	35.79	1451.94	297.55	42.91	111.47	793.91	96.55	60.47	5250
7/4/2018 17:16	20	0.29	41.57	11.30	30.27	1412.90	256.48	70.47	112.85	779.53	85.86	50.10	4065
7/4/2018 17:16	20LD	0.29											3615
7/4/2018 17:46	21	0.23	38.02	10.74	27.28	1472.92	248.06	78.57	112.34	965.36	82.47	49.80	4940
7/4/2018 18:16	22	0.16	28.55	8.74	19.81	1559.94	219.10	148.17	105.25	1094.71	65.06	36.60	3515
7/4/2018 18:46	23	0.08	20.40	7.50	12.91	1555.09	175.97	174.32	95.06	1103.31	50.73	27.30	3220
7/4/2018 19:16	24	0.05	16.16	6.67	9.49	1527.02	154.82	201.77	88.33	1149.75	33.87	20.27	3570

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished. (b)= Edwards Aquifer Research and Data Center, unpublished.

Appendix S: Summary of water quality variables measured during storm event 9.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
7/7/2018 16:10	1	0.34	345.65	72.56	273.09	2852.16	692.57	121.73	55.34	701.54	139.40	101.72	5195
7/7/2018 16:13	2	1.84	259.47	1.11	258.37	2269.22	536.96	115.94	55.34	673.82	115.20	169.24	4665
7/7/2018 16:16	3	2.04	218.02	41.65	176.37	2112.58	455.30	88.24	53.12	470.74	107.23	128.28	4045
7/7/2018 16:16	3LD	2.04											3455
7/7/2018 16:19	4	2.15	282.58	47.94	234.65	1807.73	558.39	92.77	54.83	457.93	131.73	157.61	11910
7/7/2018 16:22	5	2.56	334.90	65.61	269.29	1490.18	531.17	77.39	55.34	268.60	138.94	132.18	14255
7/7/2018 16:22	5LD	2.56				1773.42	570.83	72.23	58.08	295.44	138.94	132.18	
7/7/2018 16:25	6	3.36	303.16	57.19	245.97	2150.59	537.60	84.34	64.75	242.93	137.50	158.80	17240
7/7/2018 16:30	7	2.12	364.56	54.03	310.53	1627.47	712.72	65.07	70.91	329.77	192.60	237.82	21760
7/7/2018 16:35	8	2.01	557.27	77.35	479.92	1966.44	1378.25	46.11	65.09	425.54	357.80	378.21	17240
7/7/2018 16:35	8LD	2.01											15380
7/7/2018 16:40	9	1.99	550.07	82.94	467.14	2057.23	1044.09	54.53	74.50	388.27	284.70	403.74	24420
7/7/2018 16:45	10	2.34	639.62	85.48	554.14	1884.13	1495.27	52.95	81.00	427.65	389.30	498.62	25860
7/7/2018 16:50	11	2.07	633.70	82.63	551.07	2556.35	1724.19	48.63	100.84	447.17	439.30	511.24	23055
7/7/2018 16:55	12	1.25	579.83	73.56	506.27	2160.08	1749.91	53.48	101.01	572.11	453.80	515.67	25860
7/7/2018 17:05	13	1.16	572.24	69.16	503.08	2021.16	1655.17	50.11	124.62	768.42	390.90	446.28	13775
7/7/2018 17:15	14	0.59	404.97	51.58	353.39	2116.73	1322.82	46.84	133.34	720.34	326.60	422.03	17240
7/7/2018 17:25	15	0.39	354.15	46.83	307.32	1559.23	1205.10	45.90	144.80	703.54	299.80	392.40	15390
7/7/2018 17:25	15LD					1308.48	754.73	72.02	144.12	698.94	299.80	392.40	
7/7/2018 17:35	16	0.32	312.42	42.16	270.25	1374.95	1081.38	88.55	152.84	718.07	275.60	331.73	16275
7/7/2018 17:45	16LD	0.27	299.74	40.64	259.10						243.20	334.00	
7/7/2018 17:45	17	0.27	250.95	36.90	214.05	1557.66	948.28	61.80	155.41	648.25	243.20	334.00	10490

Appendix S. Continued.

7/7/2018 17:55	18	0.23	232.59	35.16	197.43	1437.15	702.65	55.38	150.45	753.51	214.30	257.95	10490
7/7/2018 18:25	19	0.11	137.33	27.91	109.42	1192.99	540.39	76.97	162.25	823.16	164.70	180.92	9300
7/7/2018 18:55	20	0.08	104.50	18.97	85.53	1398.76	489.59	96.24	140.53	941.50	123.60	149.49	6180
7/7/2018 18:55	20LD	0.08											13065
7/7/2018 19:25	21	0.06	86.55	15.38	71.18	789.62	203.23	185.67	127.70	940.78	110.60	121.26	6880
7/7/2018 19:55	22	0.05	72.47	13.51	58.95	1237.48	306.76	248.97	116.92	1025.68	87.54	99.74	3855
7/7/2018 20:25	23	0.05	58.05	12.40	45.66	1321.92	308.69	254.34	109.40	1065.67	72.64	76.91	3815
7/7/2018 20:55	24	0.05	42.51	10.62	31.89	1273.48	235.60	42.74	96.57	917.99	55.11	57.60	3220
7/7/2018 20:55	24FD	0.05	41.11	8.43	32.68	1292.09	202.38	43.58	106.66	1009.16	55.11	57.60	3635
7/7/2018 20:55	24FD-SSC	0.05	42.22	8.81	33.41						55.11	57.60	

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

Appendix T: Summary of water quality variables measured during storm event 10.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
7/9/2018 10:18	1	0.99	390.59	98.10	292.49	1829.49	606.41	32.32	28.79	480.77	150.58	178.95	9250
7/9/2018 10:18	1LD	0.99											9210
7/9/2018 10:21	2	2.14	287.25	60.58	226.68	1707.92	527.60	76.27	41.15	524.37	149.08	141.27	12445
7/9/2018 10:24	3	2.19	322.15	49.04	273.12	1650.97	513.18	73.80	53.51	351.10	204.22	217.91	21760
7/9/2018 10:27	4	2.15	265.99	47.37	218.62	1261.79	455.71	62.99	53.17	322.91	174.32	183.20	21760
7/9/2018 10:30	5	2.25	211.50	45.60	165.90	1069.89	392.70	123.62	57.74	278.09	101.90	137.64	25860
7/9/2018 10:33	6	2.06	184.26	37.74	146.52	1262.74	373.14	135.96	65.36	389.82	99.90	119.04	43320
7/9/2018 10:33	6LD	2.06	188.42	36.87	151.54	1385.51	373.14	165.22	64.85	366.78	99.90	119.04	
7/9/2018 10:38	7	1.14	168.88	34.31	134.57	1582.86	419.17	141.48	77.21	499.55	98.73	120.33	40820
7/9/2018 10:43	8	0.91	162.11	30.43	131.67	1638.54	461.24	128.91	93.46	526.92	99.78	122.20	70680
7/9/2018 10:48	9	0.48	236.64	44.68	191.96	1716.55	515.95	84.26	104.30	637.04	99.60	136.38	60165
7/9/2018 10:53	10	1.10	191.68	38.07	153.61	1916.69	424.89	109.87	65.87	484.76	111.63	116.07	28970
7/9/2018 10:53	10LD	1.10											30655
7/9/2018 10:58	11	2.27	326.94	72.68	254.26	1256.84	497.78	107.29	59.60	241.98	138.72	135.16	20530
7/9/2018 11:03	12	7.53	665.77	130.83	534.95	1841.09	866.15	66.16	79.41	176.95	225.48	197.67	43320
7/9/2018 11:13	13	7.53	894.38	136.50	757.88	1740.52	1776.72	54.06	95.16	506.31	403.92	524.78	99315
7/9/2018 11:23	14	7.53	1446.16	225.79	1220.37	4521.59	2159.12	61.58	137.65	646.12	552.30	652.61	60165
7/9/2018 11:33	15	3.41	676.85	86.98	589.87	3388.00	1684.28	72.51	177.61	831.57	436.20	524.45	60165
7/9/2018 11:33	15FD	3.41	651.32	84.24	567.08	2657.07	793.47	84.61	186.24	898.88	436.20	524.45	49020
7/9/2018 11:33	15FD- SSC	3.41	763.22	104.71	658.52						436.20	524.45	
7/9/2018 11:43	16	2.22	613.83	85.09	528.74	2217.97	640.19	85.20	164.91	975.48	299.60	323.80	43320
7/9/2018 11:53	17	2.01	303.51	46.63	256.88	2198.19	809.07	86.14	179.81	1181.60	191.30	253.72	30655
7/9/2018 11:53	17LD	2.01	309.46	45.24	264.22	2351.02	804.33	86.14	176.93	1226.02	191.30	253.72	

Appendix T. Continued.

7/9/2018 12:03	18	1.26	202.75	32.30	170.45	1930.45	635.05	83.90	192.85	1338.19	125.26	154.95	28970
7/9/2018 12:33	19	3.41	165.80	27.89	137.91	2215.50	515.75	89.08	138.50	1315.26	97.33	126.50	32440
7/9/2018 13:03	20	0.57	92.69	19.21	73.49	2264.33	324.55	61.70	139.35	1550.96	51.90	72.30	16275
7/9/2018 13:03	20LD	0.57											14055
7/9/2018 13:33	21	0.30	52.41	11.85	40.56	2225.90	329.10	74.50	170.16	1661.58	42.43	50.11	21760
7/9/2018 14:03	22	0.57	36.93	8.92	28.01	2167.75	251.08	54.64	170.16	1713.53	65.08	39.36	19365
7/9/2018 14:33	23	0.14	30.44	7.43	23.01	2397.31	220.26	68.39	119.03	1741.23	33.64	34.67	16275
7/9/2018 15:03	24	0.08	27.16	6.81	20.35	2345.25	188.07	191.78	103.62	1974.60	33.24	28.55	8965

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

Appendix U: Summary of water quality variables measured during storm event 11.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (a)	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
8/12/2018 12:08	1	1.20	912.03	195.13	716.90	5025.14	1911.10	40.32	95.38	1595.68	219.42	254.65	>120960
8/12/2018 12:08	1LD	1.20											>120960
8/12/2018 12:11	2	0.97	734.24	148.43	585.81	5361.23	1507.91	93.51	124.01	1847.28	344.04	437.45	>120960
8/12/2018 12:14	3	0.89	560.91	112.74	448.17	4898.01	1339.32	127.94	142.53	1624.13	286.26	335.77	120958.5
8/12/2018 12:17	4	0.48	530.68	109.30	421.38	4814.60	1395.78	150.96	181.11	1567.57	238.16	307.76	64982.5
8/12/2018 12:20	5	0.40	381.77	75.71	306.06	4172.23	907.70	165.07	238.89	1479.56	194.90	252.64	60165.5
8/12/2018 12:23	6	0.38	256.61	50.78	205.83	3582.89	804.92	170.36	206.82	1353.45	156.02	298.95	94314
8/12/2018 12:28	7	0.26	200.29	46.65	153.65	3370.71	638.12	144.09	227.57	1219.59	108.04	136.14	77655
8/12/2018 12:28	7LD					3360.46	607.70	156.16	228.08	1285.30	108.04	136.14	
8/12/2018 12:33	8	0.13	133.75	32.31	101.44	3061.92	537.12	173.14	235.80	1225.41	81.75	103.84	120958.5
8/12/2018 12:33	8LD	0.13	148.76	36.73	112.03						81.75	103.84	
8/12/2018 12:38	9	0.09	95.69	24.71	70.99	2849.43	508.49	173.79	229.28	1262.01	65.98	82.91	70680
8/12/2018 12:43	10	0.05	81.79	20.45	61.34	3253.52	471.12	127.10	195.85	1346.08	57.56	72.86	1965
8/12/2018 12:43	10LD	0.05											120958.5
8/12/2018 12:48	11	0.04	74.07	19.13	54.93	2912.84	451.83	125.43	173.39	1326.12	51.43	66.40	70680
8/12/2018 12:53	12	0.04	61.27	17.33	43.94	2917.12	415.05	132.77	174.08	1277.70	44.62	59.71	77655
8/12/2018 13:03	13	0.03	48.21	14.11	34.11	2695.82	384.24	139.82	173.22	1468.19	33.90	46.03	94314
8/12/2018 13:13	14	0.03	40.41	12.83	27.58	2759.80	342.69	143.07	175.62	1533.52	31.51	40.61	70680
8/12/2018 13:13	14LD					2901.96	346.07	148.45	177.33	1415.18	31.51	40.61	
8/12/2018 13:23	15	0.03	33.75	11.95	21.80	2725.26	323.60	151.89	159.33	1500.41	28.80	34.75	86643.5
8/12/2018 13:23	15LD	0.03	35.85	13.68	22.17						28.80	34.75	
8/12/2018 13:33	16	0.03	27.94	10.19	17.76	2854.78	294.97	155.51	141.67	1600.23	25.52	31.70	94314

Appendix U. Continued.

8/12/2018 13:43	17	0.04	25.53	10.38	15.14	2765.33	275.29	174.62	123.67	1701.43	25.23	30.95	94314
8/12/2018 13:53	18	0.05	24.29	10.64	13.66	2832.95	263.16	180.01	119.56	1697.33	24.97	29.45	120958.5
8/12/2018 14:23	19	0.11	49.01	16.80	32.20	2201.72	348.85	60.65	132.41	1162.14	49.10	59.07	32440
8/12/2018 14:53	20	0.01	26.74	11.45	15.29	1957.08	258.59	78.29	132.07	1094.37	27.04	35.35	23055
8/12/2018 14:53	20LD	0.01											
8/12/2018 15:23	21	0.02	69.75	18.48	51.27	2291.29	267.73	63.90	113.56	1183.82	21.92	24.17	34335
8/12/2018 15:23	21FD	0.02	30.87	10.78	20.10	2016.15	239.30	110.31	140.47	1232.95	21.92	24.17	46040
8/12/2018 15:23	21FD-SSC	0.02	15.64	6.74	8.90						21.92	24.17	21760
8/12/2018 15:53	22	0.01	12.30	8.18	4.11	2045.09	166.94	66.96	86.64	1328.06	14.94	17.02	46040
8/12/2018 16:23	23	0.00	6.90	5.20	1.70	2063.20	131.15	211.47	71.89	1488.43	10.54	11.25	28970
8/12/2018 16:53	24	0.00	4.20	4.49	-0.29	1879.21	92.98	283.96	47.89	1615.98	7.68	7.23	36350

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

Appendix V: Summary of water quality variables measured during storm event 12.

Time [CST] [MM/DD/YYYY HH:MM:SS]	Sample	Discharge [m3/s]	TSS [mg/L]	VSS [mg/L]	NVSS [mg/L]	TN [µg/L]	TP [µg/L]	NH_4^+-N [µg/L]	SRP [µg/L]	NO_3^--N [µg/L]	Turbidity (NTU) (b)	*E. coli* (MPN/ 100mL)
9/7/2018 5:06	1	0.79	788.95	178.30	610.65	3986.88	1552.91	109.23	61.76	733.65	257.06	120958.5
9/7/2018 5:06	1LD	0.79										120958.5
9/7/2018 5:09	2	1.07	554.76	134.75	420.00	3444.60	1034.17	67.99	91.37	992.55	284.13	40820
9/7/2018 5:09	2LD	1.07	564.02	123.81	440.21	4438.86	1000.08	76.28	86.72	964.33	284.13	
9/7/2018 5:12	3	1.12	286.79	60.02	226.77	2564.42	591.12	88.19	98.60	1067.21	178.61	8035
9/7/2018 5:15	4	1.27	240.90	57.08	183.82	2001.72	452.86	76.92	92.40	786.25	110.16	5560
9/7/2018 5:18	5	1.33	172.03	41.35	130.68	2346.86	409.40	133.69	100.66	942.60	102.55	5595
9/7/2018 5:21	6	1.30	154.28	30.22	124.06	1834.07	390.07	77.55	99.12	797.09	103.64	7105
9/7/2018 5:26	7	1.05	145.29	34.84	110.44	1638.10	379.05	52.04	107.03	558.38	86.56	34335
9/7/2018 5:31	8	0.85	159.97	34.97	125.00	1918.54	406.91	68.84	132.68	790.98	78.04	9780
9/7/2018 5:36	9	0.40	169.33	41.75	127.58	1941.36	387.57	58.84	121.84	725.73	91.02	18270
9/7/2018 5:41	10	0.34	90.47	19.52	70.95	1487.69	312.72	35.24	115.64	632.15	70.32	14935
9/7/2018 5:41	10LD	0.34										13010
9/7/2018 5:46	11	0.26	60.77	15.94	44.83	1384.36	270.31	59.48	120.63	621.92	48.74	19365
9/7/2018 5:51	12	0.21	46.23	14.78	31.44	1339.76	245.57	76.92	119.95	651.57	38.62	17240
9/7/2018 5:51	12LD	0.21	47.74	16.43	31.31	1338.33	243.49	64.80	127.00	665.77	38.62	
9/7/2018 6:01	13	0.10	30.79	10.13	20.65	1366.27	213.55	86.27	115.47	680.95	28.93	23055
9/7/2018 6:11	14	0.05	22.80	8.71	14.09	1378.20	200.04	107.11	110.31	822.23	22.66	19365
9/7/2018 6:21	15	0.05	16.93	7.58	9.35	1371.65	200.04	163.03	110.65	891.49	20.06	11795
9/7/2018 6:31	16	0.05	17.24	8.14	9.10	1524.65	182.57	101.16	108.24	909.70	18.28	9590
9/7/2018 6:41	17	0.04	15.50	7.68	7.82	1512.39	180.70	217.25	107.38	931.82	19.76	14255

Appendix V. Continued.

9/7/2018 6:51	18	0.03	14.64	7.72	6.92	1410.61	160.74	69.69	94.12	984.63	18.99	11235
9/7/2018 7:21	19	0.02	12.00	7.10	4.90	1597.64	148.27	324.83	87.93	1109.84	16.70	7195
9/7/2018 7:51	20	0.01	8.95	6.22	2.73	1610.74	116.67	453.47	71.74	1274.66	13.40	7250
9/7/2018 7:51	20LD	0.01										6770
9/7/2018 8:21	21	0.01	6.36	5.20	1.16	1673.56	104.40	800.04	57.46	1347.39	10.15	5095
9/7/2018 8:21	21FD	0.01	4.66	3.69	0.97	1798.74	105.23	431.35	74.33	1471.73	10.15	5955
9/7/2018 8:21	21FD -SSC	0.01	4.41	3.35	1.06							
9/7/2018 8:51	22	0.00	4.73	4.00	0.73	1678.09	70.72	1010.53	42.99	1534.33	7.23	5810
9/7/2018 9:21	23	0.01	2.51	3.29	-0.78	1701.69	54.92	1138.95	36.63	1648.60	4.87	3560
9/7/2018 9:51	24	0.02	2.10	3.07	-0.97	1816.05	31.63	1412.38	31.12	1700.81	2.79	2120

LD = Lab duplicate
FD = Field duplicate
SSC = Suspended Sediment Concentrations in 1 L sample.
(a) = Edwards Aquifer Authority, unpublished.
(b) = Edwards Aquifer Research and Data Center, unpublished.

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