Filterra® Bioretention System Water Quality and Hydrologic Field-Scale Performance Evaluation

Fayetteville Amtrak Station
472 Hay Street
Fayetteville, NC

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December 1, 2015

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Executive Summary

Filterra® Bioretention Systems are biofilters offering a unique version of the typical flow-through filter by coupling high volume treatment with an engineered bioretention media (140 in/hr design infiltration rate) (Lenth et al. 2010). The systems are viable options for retrofitting stormwater infrastructure in ultra-urban areas where space is of concern. The purpose of this study was to quantify the hydrologic and water quality treatment capabilities of a standalone Filterra® device to obtain performance data that supports approval by the North Carolina Department of Environmental and Natural Resources (NCDENR). This monitoring was performed in accordance with Preliminary Evaluation Period (PEP) guidelines described in the 2007 NCDENR Stormwater BMP Manual and the Quality Assurance Project Plan (NC State 2013) previously submitted to NCDENR.

North Carolina State University conducted a third-party analysis of the sediment, nutrient, and metals removal performance and hydrologic mitigation of a Filterra® Bioretention System ("Filterra"). The NCDENR total suspended sediment (TSS) design criterion is 85% removal. Another widely-implemented protocol for approval of emergent stormwater technologies is the state of Washington's Technology Assessment Protocol – Ecology (WSDE, 2011). TAPE designates a basic treatment target of (a) TSS removal greater than 80% when influent TSS range: > 200 mg/L, (b) TSS removal greater than or equal to 80% when influent TSS range is 100-200 mg/L or (c) effluent TSS concentration of less than 20 mg/L when influent TSS range: 20 – 100 mg/L. Once this basic criterion is met, additional treatment for total phosphorus may be awarded if removal of TP is greater than or equal to 50% for influent concentrations between 0.1 and 0.5 mg/L. Comparisons to both these protocols were made.

Results show the monitored Filterra® system reduced median peak flow by 56% for storms monitored in the study (0.10 to nearly 5 inches in depth). During 2013, statistically-significant bypass did not occur before 0.70 inches (Figure 5 and Table 15). The system also treated rainfall intensities up to 0.90 in/hr in 2013 before overflow is expected to occur, which meets new minimum design criteria established by NCDENR (2015) for non-storage based SCMs. When plotting the observed rainfall intensity vs. site peak outflow against the theoretical peak flows from the Rational equation's pre- and post-development conditions, the Filterra® device nearly mimics the pre-development site peak (Figure 10 and Figure 7).

Additionally 72% of inflow volume was treated by the Filterra®, while the remainder was either bypass flow (22%) or a combination of soil storage and/or instrument error (6%) (see Hydrology section). Data from Smolek et al. (2015) show that the expected overflow from a traditional stormwater BMP following NCDENR design guidance during an average year, such as a wetland or wet pond, is consistent with the overflow percent seen by the Filterra® in our study, suggesting that the Filterra® behaved similarly to widely-used and approved BMPs in North Carolina (Figure 4).

Over a 22-month monitoring period, the Filterra® significantly reduced total suspended solids concentrations with an efficiency ratio of 96%, a cumulative load reduction of 76%, and a median storm-by-storm TSS load reduction of 80%. Another sediment metric, Suspended Sediment Concentration (SSC), was measured, resulting in a 97% significant efficiency ratio, a 77% cumulative load reduction, and a 77% median storm-by-storm load reduction. The 95% confidence interval of the mean TSS removal on a per storm event basis was determined to be 90% - 94%, satisfying both NCDENR and TAPE criteria.

Total phosphorus concentrations were significantly reduced with an efficiency ratio of 64%, a cumulative load reduction of 54% and a 63% median storm-by-storm load reduction. TAPE criteria for accreditation of TP removal require 50% TP removal when influent concentrations are between 0.1-0.5 mg/L in order to account for irreducible concentrations. The mean storm-by-storm event mean concentration reduction of the 16 TAPE-qualified events was 66% with the 95% confidence interval of the mean TP removal ranging from 57% - 75%, satisfying the TAPE criteria. Overall cumulative percent loading reduction was 54%, indicating excellent removal of phosphorus that is on par and/or above the 45% pollutant removal credit awarded by NCDENR for bioretention without internal water storage (NCDENR 2009). Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low both entering and leaving the system (below what is expected on an urban watershed).

While total nitrogen is not a pollutant targeted for TAPE approval, total nitrogen concentrations were significantly reduced with an efficiency ratio of 39%, a cumulative load reduction of 39% and a 45% median storm-by-storm load reduction. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed.

This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification. Total zinc concentrations were also significantly reduced with an efficiency ratio of 69%. For the Filterra® system as a whole, cumulative percent load reductions for TSS, TP and TN were 76%, 54% and 39%, respectively. When only storms that did not produce bypass were considered, the cumulative percent load reduction increased to 96%, 75%, and 45% for TSS, TP and TN, respectively.

When looking at effluent concentrations as a benchmark, water quality of discharged and treated stormwater was generally lower than "good" and "excellent" water quality thresholds in the literature. The median effluent TP concentration of 0.038 mg/L met the 0.06 mg/L "excellent" threshold for over 80% of all measured events. The 0.53 mg/L TN median effluent concentration meant that the "excellent" benthic threshold of 0.69 mg/L determined for this specific eco-region was met or exceeded for 65% of measured events.

Future studies with higher nutrient concentrations entering the Filterra® (perhaps from watersheds with a high gross solids and leaf litter loading) will provide a better assessment of soluble phosphorus species, since nutrient influent concentrations for this site were below what is typically seen on urbanized watersheds.

Project Overview

North Carolina State University ("NC State") monitored a Filterra® Bioretention System in Fayetteville, North Carolina (Table 1, Figure 1). The existing parking lot of an Amtrak™ train station was retrofitted with a 6- by 4- foot Filterra® system, which treats 0.25 acres of impervious asphalt and concrete catchment (Figure 2). The system was installed in September of 2012 and activated October 2nd, 2012 by Contech Engineered Solutions, LLC (then Ameriscast/Filterra Bioretention Systems) staff.

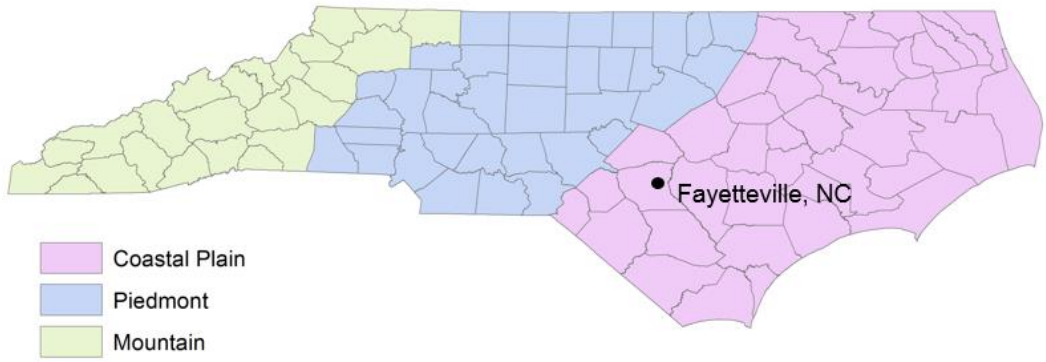


Figure 1. Location of project site in North Carolina.

Figure 2. Location of Filterra® at city-owned Amtrak™ parking lot in Fayetteville.

Filterra® System Components

The Filterra® system is a high filtration rate, small unit storage volume stormwater control measure that uses proprietary bioretention filtration media topped with mulch in combination with a planted tree species. For this project, a crape myrtle *(Lagerstroemia)* was installed as the tree genus (Figure 21). The tree frame and grate cast in the top slab of the concrete structure sits at the top-of-curb elevation, below which is a headspace. Water conveyed via curb and gutter flow enters the system through a six foot wide open-throated curb inlet and is conveyed at a design infiltration rate of 140 inches per hour through a media bed depth of 21 inches. Similar to conventional bioretention, an underdrain surrounded by washed aggregate drains treated stormwater to the existing drainage infrastructure.

Filterra® Maintenance Procedures

Routine, semi-annual maintenance is recommended for the Filterra® system. Maintenance procedures are described in the Filterra® Installation, Operation, and Maintenance Manual (see appendix). This manual and a one-year maintenance plan is provided by Contech Engineered Solutions. An extended maintenance service contract or maintenance training based on this manual for those who wish to perform their own maintenance is also offered by Contech Engineered Systems. Maintenance records indicate the Filterra® system at this study site was performed on May 16th, 2013 and December 17th, 2013, and October 20th, 2014.

Table 1. Site Details of the Filterra Monitoring Project

Site Address	472 Hay St, Fayetteville, NC 28301
Geographic coordinates	35.055968, -78.884026
River Basin (Hydrologic Unit Code)	Cape Fear (030300040704)
Sub-Basin	Upper Cape Fear
Sub-Watershed	Cross Creek
Predominant soil types	Sand / Sandy loam

Filterra® Sizing

Filterra® sizing utilizes a conservative design flow rate of 140 inches per hour (Geosyntec, 2008). To design the Filterra® to treat the necessary (1" or 1.5") water quality volume, Withers and Ravenel (2008) conducted an engineering analysis that developed sizing for Filterra in North Carolina. Through this analysis, the maximum size drainage area to each size of Filterra® unit was determined. Sizing charts were developed for both the 1" and 1.5" water quality treatment goals required for the state of North Carolina using a "worst case" 100% impervious drainage area.

Engineers for projects in North Carolina will be able to use these sizing charts to choose the correct size of Filterra® unit based on their location within the state and the size of drainage area going to the unit. Contech offers engineering support and review to specifying engineers to help with sizing and proper placement. As a condition of permit approval, Contech proposes to the State of North Carolina that a plan approval letter from Contech Engineered Solutions be required for all projects. This ensures that Contech provides a QA/QC check on the engineer's design and would prevent misuse of the product. Contech routinely provides this service to other parts of the country where the state or other approving authority has required it as part of the condition of permitted use.

Literature Review of Stormwater Filtration in North Carolina

Bioretention, also known as rain gardens, biofilters, and bio-infiltration devices, is an engineered stormwater control measure that provides soil and vegetation treatment of stormwater runoff. Traditional bioretention generally has 2-3 feet of engineered media replacing the *in-situ* native soil, with 6 to 12 inches of vegetated ponding area to allow temporary storage of stormwater before it infiltrates through the media, finally discharging through an underdrain system and/or exfiltrating into the sub-soil. In North Carolina, bioretention engineered media must meet composition specifications. The media must be 85-88% sand, 8-12% "fines" (clay and silt), and 3-5% organic matter (by volume). Drawdown or infiltration from the ponding zone into the media must be 1-2 inches per hour, resulting in a general 24 to 48 hour drawdown period.

Studies have been conducted on bioretention looking at its performance in removing nitrogen, phosphorus, sediment, heavy metals, and bacteria. These pollutants exist in both the solid and aqueous phases. Dissolved pollutants in stormwater typically exist as specific forms due to solubility, pH, and other chemical constraints present in the stormwater environment. Dissolved phosphorus is generally in the form of inorganic orthophosphate, while dissolved nitrogen is generally nitrate and nitrite ($NO_{3/2}$) and ammonia and ammonium ($NH_{3/4}$), the latter generally being dominated by NH_4 at typical stormwater pH values (Pitt et al, 1995). Dissolved pollutant removal in "traditional" bioretention occurs through transformation by adsorption, precipitation, ion exchange, and biological processes, with many design variations of the media and/or drainage configuration to target specific pollutants (Davis et al., 2009). Many pollutants are associated with sediment, allowing for physical processes like sedimentation and filtration to remove them from the stormwater pollutant stream. Table 2 shows common pollutants targeted in bioretention, their typical removal efficiencies, and mechanisms that result in removal.

Table 2. Summary of mechanisms of pollutant removal supported by published field studies on bioretention performance.

Parameter of Interest	Load reduction (%)	Mechanism of removal	Factors affecting removal
Metals	54-99%*	Sorption Filtration Plant uptake Hydrolysis Precipitation	Media characteristics[bdfg] Flow rate[cf] Vegetation[l] Age/maturity of facility[c] Interaction with metal-emitting material[cd]
Phosphorus	52-99%†	Filtration Sorption Plant uptake	Media characteristics[adefghk] Saturation of soil[fh] Rooting depth[gl]
Nitrogen	30-99%¥	Microbial metabolism Plant uptake Denitrification	See Phosphorus
Total suspended solids	54-99%	Filtration Sedimentation	Flow rate[fik] Clogging of media[i] Media particle size[ik]

*: Zn only; †: total phosphorus (TP); ¥: total nitrogen (TN)

The data in Table 1 are based on the following studies: **a.** Davis et al. (2009), **b.** Davis (2007), **c.** Davis et al. (2003), **d.** Dietz & Clausen (2006), **e.** Dietz & Clausen (2005), **f.** Hatt et al. (2009), **g.** Hunt et al. (2012), **h.** Hunt et al. (2006), **i.** Li & Davis (2008), **j.** O'Reilly et al. (2012), **k.** O'Neill & Davis (2012), **l.** Passeport et al. (2009), **m.** Sun & Davis (2007)

Sediment removal is generally high in bioretention, since the surface of the systems can filter and settle out solids in stormwater (Table 2). The top mulch layer has been shown to filter most of the TSS in the runoff (Hsieh and Davis, 2005). Bioretention filter media are generally clogging-limited (rather than breakthrough limited), thus warranting suggestions that the top 20-cm of media depth is the most crucial for maintenance purposes in insuring long-term removal of urban particles (Li and Davis, 2008).

Phosphorus in stormwater is generally considered to be about 55% bound to particles (Erickson et al., 2012). Phosphorus bound to sediment can be removed via filtration and sedimentation. Dissolved phosphorus is a more challenging constituent to remove in traditional bioretention due to complex chemical interactions in the media. Phosphorus has been known to leach due to the high background P in the media itself (often measured vis-à-vis the P-index). Organic matter is often correlated with phosphorus leaching (Bratieres et al. 2008). Media with low P indices and high cation exchange capacities are recommended (Hunt et al. 2006). Zhang et al. (2008) found 66-85% mass removal of dissolved phosphorus with fly ash amendment in bioretention. A conventional field cell in NC showed 14-91% dissolved phosphorus removal (Hunt and Line, 2009). Two internal water storage-modified bioretention cells showed 52 and 77% ortho-phosphate removal efficiencies (1.5 and 2.5 feet deep IWS zones, respectively). Vegetation has been suggested as an important way to remove orthophosphate as well, with 97-100% removal of Ortho-P seen in vegetated mesocosms vs 48-100% for non-vegetated (Henderson et al. 2007).

Nitrate is a challenging constituent to remove in stormwater because of its high solubility and low media sorbtive capability. In aerobic environments, nitrate will not be the primary electron recipient because of the availability of the much more electronegative constituent oxygen (O_2). To exacerbate the removal challenges, aerobic environments in soil media often promote nitrification, which is the conversion of ammonia/ammonium to nitrite (and eventually nitrate) by ammonia-oxidizing bacteria. Thus, aerobic bioretention conditions, which are common in flow-through media in bioretention, have been known to *add* nitrate-nitrogen rather than remove it. Only under anoxic conditions can nitrate be significantly converted to nitrogen gas (N_2), which is released from the system to the atmosphere. This occurs through the design variants seen in some bioretention cells commonly known as an upturned elbow, anoxic zone, or internal water storage zone. Table 3 (from LeFevre et al., 2015) shows the various studies of bioretention removal of nitrate under both conventional (no anoxic zone) and modified (internal water storage zones) specifications.

Table 3. Summary of nitrate removal studies for bioretention in the Atlantic region

Study	Study Location	Nitrate mass reduction (negative indicates export)	Drainage configuration
Davis et al. (2001)	Lab (MD, USA)	-204 to 24%	Conventional
Dietz and Clausen (2005)	Field (CT, USA)	35%	Conventional
Hsieh and Davis (2005a)	Lab (MD, USA)	1-43%	Conventional
Hsieh and Davis (2005b)	Lab (MD, USA)	-64 to 19%	Conventional
Davis et al. (2006)	Lab, field (MD)	<20%	Conventional
Davis (2007)	Field (MD, USA)	90%	Conventional
Hsieh et. al. (2007)	Lab (MD, USA)	-21% to 41%	Conventional
Line and Hunt (2009)	Field (NC, USA)	-766 to -26%	Conventional
Passeport et. al. (2009)	Field (NC, USA)	1-43%	Modified IWS
Diez and Clausen (2006)	Field (CT, USA)	36-87%	Modified IWS
Kim et al. (2003)	Lab (MD, USA)	80%	Modified IWS

Heavy metals in stormwater runoff generally come from anthropogenic sources. Major sources include metal roofing, tire wear, catalytic converters, brake linings (copper), and galvanized steel (Davis et al., 2001). In bioretention, most metal removal occurs in the top 2 to 9 inches of media and mulch (Davis et al, 2003). The following table adapted from Fears (2014) summarizes load reductions of heavy metals in traditional bioretention.

Table 4. Summary of Heavy Metal Performance of Various Field-scale Bioretention Studies (Fears, 2014).

Study	**Location**	**Source of Runoff**	**Events Monitored (#)**	**Load Reduction (%)*** Cu	Pb	Zn
Hatt et al., 2009	Melbourne, Aus.	Multi-level parking deck	7	67	80	84
Li & Davis, 2009	College Park, MD	Parking lot & roadway	15	60	65	83
	Silver Spring, MD	Parking lot	8	100	96†	100

Davis, 2007	College Park, MD-Cell A	Parking lot (asphalt)	12	83	88	54¥
	College Park, MD-Cell B	Parking lot (asphalt)	12	77	84	69
Hunt et al., 2006	Greensboro, NC	Parking lot	11	99	81	98

*: Average load reduction reported except for Li & Davis, 2009 (median load reduction reported)
†: 15 events monitored
¥: One outlier removed

Based on research, feasibility, state water quality goals, and engineering judgement, North Carolina credits bioretention based on design variants outlined in Table 5 below. Lack of internal water storage results in lower nitrogen credit due to (a) inability to denitrify nitrate and (b) internal water storage results in larger volume reduction, and hence a larger pollutant mass reduction.

Table 5. Credit given to bioretention in North Carolina (Source: NCDENR BMP Manual)

Site and Design Specification	Analyte	Credit
No Internal Water Storage	Total Suspended Solids	85%
	Total Nitrogen	35%
	Total Phosphorus	45%
With IWS - Coastal Plain & Sand Hills	Total Suspended Solids	85%
	Total Nitrogen	60%
	Total Phosphorus	60%
With IWS – Piedmont & Mountains	Total Suspended Solids	85%
	Total Nitrogen	40%
	Total Phosphorus	45%

Site Description

The study site is an Amtrak™ train station located at 472 Hay Street in Fayetteville, North Carolina, 28301 (Figure 1). Fayetteville is a city located in the coastal plain of North Carolina, and receives 41.3 inches of rainfall per year (NOAA Station 316891). The site is located in 12-digit hydrologic unit code 030300040704 in the Cape Fear basin (9,700 mi^2), Upper Cape Fear sub-basin (1,630 mi^2), and the Cross Creek watershed. The region is comprised of predominately sandy or sandy loam soils.

The drainage area for the Filterra® system consists of overland and gutter channel flow from 0.25 acres of impervious asphalt parking lot through a modified curb cut (Figure 3). Due to additional impervious area not thought to originally drain to the system (measured via a Total station survey and confirmed by observing runoff on-site), the Filterra® ended up being slightly undersized. The original survey did not consider a small area of impervious that was actually contributing to the system. The maximum impervious drainage area for the 6-foot by 4-foot system installed in Fayetteville is 0.21 acres according to the Filterra® sizing chart for the Piedmont/Sandhills region (1" design storm).

Figure 3. Filterra® at city-owned Amtrak™ parking lot in Fayetteville.

Data Collection

Automated, flow-proportional water quality samplers were installed to collect influent and effluent aliquots (minimum 10) for the Filterra® device, and were completely powered by solar-charged by 12-volt marine batteries. All rainfall at the site was measured using a 0.01-inch resolution tipping-bucket rain gauge affixed approximately 6 feet above the ground (Davis Instruments, Hayward, California). To obtain flow-weighted composite samples for each storm event, runoff was routed to the influent sampling location into a sharp-crested compound weir flow-measuring device (Figure 22). The weir contained a stilling area for water to pond and spill over the weir, which allowed measuring flow proportional to water head. A bubbler was affixed to the bottom of the stilling area before the weir to measure water head, and was connected to an ISCO 6712 automated sampler (Teledyne-Isco, Lincoln, Nebraska). A sample tube was also placed in this collection area to draw water quality aliquots for laboratory analysis at intervals that were proportional to the flow passing over the weir. Effluent flow was measured by two methods: (1) Prior to September 11, 2013, effluent flow was measured using an area-velocity flow meter installed in the 4-inch diameter pipe draining the Filterra, (2) After September 11, 2013, the 4-inch pipe was fitted with a Cipoletti-style weir and flow rate was continuously monitored by a bubbler placed just upstream of the weir. The area-velocity meter relied on ultrasonic pulses to determine flow velocity, which could then be converted to flow rate given water depth and pipe geometry. The primary measuring device was changed due to technical difficulties experienced during the fall of 2013. Despite this, flow-proportional sampling was maintained at all times during the study. Both flow measurement devices were relayed to the same ISCO 6712 automated sampler for flow-proportional aliquot sampling.

All flows not treated by the Filterra® were measured using an 8-inch diameter PVC bypass pipe installed in the curb island just downslope of the Filterra (Figure 20). The pipe upstream invert was flush with the existing pavement so as to immediately register bypass flow. A stand-alone bubbler was placed halfway down the pipe at its invert. All head measurements were converted to flow rate using the Manning's equation for open-channel flow using the pipe geometry, a roughness coefficient, and head as inputs.

Table 6. Equipment used for monitoring at various locations of the Filterra System

Measurement	**Equipment**	**Qty.**
Water velocity	ISCO® 750 Area Velocity Flow Module	1
Water head	ISCO® 730 Bubbler Module	3
Sample collection and storage	ISCO® 6712 Full-Size Portable Sampler	2
Head-to-flow Relationship (in)	Sharp-crested compound v-notch + rectangular weir	1
Head-to-flow Relationship (out)	Cipolleti-style weir	1
Rainfall	Davis Instruments 0.01-inch precision tipping bucket rain gauge ("Rain Collector" model)	1

Water quality samples were tested for event mean concentrations of total suspended solids (TSS), suspended sediment concentration (SSC), total ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen ($NO_{2,3}$-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total copper (Cu), dissolved copper, total zinc (Zn), and dissolved zinc. A summary of laboratory methods and handling for all analytes is shown below.

Table 7. Summary of water quality parameters tested.

Analyte	Test method	Maximum Hold time	Method detection limit (mg/L)	Laboratory
TSS	EPA S.M. 2540D	7 d	1.0	ENCO Laboratories, Inc. (Cary, NC)
SSC	ASTM D-3977	7 d		NCSU Center for Applied Aq. Ecology (Raleigh, NC)
PSD	Laser diffraction	7 d		NCSU Dep. Of Marine, Earth, and Atm. Sciences
TKN	EPA 351.2	28 d	0.26	ENCO Laboratories, Inc. (Cary, NC)
$NO_{2,3}$-N	EPA 353.2	7 d	0.041	ENCO Laboratories, Inc. (Cary, NC)
TAN	EPA 350.1	28 d	0.045	ENCO Laboratories, Inc. (Cary, NC)
TN	TN = TKN+ $NO_{2,3}$-N	N/A	N/A	ENCO Laboratories, Inc. (Cary, NC)
TP	EPA 365.4	28 d	0.025	ENCO Laboratories, Inc. (Cary, NC)
TDP	EPA 365.4	28 d	0.025	ENCO Laboratories, Inc. (Cary, NC)
SRP	SM 4500 PF F-1999	48 h	0.16	ENCO Laboratories, Inc. (Cary, NC)
Cu	EPA 200.8	6 mo	0.002	NCDENR DWR Metals and Microbiology Unit
Zn	EPA 200.8	6 mo	0.010	NCDENR DWR Metals and Microbiology Unit

Table 8. Storm Sampling Criteria

Storm Criteria	Value	Criteria satisfied?
Minimum # of aliquots	10	YES
Minimum storm coverage	≥ 70%	YES
Total precipitation (in.)	> 0.10	YES
Antecedent dry period (h)*	6	YES
Minimum # of storm events	10	YES

* *Driscoll 1989*

Data Analysis

Hydrology

Discrete hydrologic storm events were identified by a gap in precipitation exceeding six hours (Driscoll, 1989). The target storm size range for water quality sampling was generally 0.10 to 2.0 inches of depth, although a broader range was measured for non-water quality-related events. In general, storms were considered “completely captured” if flow-proportional sampling occurred for at least 70% of the hydrograph (by volume). To calculate influent and effluent runoff volumes from the raw weir level data, flow conversion was performed in FlowLink 5.1 (Teledyne-Isco, Lincoln, Nebraska). Occasionally, runoff volumes exceeded the capacity of the weir. When ponding levels exceeded the maximum height of the weir, the precise head-to-flow rate relationship no longer becomes valid. This was noted and addressed for each applicable storm. When this occurred, the modified NRCS Curve Number Method was used to estimate influent runoff volume instead (Eq. 1). Additionally, the Rational Method was used to estimate influent peak flow (NCDENR, 2009).

$$Q = \frac{(P - 0.05S_{0.05})^2}{P + 0.95S_{0.05}} * A * C \tag{1}$$

where Q = runoff volume (ft^3), P = storm event precipitation depth (in), $S_{0.20}$ = potential maximum retention (in) = $\frac{1000}{CN} - 10$, CN = Curve Number (98 for impervious surfaces), $S_{0.05}$ = modified maximum retention (in) = $1.33 * S_{0.20}{}^{1.15}$, A = watershed area (ft^2), C = conversion factor $\left(\frac{1\,ft}{12\,in}\right)$

Influent and effluent runoff volumes were compared to determine volume retention in the Filterra device. If the validity of flow data for any storm event was in question (i.e., noticeable drift in water level readings, water in weir froze during storm events, etc.), the most conservative approach of assuming negligible volume retention was used. Peak flow reduction and lag to peak were also assessed.

Additional peak flow metrics computed include the peak flow reduction factor (R_{peak}) and peak flow delay (R_{delay}) on a storm-by-storm basis (adapted after Davis *et al.*, 2008).

$$R_{peak} = \frac{q_{peak-out}}{q_{peak-in}} \quad (6)$$

$$R_{delay} = \frac{t_{q-peak-out}}{t_{q-peak-in}} \quad (7)$$

In the “Individual Storm Hydrograph” Appendix, the average underdrain flow rate was calculated for each water quality storm by dividing the event volume by the duration, yielding flow rate as cubic feet per second (cfs). Furthermore, next to each value in the Appendix is a hydraulic loading (or *volumetric flux*), which is simply the average flow rate divided by the filter media area (in this case 24 square feet). This volumetric flux is expressed as depth per time, but should not be confused with a measured saturated hydraulic conductivity reading or a surface infiltration test (ASTM D7764 and ASTM D3385, respectively).

Water Quality

Multiple analytes at various sites had a significant portion (>10%) of measured concentrations reported below the minimum detection limit (MDL). For such cases, robust regression on order statistics was performed after log-transforming the data (Bolks et al., 2014), in order to calculate summary statistics such as mean, median, standard deviation, and interquartile range (IQR). Both the efficiency ratio (ER, eq. 2) and the relative median efficiencies (RE_{median}, eq. 3, Drake *et. al.*, 2014) were calculated for ammoniacal nitrogen (TAN), nitrate/nitrite-nitrogen ($NO_{2,3}$-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total suspended solids (TSS), suspended sediment concentration (SSC), total copper (Tot. Cu), dissolved copper (Diss. Cu), total zinc (Tot. Zn), and dissolved zinc (Diss. Zn). TN was determined by adding event mean concentrations (EMCs) of TKN and $NO_{2,3}$-N.

$$ER = \left(\frac{EMC_{inavg} - EMC_{out,avg}}{EMC_{in,avg}}\right) \quad (2)$$

$$RE_{median} = \left(\frac{EMC_{in,median} - EMC_{out,median}}{EMC_{in,median}}\right) \tag{3}$$

where $EMC_{in,avg}$ = average inlet event mean concentration (mg/L), $EMC_{out,avg}$ = average outlet event mean concentration (mg/L), $EMC_{in,median}$ = median inlet event mean concentration (mg/L) and $EMC_{out,median}$ = median outlet event mean concentration (mg/L) .

All water quality data sets were log-transformed and checked for normality using the Shapiro-Wilk test and visual confirmation of residual plots. When data were log-normal, paired t-tests were performed to determine significant differences in influent and effluent pollutant concentrations. Otherwise, the Peto & Peto modification of the Gerhan-Wilcoxon test (Bolks et al., 2014) was used to detect whether influent concentrations were significantly greater than effluent concentrations. Due to varying size of storm events and scope of the sampling regime, pollutant analysis for every sampling location was not possible for every storm event, therefore sample size varied for each pollutant. All analyses were performed in R 3.1.2 (R Core Team, 2014).

Individual and cumulative load reductions through the Filterra® unit were also assessed by pairing event mean concentrations for all pollutants with measured flow data (eqs. 4 and 5). Each EMC was paired with the stormwater volume pertinent to the sampling location for each storm. Event loading (mass per storm) was calculated by multiplication of the total volume and the event mean concentration. Percent load reduction on a storm-by-storm basis was assessed by calculating the percent mass of pollutant loading reduced. The cumulative percent load reduction was calculated by determining the percent reduction of the cumulative influent and effluent loads.

$$Individual\ Load\ Reduction = 100 \times \left(1 - \frac{L_o}{L_i}\right) = 100 \times \left(1 - \frac{EMC_{out,i} * V_{out,i} + V_{over,i}}{EMC_{in,i} * V_{in,i}}\right) \tag{4}$$

$$\begin{aligned} Cum.Perc.Load\ Reduction &= 100 \times \left(1 - \frac{\sum_{i=1}^{n} L_o}{\sum_{i=1}^{n} L_i}\right) \\ &= 100 \times \left(1 - \frac{\sum_{i=1}^{n} EMC_{out,i} * V_{out,i} + \sum_{i=1}^{n} EMC_{in,i} * V_{over,i}}{\sum_{i=1}^{n} EMC_{in,i} * V_{in,i}}\right) \end{aligned} \tag{5}$$

where L_i = inlet load (mg), L_o = outlet load (mg) $EMC_{in,i}$ = inlet EMC for event i (mg/L) and $EMC_{out,i}$ = outlet EMC for event i (mg/L), $V_{in,i}$ = total runoff volume for event i, $V_{out,i}$ = effluent volume for event i, and $V_{over,i}$ = overflow volume for event i.

In equations 4 and 5, the sum of outlet loads includes both the underdrain outflow load and the overflow load when applicable, which is assumed to be untreated. Bootstrapping methods (Canty and Ripley, 2014; Davison and Hinkley, 1997) were used to determine the 95% confidence interval associated with the mean pollutant removal efficiency and mean individual load reduction per the TAPE protocol (WSDE, 2011). Mean pollutant removal efficiencies and mean load reductions for events that did not generate bypass were also included as additional analyses.

Results

Hydrology

A summary of the rainfall measured onsite is given in Table 9. Over the 22-month monitoring period, a variety of conditions were observed, including a maximum 5-minute intensity equivalent to the 2-year, 5-min storm, and a prolonged dry period of approximately 31 days. Analysis of the volume treated by the Filterra® system indicates 72% of runoff left as treated effluent through the Filterra® underdrain, while 22% was measured to have bypassed the system via the overflow pipe. The remaining 6% of unaccounted runoff volume losses was likely a composite of instrumentation error and potential soil storage and evapotranspiration.

Table 9. Analysis of all 125 hydrologic storm events from February 2013 to December 2014.

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.01	0.12	0.003	0.3
Median	0.40	0.07	1.02	0.214	3.1
Max.	4.94	2.10	6.36	1.516	31.3
Average	0.64	0.16	1.46	0.328	5.0

Table 10. Analysis of sediment-sampled hydrologic storm events (n=29).

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.02	0.30	0.043	0.26
Median	0.61	0.08	1.38	0.350	2.39
Max.	1.95	2.20	5.64	1.344	13.40
Average	0.73	0.19	1.57	0.369	4.02

Table 11. Analysis of nutrient-sampled hydrologic storm events (n=34).

	Depth (in)	Average Intensity (in/hr)	5-min Peak Intensity (in/hr)	Catchment Peak Flow (cfs)	Antecedent Dry Period (days)
Min.	0.10	0.02	0.30	0.038	0.26
Median	0.59	0.07	1.20	0.286	2.39
Max.	1.95	2.20	5.64	1.344	13.40
Average	0.69	0.17	1.42	0.327	3.87

Table 12. Fate of rainfall at Filterra® site for all 125 hydrologic storms.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	53,953	38,973	11,920	3061
Percent of Inflow (%)	NA	72	22	6

In 2013, the year encompassing a large portion of the sampling events, the total rainfall was 50.2 inches, which represents the 80th non-exceedance percentile historically. During this year, overflow was equivalent to 15% of the inflow volume (Table 13). In 2014, the total rainfall was 37.9 inches, which was a 14th-percentile year for the City of Fayetteville. During 2014, 29% of flow to the Filterra® was bypassed (Table 14). The increase in bypass percentage is hypothesized to be caused by surface clogging, potentially from decreased maintenance in 2014, which in turn caused the surface infiltration rate of the Filterra® to decrease. The 2013, 2014, and overall values for percent overflow from this study were compared to data from Smolek et al. (2015), which analyzed percent of total volume bypassed from traditional detention-based stormwater best management practices (BMPs) in North Carolina (e.g. wetland or wet retention pond) using the last 10 years of historical rainfall. Despite hydrologic goals targeting 10% bypass, detention-based BMPs with at least 3-day drawdown times can exceed 16% bypass of inflow. In 2013, when the system was properly maintained, the volume bypassing the Filterra® was comparable to detention-based BMPs with a 3-day drawdown (Figure 4).

Table 13. Fate of rainfall at Filterra® site from February 2013 to December 2013.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	28,173	22,512	4,431	1,330
Percent of Inflow (%)	NA	80	15	5

Table 14. Fate of rainfall at Filterra® site from January 2014 to December 2014.

	Inflow	Outflow	Bypass	Other
Total Volume (ft^3)	25,781	16,461	7,589	1,731
Percent of Inflow (%)	NA	64	29	7

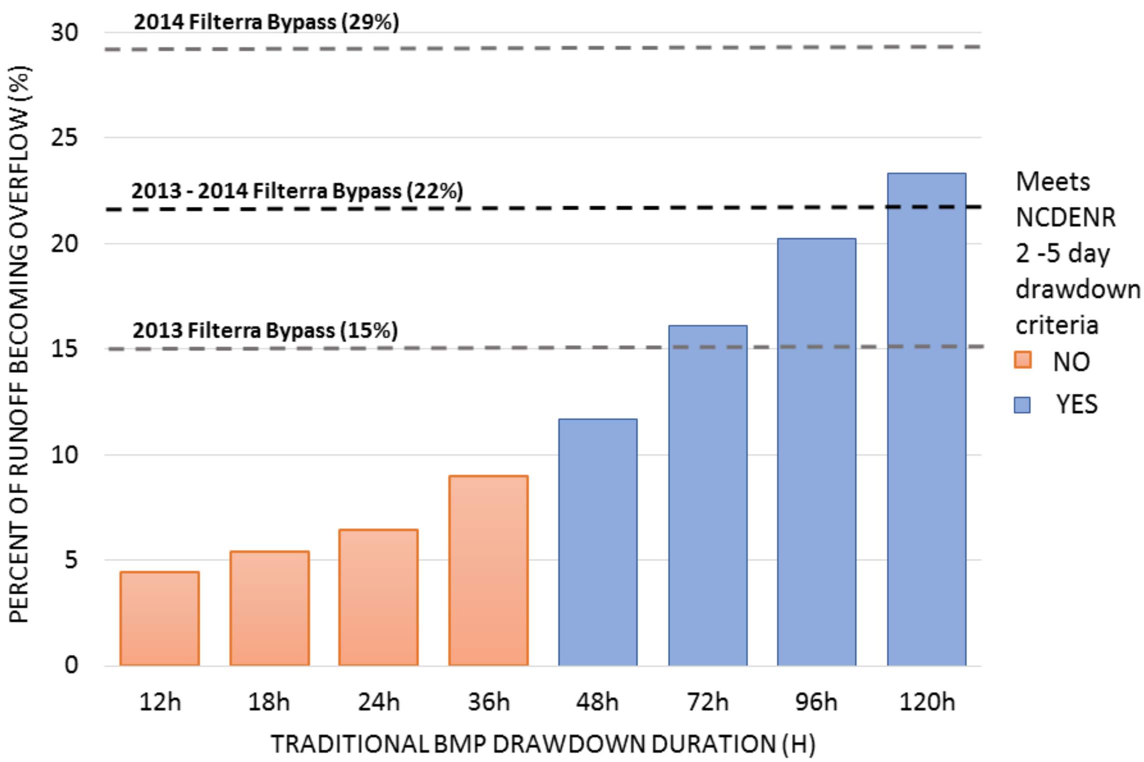


Figure 4. Calculated percent annual overflow from traditional BMPs during an average rainfall year (from Smolek et al. 2015). The monitored Filterra® showed 22% total bypass volume (dashed line).

Using a “hockey-stick” piece-wise linear regression (Chiu and Lockhart, 2010; Vito, 2008), where two piece-wise linear regressions are performed to find a “break point” value for a data set, the inflection point above which significant bypass is expected to occur was determined based on input rainfall depths and rainfall intensities. The data set included all rainfall events equal to or greater than 0.10 inches. The plots and analyses were divided into three categories: storms occurring in 2013, storms occurring in 2014, and all storms (2013-2014). Below the plots, a table of the regression data for storm depth is included. This shows the calculated breakpoints (the “inflection point” separating two lines with statistically-different slopes) and the estimated slopes of each of the two lines per regression (labelled lines “A” and “B”). In brackets, the 95% confidence interval of each of the slopes is shown. The telling value of the confidence interval is that if it encompasses or is very near 0, then the line can be qualitatively judged to be “flat”.

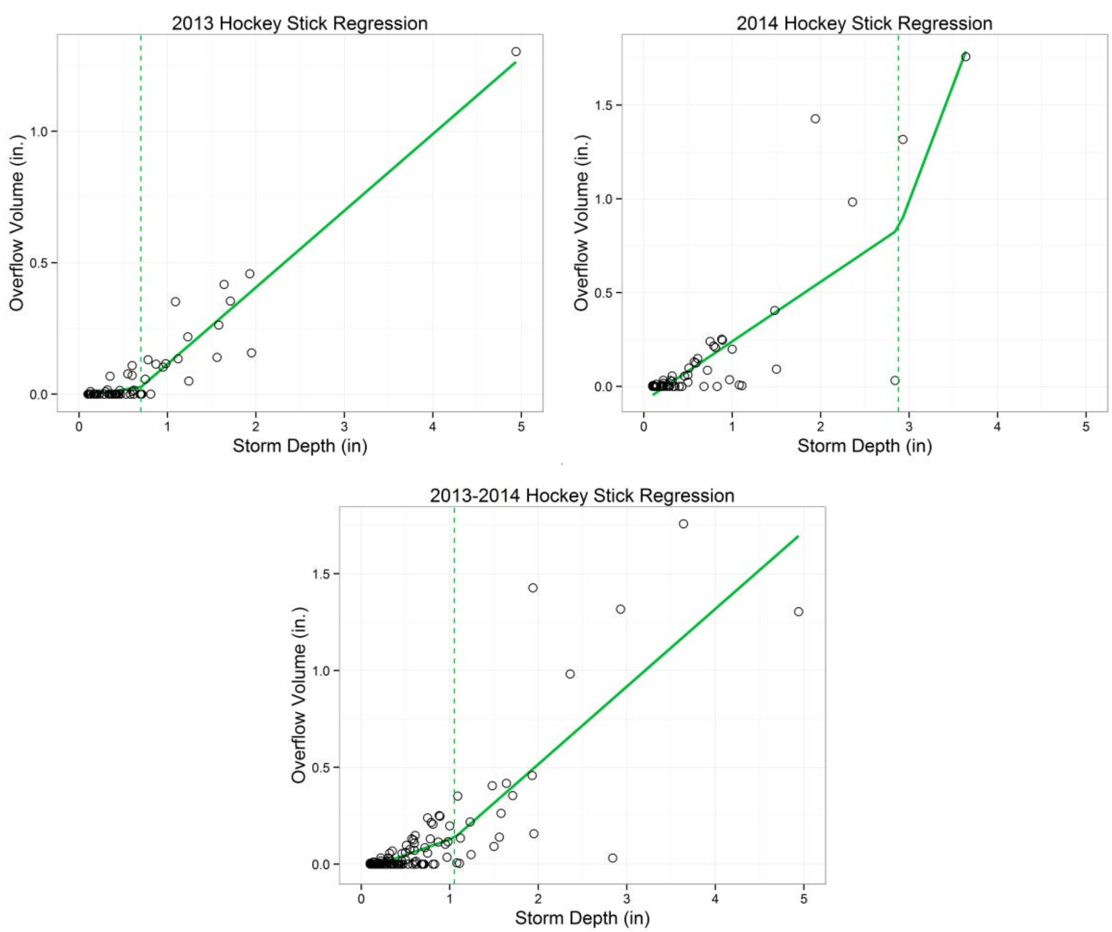


Figure 5. Piece-wise regression of storm depth and overflow volume (normalized to a depth value) for three time periods: (a) 2013, (b) 2014, and (c) 2013-2014.

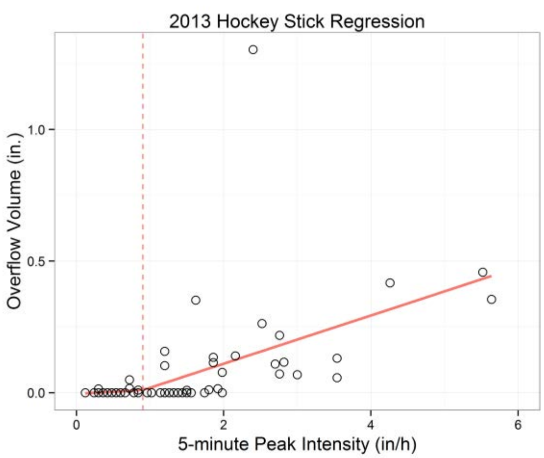
Table 15. Regression estimates of rainfall depth breakpoints, and segment slopes by year.

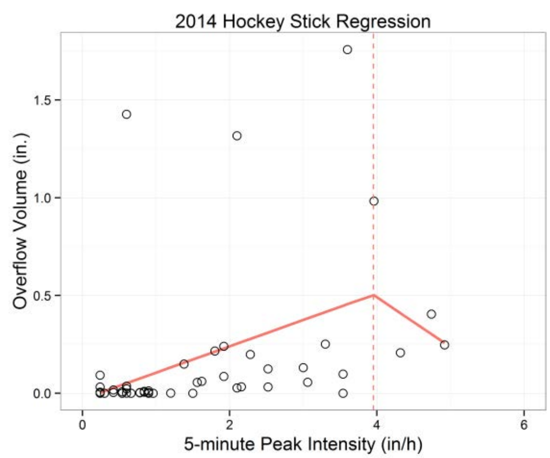
Time Period	Est. Breakpoint	Std. Error	Slope A	Slope B
2013	0.70	0.10	0.05 [-0.03, 0.10]	0.29 [0.26, 0.32]
2014	2.80	0.24	0.31 [0.19, 0.42]	1.17 [0.53, 1.81]
2013-2014	1.05	0.26	0.16 [0.04, 0.28]	0.40 [0.33, 0.47]

Bracketed values represent the 95% confidence interval around the estimated slopes.

In 2013, the estimated breakpoint was 0.70 inches of rainfall. As can be seen in the slope of the first "flat" section, the confidence interval spans zero, meaning no overflow was expected below 0.70 inches in that year. Line "B" for 2013 shows a non-flat slope (0.29 slope value). This is visible in the plot of 2013's rainfall depth vs. overflow above. The 2014 regression shows an estimated breakpoint at 2.80 inches. This does not mean no runoff is expected below 2.80, but rather 2.80 was the optimal breakpoint of the data. The slope of the first segment was *not* zero (confidence interval of 0.19 – 0.42), meaning bypass was predicted at a lower rainfall threshold than in 2013. When aggregating 2013 and 2014, the estimated breakpoint was 1.05 inches; as with the 2014 data, the slope of the first piecewise line was greater than zero, indicating some runoff was expected below the breakpoint of 1.05 inches (though not as much as in 2014). Undersizing of the system (and a higher than average rainfall year) likely caused the runoff threshold in year 1 of the study to be less than 1 inch. Maintenance records indicate the Filterra® was serviced only once in 2014 (October 20), as opposed to biannual servicing in 2013. Thus, a hypothesized explanation for the decreased runoff threshold in year 2 of the study is progressive clogging of the media bed, which likely caused the capacity of the Filterra® to be exceeded more frequently in 2014, resulting in lower bypass thresholds. A recommendation stemming from this data suggests that the system needs to be maintained with a recommended frequency of at least twice per year.

Performing the same analysis as above, but substituting 5-minute peak rainfall intensity for storm depth, yields further evidence the system performed better during the 2013 year. In 2013, the first segment of the piece-wise regression is "flat", indicating storm events with rainfall intensities below 0.90 in/hr did not generate significant bypass. New minimum design criteria from NCDENR (2015) require that non-storage based BMPs such as vegetated swales and level spreader-vegetated filter strip systems designed for water quality treat a design rainfall intensity of 0.75 in/hr. The rainfall intensity data from 2013 show the Filterra® met that treatment target. Data from the 2014 and aggregated 2013-2014 years yield a different result from 2013: a non-zero slope is observed for the first segment of each pairwise comparison and the significant change in overflow occurs at breakpoints of 3.95 and 4.00 in/hr, respectively. The lack of a clear flat line for 2014 and 2013-2014, despite the prevalence of many non-overflow events between 0 and 1.5 inches per hour, is likely due to isolated overflow events during relatively low peak 5-minute intensity events (see the three data points in Figure 6 (b) with overflow near 1.5 inches that occur before the breakpoint is reached). These data values may be skewing what otherwise appears to be a 1-2 inch per hour threshold before runoff is *consistently* occurring. Figures 6(a) and 6(c) clearly shows a cluster of zero-overflow events for intensities up to about 2 inches per hour before bypass consistently occurs.





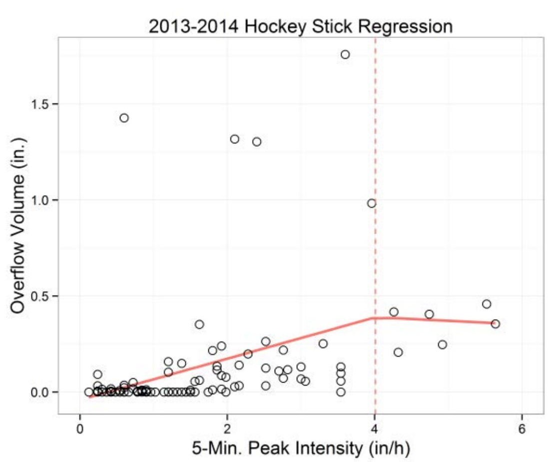


Figure 6. Piece-wise regression of recorded 5-minute peak rainfall intensities and overflow volume (normalized to a depth value) for three time periods: (a) 2013, (b) 2014, and (c) 2013-2014.

Table 16. Regression estimates of rainfall intensity breakpoints, and segment slopes by year.

Time Period	Est. Breakpoint	Std. Error	Slope A	Slope B
2013	0.90	1.05	0.02 [-0.27, 0.30]	0.09 [0.05, 0.14]
2014	3.95	0.82	0.13 [0.05, 0.22]	-0.26 [-1.15, 0.64]
2013-2014	4.00	1.70	0.11 [0.06, 0.16]	-0.02 [-0.41, 0.37]

Bracketed values represent the 95% confidence interval around the estimated slopes.

Since recently imposed design criteria for non-storage based SCMs are based on rainfall intensity (as opposed to rainfall depth), it is reasonable to assert that in 2013, when the system was properly maintained, the Filterra® met water quality treatment goals by treating rainfall events with rainfall intensities less than 0.90 in/hr. Were the system adequately sized, it is expected bypass would have occurred at higher thresholds for both intensity and depth. The installed system was 4 ft x 6 ft (surface area: 24 ft^2); charts from Withers and Ravenel (2008) suggest that a 4 ft x 8 ft (surface area: 32 ft^2) system should have been used for the given drainage area. A simple adjustment of the depth and intensity breakpoints for 2013 (0.70 in and 0.90 in/hr, respectively) based on the ratio of the two surface areas suggest new breakpoints for the data might have been 0.93 in and 1.20 in/hr, respectively. Considering 2013 was an 80th percentile rainfall year (the median year being 50th percentile), performance by the Filterra® should meet water quality goals when properly sized *and* properly maintained.

Peak Flow

In addition to facilitating volume reduction, the Filterra® also reduced peak flows by a median of 56%. Table 17 summarizes peak flow reduction by the system. Comparing the peak outflow to the estimated pre-development conditions (using the Rational Method with a Rational Coefficient of 0.35 for a forested condition), peak flows only exceeded the expected pre-development conditions approximately 21% of the time (Figure 7).

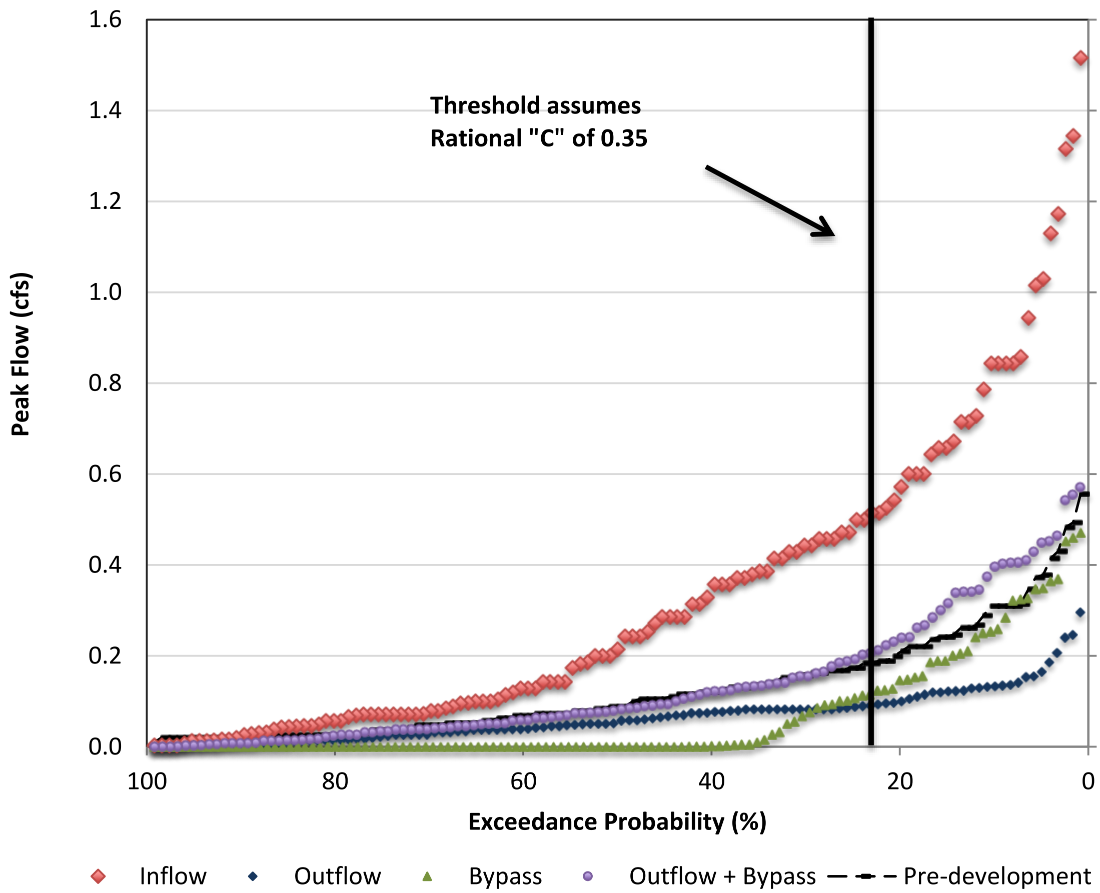


Figure 7. Exceedance probability of peak flows for the Filterra® unit.

Peak flow reduction ratio is a metric used to quantify how much reduction of peak flow is occurring because of a stormwater control measure (SCM). The median peak flow reduction ratio for the Filterra® system for all storm events was 0.44. By comparison, results from the literature for optimal bioretention peak flow ratios suggests 0.33 as a target hydrologic value for traditional bioretention systems (Davis *et al*., 2008), with lower numbers indicating better peak flow reduction. The peak delay ratio is a measure of lag to peak; in general, time of peak outflow from the Filterra® did not vary substantially from the time of peak inflow. Overall, it can be reasonably concluded that the outflow peak for the studied Filterra® is generally near 50% of the value of the inflow peak for a large range of storms (0.10 to 4.94”; see Table 17).

Table 17. Summary of peak flow results for all hydrologic events (*n =125* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.21	0.08	0.44	57%	1.02
Mean	0.33	0.13	0.50	50%	5.06
St. Dev.	0.33	0.14	0.35	35%	29.5

Table 18. Summary of peak flow results for sediment-sampled events (*n =29* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Average Effluent Flow (in/hr)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.35	0.11	22.9	0.39	58.61	1.01
Mean	0.37	0.13	35.8	0.43	53.22	1.39
St. Dev.	0.29	0.10	39.6	0.24	24.38	2.45

Table 19. Summary of peak flow results for nitrogen-sampled events (*n =34* storms)

Metric	Influent Peak Flow (cfs)	Effluent Peak Flow (cfs)	Average Effluent Flow (in/hr)	Peak Flow Reduction Ratio (unitless)	Peak Flow Reduction (%)	Peak Delay Ratio (unitless)
Median	0.29	0.09	20.1	0.39	58.61	1.01
Mean	0.33	0.12	31.2	0.45	52.36	1.35
St. Dev.	0.29	0.10	37.0	0.24	24.30	2.29

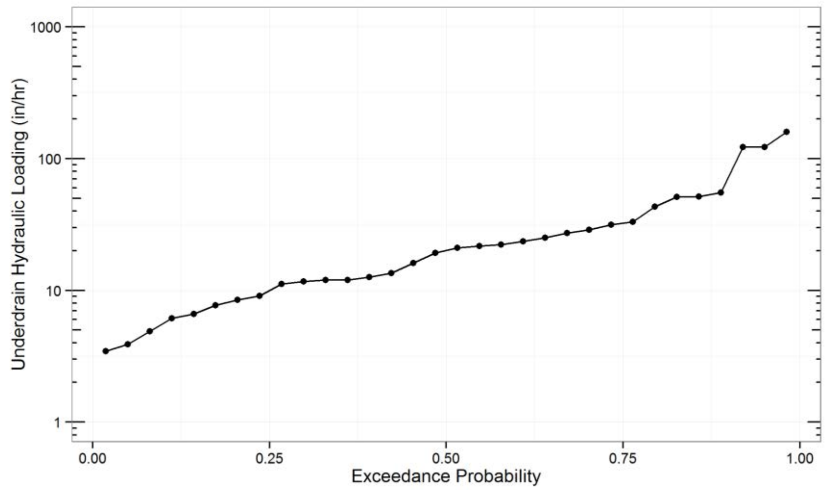


Figure 8. Exceedance probability plot of average underdrain volumetric flux (in/h)

Figure 8 shows a plot of all of the underdrain average volumetric fluxes (in inches per hour), where each data point is associated with each storm event sampled for water quality (see Appendix on “individual hydrographs” for specific information per storm). The underdrain flux values ranged from 3 in/h to 160 in/h, with a median (50^{th} percentile) value of 20.1 in/hour. Little linear correlation was found between the volumetric underdrain flux and rainfall depth or inflow volume. With what little dataset exists, however, it appears there may be a slight seasonal variation with higher rates occurring during the more intense summer rainfall months (Figure 9). The maximum flow through the system will necessarily be governed by the surface infiltration rate of the system--if any impediment to flow was occurring in the surface layer due to temporary clogging or otherwise, this would limit the average underdrain volume flux observed for any given storm. The highest average value (160 in/h) translates to 0.088 cfs of flow. Compared to the theoretical maximum open channel flow a 4-inch underdrain can carry (using the Manning’s equation) of 0.15 cfs, these lower values indicate that the underdrain is likely not flowing full a majority of the time.

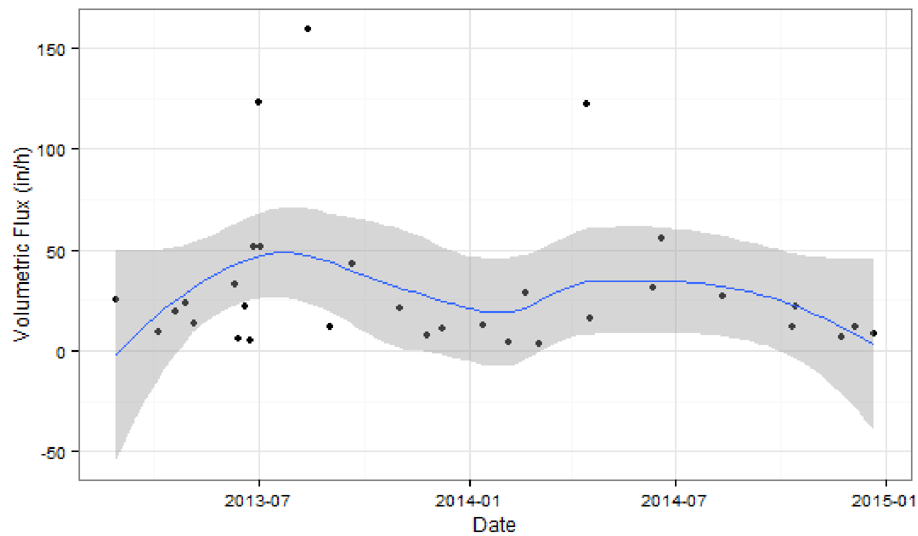


Figure 9. Volumetric flux time series (for water quality-sampled storms only, covering a range from 0.11 to 1.95 inches of precipitation).

Often, the flows of concern for peak flow reduction are much larger than the most common storms, which are usually an inch or less. For many regulatory purposes, peak flows of significant recurrence interval storms (1-year recurrence and above) are targeted for reduction. The North Carolina Administrative Code 15A NCAC 2H. 1008(h)(2) states that the 1-year peak flow of a watershed with an alternative stormwater control measure must be about equal to the peak flow of the pre-developed condition of the watershed. Assuming a forested condition, and a time of concentration of 5 minutes, the combined underdrain + bypass (i.e. total outflow) data were compared to this theoretical benchmark. Figure 10 shows the outflow peak flow data (with linear fit) from the study site plotted against theoretical Rational Method peak flow curves for pre- and post-development conditions. As can be seen, the site roughly follows, and is slightly less, than the calculated pre-development peak flow conditions. At the 1-year intensity (5.17 in/hr) for the site, peak outflow from the site roughly matches the calculated values.

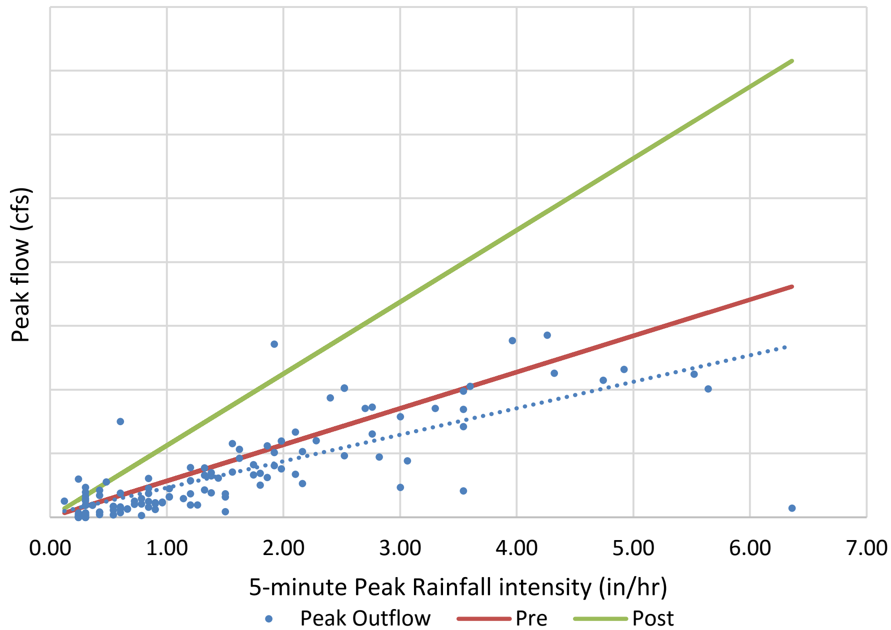


Figure 10. Plot of Filterra® combined peak outflow (underdrain + bypass) plotted and linearly-fit in comparison to pre-development and post-development theoretical peak flows. C = 0.35 and 0.90 for pre- and post-dev. watersheds, respectively, and a time of concentration of 5 minutes.

Water Quality

The NCDENR Preliminary Evaluation Protocol (PEP) requires data be collected from 10 qualified events over the course of at least 1 full year with samples collected in each of the four seasons (NCDENR 2007). This requirement was met for all analytes except SRP, where concentrations were never detected above the minimum detection limit (MDL). For other analytes, when data were censored, the concentration was estimated at half the minimum detection limit for storm-by-storm paired comparisons and loading calculations. All other summary statistics including mean ($\bar{x}$), median ($\tilde{x}$), interquartile range, etc., were estimated using the following criteria: A) if the number of data points below the MDL was less than 10%, half the minimum detection limit was used, B) if the number of data points below the MDL was between 10% and 80%, a robust order on regression was used, or C) if the number of data points below the MDL was greater than 80% summary statistics were not calculated. Per the state of Washington's Technology Assessment Protocol – Ecology (TAPE), the two primary criteria assessed were the pollutant removal efficiency and pollutant load reduction for individual storms (eqs. 2 and 4) (WSDE, 2011). TAPE designates a basic treatment target of greater than 80% TSS removal using either method (influent concentration: > 200 mg/ L), greater than or equal to 80% TSS removal (influent range: 100 – 200 mg/L), or an effluent TSS concentration less than or equal to 20 mg/L (influent TSS range: 20 – 100 mg/L). Once this basic criterion is met, additional treatment for total phosphorus may be awarded if removal of TP exceeds 50% when the influent range of TP is between 0.10 and 0.50 mg/L. . The TAPE program has these data analysis and screening criteria in order to account for irreducible concentrations. Irreducible concentrations in stormwater monitoring has been a publicly discussed issue for many years (Schueler, 1996) and is noted in several regulatory programs throughout the United States. Comparisons to the 85% sediment removal targeted under the NCDENR PEP were also made.

Summary statistics for each analyte at each site are displayed in Table 20. Table 21 summarizes the ER and RE_{median} for each pollutant based on the unpaired, overall distributions. Significant differences between the overall distributions were determined based on the appropriate test for the distribution.

Table 20. Summary Statistics of Event Mean Concentrations of Sampled Parameters

Pollutant	Location	<MDL (%)	n	Statistical Parameters (in mg/L) $\bar{x}$	$\tilde{x}$	SD	IQR
TSS	IN	0	29	122	68	137	117
	OUT	0		5	4	4	4
SSC	IN	0	22	118	82.4	95.46	128.3
	OUT	0		4	3.1	2.78	3.3
TP	IN	0	33	0.130	0.10	0.115	0.148
	OUT[a]	24		0.047	0.038	0.031	0.03
TP (TAPE)	IN	0	16	0.208	0.185	0.121	0.113
	OUT[b]	6		0.063	0.052	0.037	0.054
TDP	IN[a]	58	31	0.068	0.014	0.147	0.057
	OUT[a]	61		0.024	0.016	0.021	0.020
OrthoP	IN[c]	94	32	---	---	---	---
	OUT[c]	100		---	---	---	---
NH_3/NH_4^+-N	IN[a]	32	34	0.15	0.09	0.16	0.15
	OUT[a]	47		0.07	0.05	0.09	0.06
TKN	IN	0	34	1.08	0.99	0.57	0.58
	OUT[a]	12		0.56	0.46	0.32	0.35
NO_3^-/NO_2^--N	IN[a]	15	34	0.13	0.11	0.10	0.14
	OUT[a]	12		0.18	0.15	0.16	0.13
Cu (Total)	IN[b]	8	13	0.0080	0.0073	0.0069	0.0057
	OUT	0		0.0062	0.0049	0.0034	0.0063
Cu (Diss.)	IN[a]	40	5	0.0043	0.0044	0.0017	0.0075
	OUT	0		0.0055	0.0048	0.0028	0.0030
Zn (Total)	IN[b]	8	13	0.059	0.049	0.047	0.060
	OUT[a]	46		0.018	0.013	0.010	0.015
Zn (Diss.)	IN	0	5	0.060	0.049	0.008	0.013
	OUT[a]	60		0.026	0.026	2.5E-17	3.5E-12

[a] Robust regression on order statistics were used (Bolks et al. 2014)
[b] For data reported below detection limit, simple substitution of ½ the min. detection limit was performed
[c] All data were below detection limit. No population statistics computed.

Table 21. Efficiency Ratios (Eqs. 2 and 3) for Measured Water Quality Analytes. Significant values are bolded.

Pollutant	Efficiency Ratio	Removal Efficiency (Median)	In vs. Out Significance p-value	Test Performed
TSS	0.95641	0.94118	**5.23e-16**	paired t-test with log-trans EMCs
SSC	0.96689	0.9624	**3.43e-13**	paired t-test with log-trans EMCs
TP	0.63846	0.62	**3.76e-6**	Peto & Peto mod. of Gehan-Wilcoxon test
TP (TAPE)	0.82692	0.71892	**7.71e-7**	paired t-test with log-trans EMCs
TDP	0.64705	-0.14286	0.352	Peto & Peto mod. of Gehan-Wilcoxon test
OrthoP	--	--	--	
TN[a]	0.3932	0.2534	**0.0002**	unpaired t-test with log-trans EMCs
TAN	0.5294	0.44444	**0.0299**	Peto & Peto mod. of Gehan-Wilcoxon test
TKN	0.4944	0.53535	**7.05e-6**	Peto & Peto mod. of Gehan-Wilcoxon test
$NO_{2,3}$¯N	-0.4603	-0.3636	0.0974	Peto & Peto mod. of Gehan-Wilcoxon test
Cu (Total)	0.225	0.32877	0.5954	paired t-test with log-trans EMCs
Cu (Diss.)	-0.2941	-0.0909	0.251	Peto & Peto mod. of Gehan-Wilcoxon test
Zn (Total)	0.69492	0.73469	**0.0019**	Peto & Peto mod. of Gehan-Wilcoxon test
Zn (Diss.)	0.56667	0.46939	0.0663	Peto & Peto mod. of Gehan-Wilcoxon test

[a] Calculation of total nitrogen assumed ½ the detection limit when TKN or $NO_{2,3}$-N data were censored

Censored data includes all data that was measured below the minimum detection limit. When the data sets were comprised of 10% or greater censored data, a maximum likelihood estimation fit the data to a known distribution so the samples could be compared to each other. For other paired storm-by-storm analyses and calculation of loading, if data were censored, half the detection limit was used. Results from Table 20 and Table 21 show significant reduction (p-value < 0.05) of all analytes except nitrate/nitrite-nitrogen, total dissolved phosphorus, total and dissolved copper, and dissolved zinc. More thorough discussion of pollutant removal performance can be found in the following sections.

Table 22 summarizes cumulative percent load reductions for all sampled storms both with and without censored data included. For all sampled storms, the cumulative percent load reduction exceeded 75% for sediment removal and 50% for TP. When only storms that did not produce bypass were considered, percent load reduction increased to over 95% and 70% for sediment and TP, respectively. TN loading removal was lower at 39%, but exceeds NCDENR's regulatory credit of 35% TN removal for bioretention without internal water storage (NCDENR 2009).

Table 22. Summary of cumulative loading reductions (%) for all analyzed parameters

Pollutant	Cumulative Load Reduction (all storms)	Cumulative LoadReduction (storms without censored[a] data)	Cumulative Load Reduction (all storms without bypass)	Cumulative Load Reduction (all storms without bypass or censored data)	Sample size (n)
TSS	76	76	96	96	29
SSC	77	77	98	98	22
TP	54	50	70	73	33
TP (TAPE)	58	57	84	83	16
TDP	66	40	65	86	31
OrthoP	--	--	--	--	32
TN[b]	39	37	45	52	34
NH_3/NH_4^+-N	49	42	40	48	34
TKN	46	44	54	54	34
NO_3^-/NO_2^--N	-22	-10	34	-27	34
Cu (Total)	14	18	-11	-11	13
Zn (Total)	63	61	74	73	13

[a]Censored data are values reported below the minimum detection limit
[b]Load reduction for TN based on substituting half the detection limit if TKN or $NO_{2,3}$-N were censored

To demonstrate the diversity of storm events sampled in the study, a summary of the rainfall depths and seasonal distribution of sampled events for each analyte are given in Table 23 and Table 24, respectively.

Table 23. Rainfall depths of sampled storm events.

	TSS	SSC	Phosphorus Species	Nitrogen Species	Total Metals	Dissolved Metals
Min (in.)	0.10	0.25	0.10	0.10	0.25	0.46
Med (in.)	0.61	0.72	0.60	0.60	0.81	0.81
Max (in.)	1.95	1.95	1.95	1.95	1.95	1.71
n	29	22	33	34	13	5

Table 24. Seasonal distribution of sampled storm events.

	TSS	SSC	Phosphorus Species	Nitrogen Species	Total Metals	Dissolved Metals
Winter	5	2	6	6	2	2
Spring	9	8	11	11	4	1
Summer	7	7	7	8	5	1
Fall	8	5	9	9	2	1
n	29	22	33	34	13	5

Sediment

Sediment data collected from the influent and effluent runoff are displayed in Figure 11. It is observed that despite a large variation in influent TSS concentration, the measured concentrations after treatment by the Filterra® never exceeded 20 mg/L (maximum concentration: 16 mg/L).

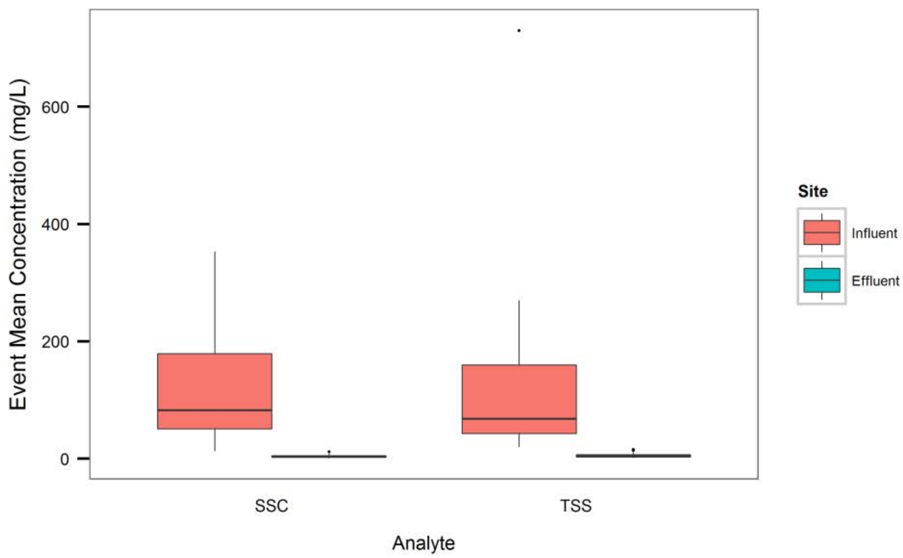


Figure 11. Boxplot of measured sediment event mean concentrations (as both Total Suspended Solids, TSS and Suspended Sediment Concentration, SSC)

Table 25 summarizes all performance metrics for TSS and SSC. Individual storm EMC removal was quite high, with a 94% and 97% median reduction in EMCs for TSS and SSC, respectively. This meets the 85% sediment removal criterion targeted by NCDENR. Due to the occurrence of bypass, load reduction was somewhat less than the EMC reduction. When only storms that did not produce bypass were considered in the calculations, the overall load efficiency of the system increased to over 95% for both TSS and SSC, indicating excellent sediment removal for small storms. The lower-bound of the 95% confidence interval for the TSS EMC percent removal by the Filterra® was 90%, meeting the 80% target set by TAPE. Additionally, the upper bound of the 95% confidence interval on the outlet mean was 6.6 mg/L. The TAPE basic treatment criteria was met in that the Filterra® consistently exceeded the effluent goal of less than or equal to 20 mg/L when the TSS influent was in the range of

20-100 mg/L, greater than or equal to 80% TSS removal was observed for TSS influent in the range of 100 – 200 mg/L, and greater than 80% TSS removal occurred for influent samples greater than 200 mg/L. The highest effluent value recorded for all 29 TSS samples was 16 mg/L.

Table 25. Summary statistics of sediment performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	TSS	SSC
Event Mean Concentration (EMC)	N	29	22
	inlet mean [std. dev.] (mg/L)	122 [137]	118 [96]
	inlet median (mg/L)	68	82.4
	outlet mean [std. dev.] (mg/L)	5 [4]	4.0 [3]
	outlet median (mg/L)	4	3.1
	outlet Boot. 95% CI (mg/L)	3.9 – 6.6	2.8 – 5.0
	log-trans. paired t-test p-values	<0.001	<0.001
EMC Percent Removal (all storms)	N	28[a]	21[a]
	Mean	92%	94%
	Median	94%	97%
	std. dev.	7%	6%
	Bootstrapped 95% Conf. Int. (+/-)	90% - 94%	92% - 97%
EMC Percent Removal (storms with no bypass only)	N	9	4
	Mean	92%	97%
	Median	95%	97%
	std. dev.	7%	1%
Individual Load Reductions (all storms)	N	28[a]	21[a]
	Mean	81%	79%
	Median	80%	77%
	std. dev.	13%	12%
	Bootstrapped 95% Conf. Int. (+/-)	77% - 86%	74% - 84%
Individual Load Reductions (storms with no bypass only)	N	9	4
	Mean	94%	97%
	Median	96%	97%
	std. dev.	6%	1%
Load Efficiency (all storms)		76%	77%
Load Efficiency (only storms with no bypass)		96%	98%

[a]Pair-wise comparison for 11/24/2014 – 11/26/2014 storm excluded because < 75% of the storm was captured.

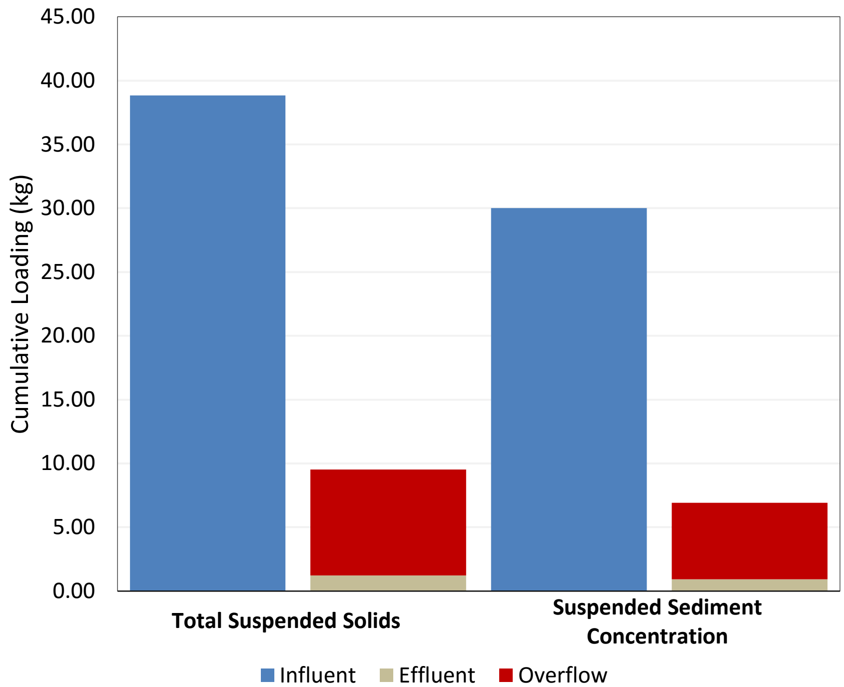


Figure 12. Cumulative sediment loading for total suspended solids (n = 29) and suspended sediment concentration (n = 22).

Particle Size Distribution

Particle size distributions were determined for storm events when enough material was present in the sampling bottles for analysis. A total of fifteen (15) samples were taken over the course of the study, and sent to the Department of Marine, Earth, and Atmospheric Sciences for laser diffraction analysis. The result of each sample analysis is a particle size (in µm) vs. percent-finer-than data set for that particular storm event and sampling site (influent or effluent of the Filterra® system).

Due to lack of material for proper laser diffraction analysis, only four outlet particle size distributions were obtained. The sediment concentrations were deemed too low in the other effluent samples to run the analysis. The four events for which effluent data were calculable, the rainfall intensities of the respective storms were relatively high, ranging from the median to the 99.9th percentile 5-minute peak intensities. A summary of when each inlet and outlet PSD were collected is outlined in Table 25.

Table 25. Summary of Sample Collection Dates for Particle Size Distribution

Storm Event Date	PSD Collected at Inlet?	PSD Collected at Outlet?
Feb. 26, 2013	X	
Mar. 04, 2013	X	
Mar. 19, 2013	X	
Mar. 29, 2013	X	
Jun. 10, 2013	X	
Jun. 26, 2013	X	X
July 02, 2013	X	X
Aug. 13, 2013	X	
Sep. 2, 2013	X	X
Sep. 21, 2013	X	
Nov. 1, 2013	X	
Feb. 19, 2014	X	
Apr 15, 2014	X	X
Apr. 19, 2014	X	
June 12, 2014	X	

For each individual particle size distribution, a set of common descriptive metrics were calculated. "Percent-finer-than" particle diameters were determined for the 10th, 30th, 50th (or median), 60th, and 90th percentile (percent finer than), the diameters of which are hereafter referred to as d_{10}, d_{30}, d_{50}, d_{60}, and d_{90}, respectively. Two additional common metrics were also calculated for each particle size distribution to quantify the variability or spread of the data. Span is the width of the particle size distribution based on the 10%, 50%, and 90% quantile:

$$Span = \frac{D_{90} - D_{10}}{D_{50}}$$

where:

D_{90} = Diameter of the 90th percentile particle size

D_{10} = Diameter of the 10th percentile particle size

D_{50} = Diameter of the 50th percentile particle size

The coefficient of uniformity is the measure of how tightly the PSD curve is maintained from 0 to 100 percent-finer-than. In soil science, the larger the value of C_u, the more well-graded the soil is considered, with smaller values indicating a highly-uniform particle size mix.

$$Coefficient\ of\ Uniformity\ (C_u) = \frac{D_{60}}{D_{10}}$$

Finally, to compare inlet and outlet average particle sizes for each of the chosen percentiles above, a percent difference was calculated. A summary of PSD parameters and their relative difference is shown in both Table 26 and 27. Table 26 summarizes all inlet and outlet samples taken, even if they were not able to be paired. Table 27 limits the analysis to only the four dates on which inlet and outlet were successfully paired (see Table 25 for the particular dates).

Table 26. Summary of average particle diameters for critical particle size bins for Filterra® inlet and outlet (inlet n = 15, outlet n = 4) (all D values in micrometers, *μm*)

	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	Span	C_u
Inlet (n = 15)	24.6	67.1	146.6	225.1	793.1	5.8	8.5
Outlet (n = 4)	17.0	44.6	69.1	83.0	226.7	3.5	5.2
Percent Diff.	31%	33%	53%	63%	71%	40%	39%

Table 27. Summary of average particle diameters for critical particle size bins for Filterra® inlet and outlet for only paired events (n = 4) (all D values in micrometers, *μm*)

	D_{10}	D_{30}	D_{50}	D_{60}	D_{90}	Span	C_u
Inlet (n = 4)	27.4	73.8	175.3	241.9	872.0	6.0	7.9
Outlet (n = 4)	17.0	44.6	69.1	83.0	226.7	3.5	5.2
Percent Diff.	38%	40%	61%	66%	74%	41%	34%

Looking at the paired data only (Table 27), the percent difference between the larger particle diameters (D_{60} and D_{90}) are greater than the percent differences for finer particles. This makes sense, as any media will more easily be able to filter larger particles than smaller ones. Looking at the span and C_u values, it is also evident that the effluent PSDs are not as highly-varied with respect to particle sizes than the influent, meaning the effluent PSDs are not influenced as much by extremely large or small PSDs. From a graphical perspective, Figure

13 shows the entirety of the four paired inlet / outlet PSDs as well as a comparison to USGS soil-classification categories for sand/silt/clay.

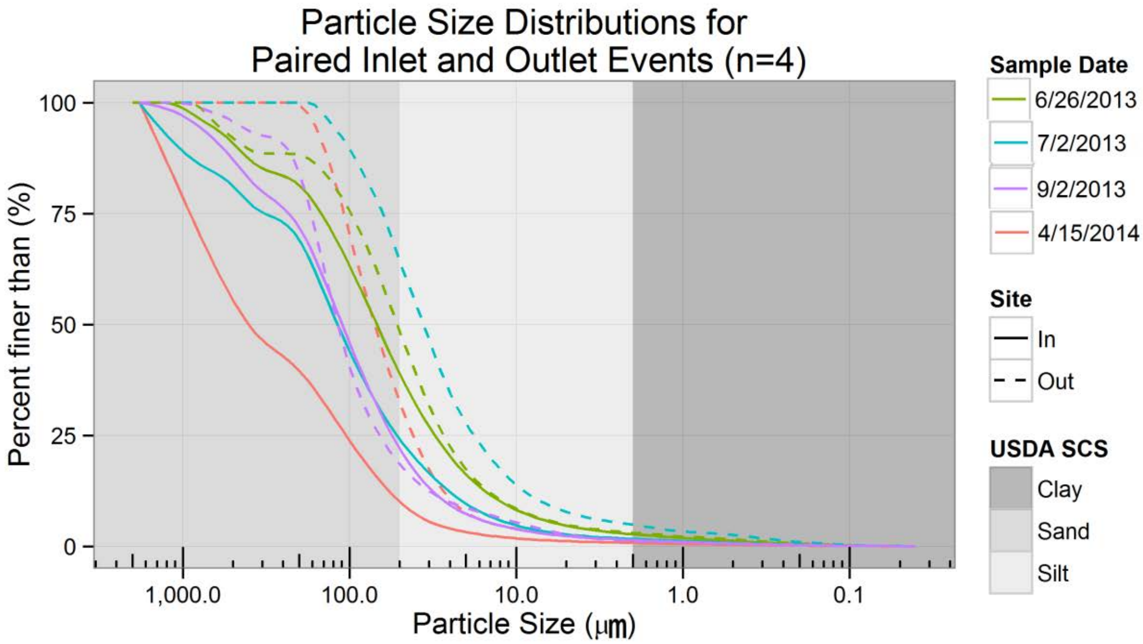


Figure 13. Entire continuous particle size distribution for each paired sample at the respective sampling location (inlet vs. outlet) on a given sampling date. PSDs generally shifted from sand-dominant to a very fine sand / large silt range.

Each event shows the effluent PSD is shifted right of the inlet PSD, indicating filtration of larger particles is being performed. For percentiles above about the 25th percentile, the effluent PSD is "right-shifted" nearly an order of magnitude. For large sand-sized particle fractions, nearly two orders of magnitude decrease is evident in some cases (7/2/2013). As one gets toward the clay particle size, the curves deviate less and less, demonstrating the potential difficulty all bioretention and filtration systems face in capturing the smallest of particles. Due to the lack of numerous paired data, statistical significance was not able to be determined.

The relationship between 5-minute peak rainfall intensity and PSD metrics was hypothesized, which led to a further investigation of the potential relationship. A simple linear regression of inlet particle size for each percentile group as a function of 5-minute peak rainfall intensity did not detect any significant slope or linear fit, as can be seen in Figure 14.

Finally, for the paired storm event PSDs, a comparison was made with the TSS concentration of each respective storm at a given sampling site. There was a lack of strong linear trend for the influent and effluent PSD percentiles vs. TSS (Figure 15 and 16).

In summary, the particle size distribution data helps compliment the sediment analysis insofar as it demonstrates that not only is sediment being reduced, but the PSD is shifting away from the larger particle fractions and toward a dominance of small, hard-to-capture particles. Because the effluent sediment concentrations were so low across the board, however (average of 5 mg/L, median of 4 mg/L), PSDs were indeterminate for a vast majority of events. The events for which effluent data were produced (n = 4), may exist only because they resulted from extremely high intensity rainfall intensities, which may dislodge materials in the media or force through enough sediment to allow for enough material to analyze. Of the four storms with detectable effluent PSD, the rainfall intensities were high, representing the 56th, 81st, 96th and 99.9th percentile intensities for the 9/2/2013, 7/2/2013, 4/15/2014, and 6/26/2013 storms, respectively. For these four events, TSS effluent values were an average of 6.6 mg/L and median of 7.4 mg/L, which all are considered excellent water quality values. The effluent PSDs from these high-intensity events do not represent the entire spectrum of storm events, but rather represent the only storms with detectable PSD. No statistical conclusions could be made with the data.

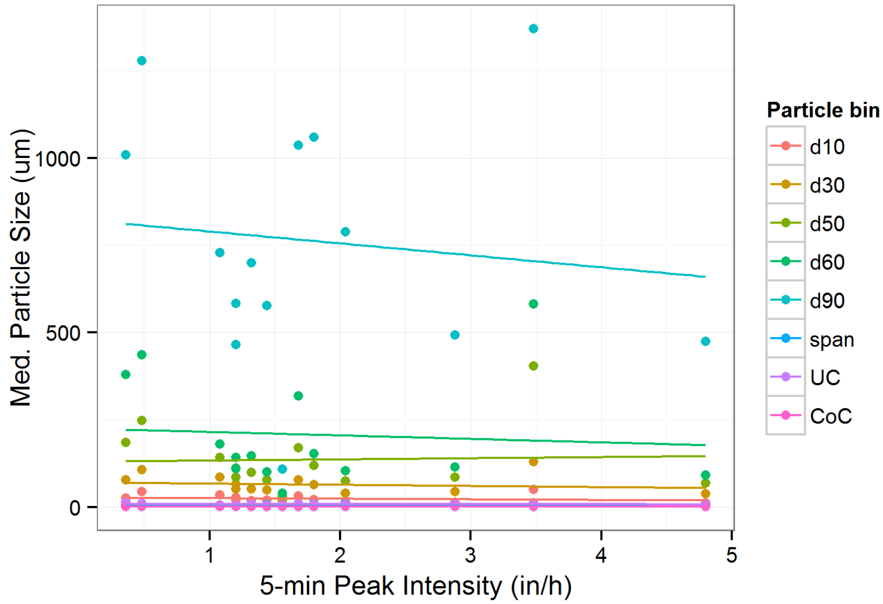


Figure 13. Linear regression of peak intensity vs median particle size for various bins which does not suggest significant correlations with the data collected (10-90th percentile bins).

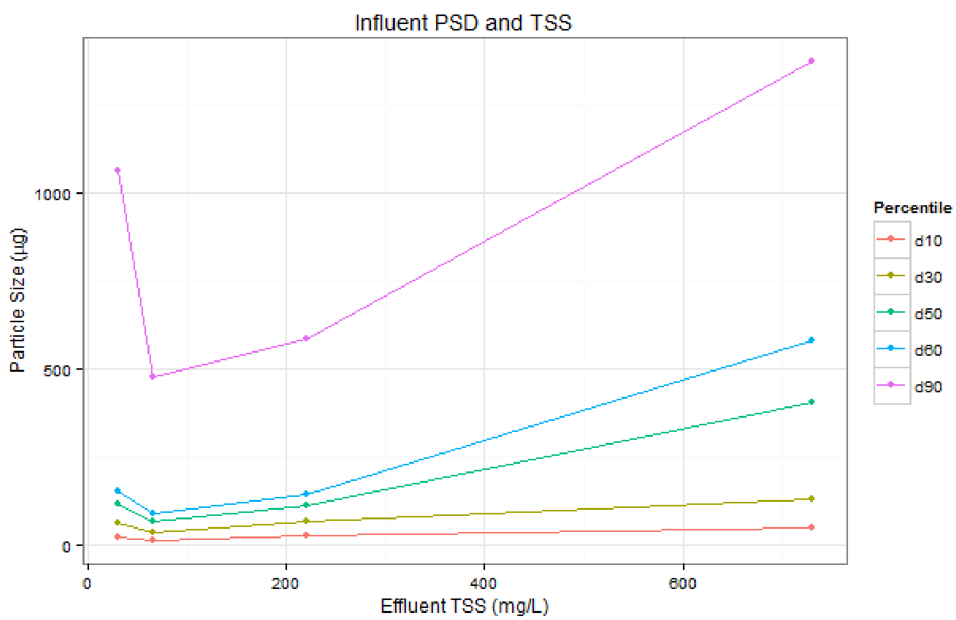


Figure 15. Influent TSS vs. various particle sizes, grouped by percent-finer-than designations

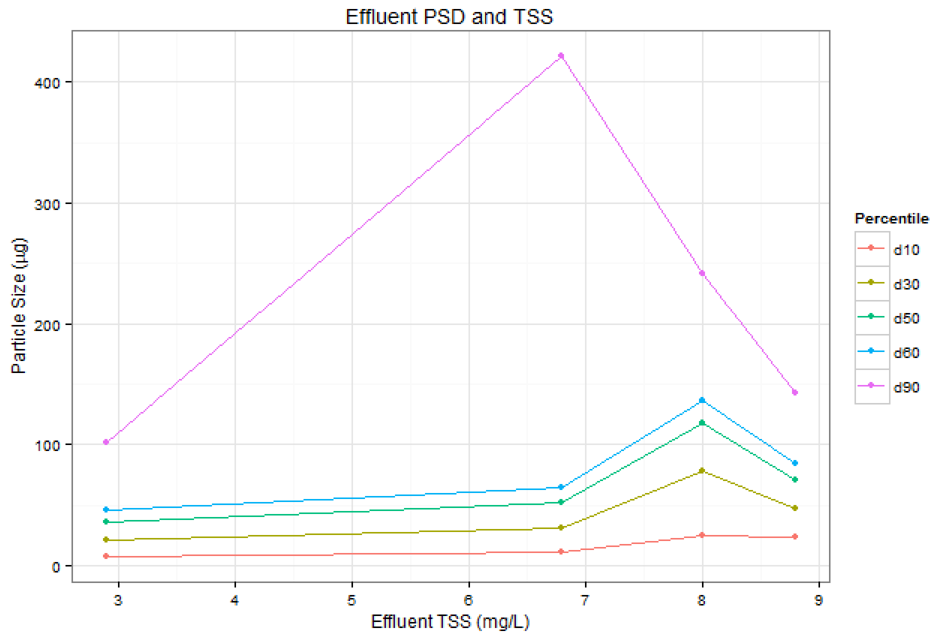


Figure 16. Effluent TSS vs. effluent particle sizes.

Phosphorus

Table 28 summarizes performance metrics for total phosphorus (TP), total dissolved phosphorus (TDP), and TAPE-qualified TP events (influent TP concentration between 0.1 and 0.5 mg/L). While soluble reactive phosphorus (SRP) was also analyzed, concentration levels failed to exceed the minimum detection limit and therefore analysis of this analyte was not possible. Figure 14 displays TP data collected at the inlet and the outlet. The data are ranked in ascending order to determine the cumulative probability of occurrence for the overall distribution. McNett et al. (2010) established that an effluent TP concentration of 0.06 mg/L corresponded to excellent ambient water quality and benthic macroinvertebrate health in North Carolina. Effluent concentrations of TP met this target approximately 80% of the time.

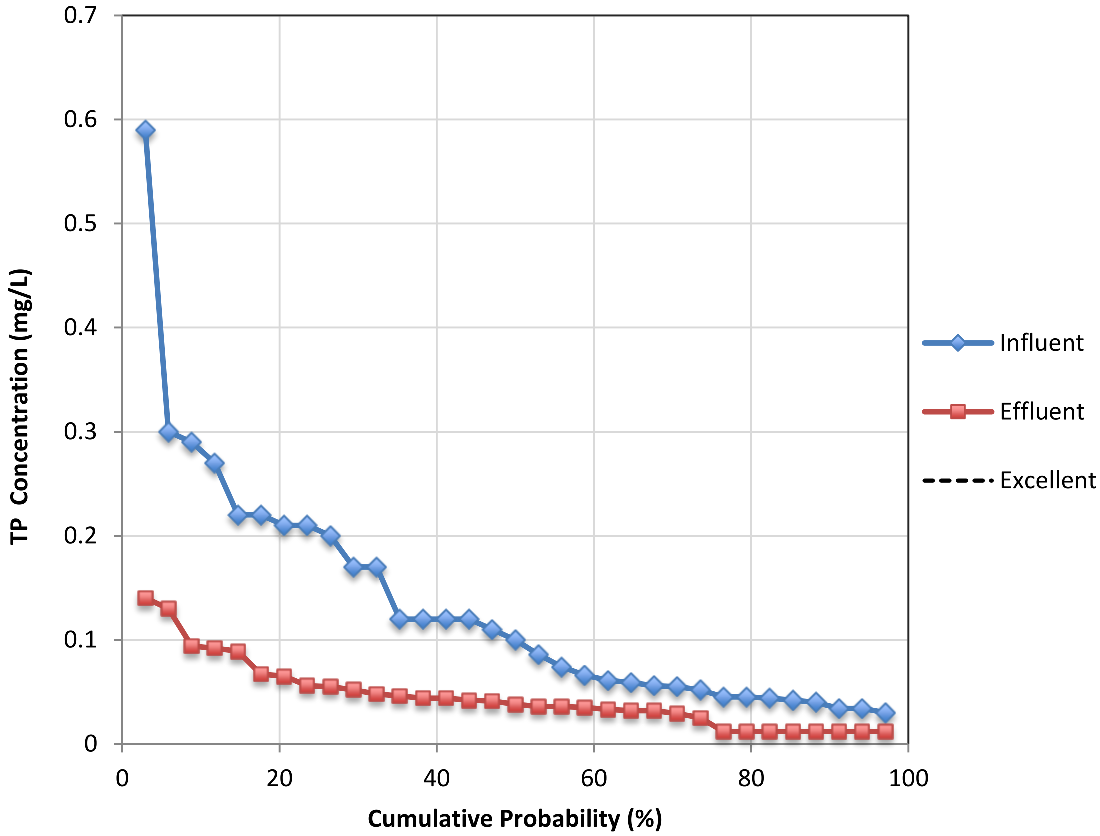


Figure 14. Exceedance probability of measured influent and effluent total phosphorus (TP).

For all total phosphorus data, storm-by-storm median removal efficiencies for EMC and load were 60% and 63%, respectively. The TAPE criterion for TP requires a minimum of 50% TP removal when influent concentrations range from 0.1 – 0.5 mg/L. 16 of the 33 events met this criterion; for these events, median removal efficiencies for EMC and load increased to 70% and 72%. The lower limit of the bootstrapped 95% confidence interval on the mean EMC for TAPE qualified events was above the 50% target set by TAPE (95% CI: 57% - 75%). The lower limit for the mean individual load reduction was also above the target with a 95% confidence interval of 56% - 76%, although the overall percent load reduction was lower at 54%. Cumulative loading reduction increased to 75% when storms with bypass were excluded from the analysis, indicating excellent TP removal. Total dissolved phosphorus (TDP) testing showed an average influent concentration of 0.068 mg/L, and an average effluent concentration of 0.024 mg/L. The detection limit was 0.025 mg/L, so robust order on regression was performed to compute population statistics. Despite a 65% lower average EMC in the effluent than the influent, and a 66% overall percent load reduction, the percent reduction (or efficiency ratio) is not statistically significant. Despite a lower-than-expected and wide range of influent TDP values, the effluent concentrations were at or below detection limits 61% of the time. The traditional TAPE protocol for dissolved phosphorus removal cannot be applied due to the lack of qualifying influent TDP concentrations, limiting conclusions that can be made within that protocol. Overall, the system performed well and met TAPE criteria for total phosphorus removal, as well as exceeding the regulatory credit of 45% phosphorus removal awarded to bioretention without internal water storage by NCDENR (2009).

Table 28. Summary statistics of phosphorus performance metrics evaluated in the study

Evaluation Metric	Statistical Parameter	TP	TP (TAPE Qualified)	TDP
Event Mean Concentration (EMC)	N	33	16	31
	inlet mean [std. dev.] (mg/L)	0.130 [0.115]	0.208 [0.121]	0.068 [0.147]
	inlet median (mg/L)	0.10	0.185	0.014
	outlet mean [std. dev.] (mg/L)	0.047 [0.031]	0.063 [0.037]	0.024 [0.021]
	outlet median (mg/L)	0.038	0.052	0.016
	p-value for test of differences	<0.001[a]	<0.001[b]	0.352[a]
EMC Percent Removal (all storms)	N	32[c]	16	30
	Mean	54%	66%	2%
	Median	62%	70%	0%
	std. dev.	33%	19%	71%
	Bootstrapped 95% Conf. Int.	43% - 65%	57% - 75%	-27% - 23%
EMC Percent Removal (storms with no bypass only)	N	11	6	9
	Mean	59%	76%	0%
	Median	60%	79%	10%
	std. dev	28%	15%	72%
Individual Load Reductions (all storms)	N	32	16	30
	Mean	55%	66%	15%
	Median	63%	72%	19%
	std. dev.	32%	22%	61%
	Bootstrapped 95% Conf. Int.	44% - 66%	56% - 76%	-6% - 37%
Individual Load Reductions (storms with no bypass only)	N	11	6	9
	Mean	70%	84%	31%
	Median	79%	85%	64%
	std. dev.	28%	7%	80%
Cumulative Load Reduction (all storms)		54%	58%	66%
Cumulative Load Reduction (all storms without censored data)		50%	57%	40%
Cumulative Load Reduction (only storms with no bypass)		75%	84%	65%

[a] Peto & Peto modification of Gehsan-Wilcoxon test
[b] log-transformed paired t-test
[c] Pair-wise comparison for 11/24/2014 – 11/26/2014 storm excluded because < 75% of the storm was captured.

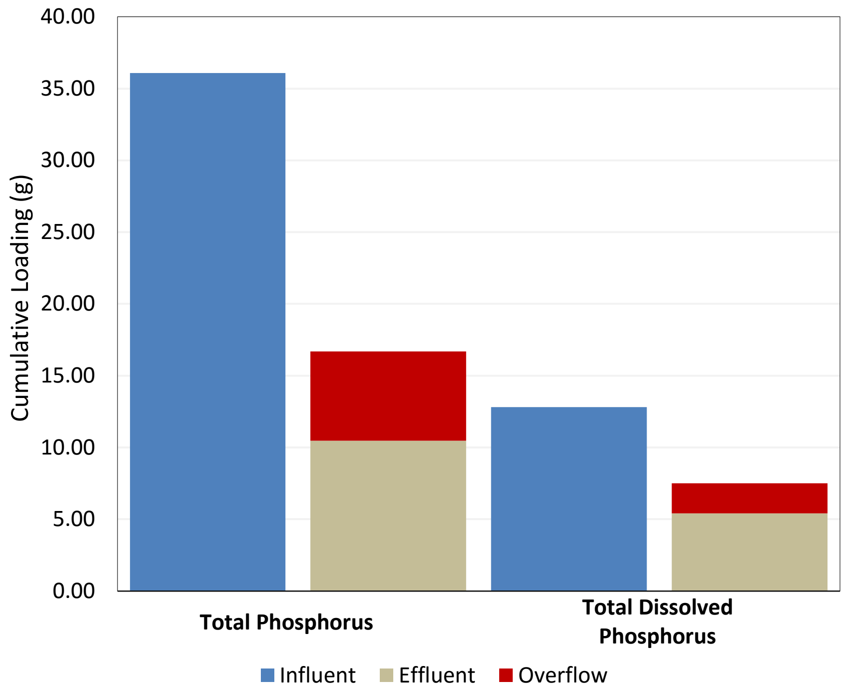


Figure 15. Cumulative loading for total phosphorus (n = 33) and total dissolved phosphorus (n = 31).

Nitrogen

Figure 16 displays the exceedance probability of nitrogen data collected from the inlet and the outlet. For the calculation of total nitrogen, if either TKN or $NO_{2,3}$-N was below the minimum detection limit, half the detection limit was used. McNett et al. (2010) determined the ambient water quality concentration for total nitrogen correlating to excellent stream health in North Carolina was 0.69 mg/L; treatment by the Filterra® reduced total nitrogen below this limit approximately 65% of the time.

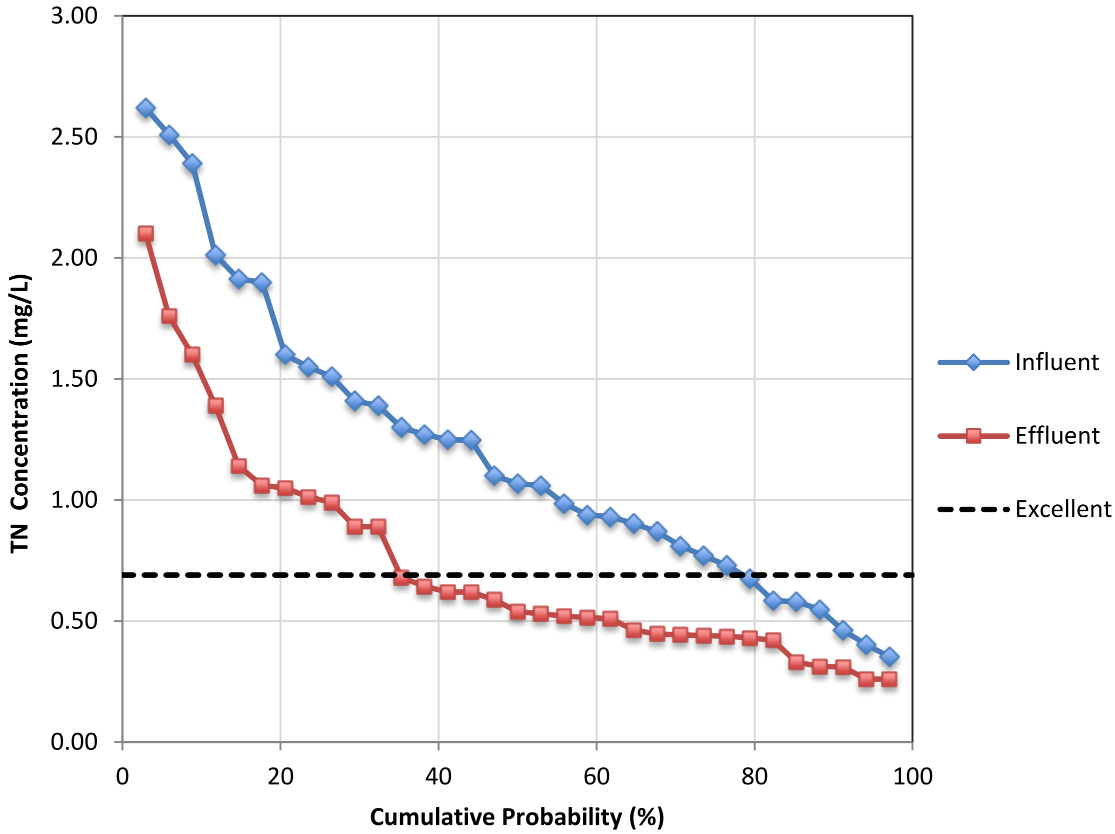


Figure 16. Exceedance probability of measured influent and effluent total nitrogen (TN).

Table 29 displays summary statistics for total nitrogen and all other nitrogen species. Treatment by the Filterra® significantly reduced all nitrogen species except $NO_{2,3}$-N. The storm-by-storm median EMC and loading removal for TN was 35% (95% CI: 21% - 44%) and 45% (95% CI: 29% - 50%), respectively, with an overall load reduction of 39%. This is on par with the 35% nitrogen removal credited to bioretention without internal water storage in North Carolina (NCDENR). When loading attributed to untreated bypass was not included into the analysis, cumulative load reduction increased to 45%, indicating excellent removal of TN.

Nitrate concentrations increased after treatment by the Filterra®, although not significantly. This is explained by the introduction of NO_3^- via the nitrification of NH_4^+, which has been documented in several other bioretention studies that do not have internal water storage, and thus have commonly shown export of nitrate-nitrogen (Davis et al., 2001; Dietz and Clausen, 2006; Hunt et al. 2006). Under aerobic conditions, NH_4^+ is readily oxidized to NO_3^-, a much more stable and mobile form of nitrogen, which is highly soluble and does not readily sorb to bioretention media (Davis et al., 2006; Clark and Pitt, 2012). Denitrifying NO_3^- to N_2 gas requires anaerobic conditions (typically created through a saturated zone) and the presence of organic carbon. Without internal water storage, the Filterra® system does not have a mechanism to create anaerobic conditions, thus concentrations of NO_3^- tended to persist in the effluent. Still, all other nitrogen forms were significantly reduced and contributed to an overall reduction of total nitrogen. Since the primary removal mechanism of Filterra® is filtration and sedimentation, it makes sense that the greatest reduction observed was for TKN, a primarily sediment-bound form of nitrogen.

Table 29. Summary statistics of all nitrogen performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	TN[a]	TKN	$NO_{2,3}$-N	TAN
Event Mean Concentration (EMC)	n	34	34	34	34
	inlet mean [std. dev.] (mg/L)	1.17 [0.63]	1.08 [0.57]	0.13 [0.10]	0.15 [0.16]
	inlet median (mg/L)	1.06	0.99	0.11	0.09
	outlet mean [std. dev.] (mg/L)	0.71 [0.46]	0.56 [0.32]	0.18 [0.16]	0.07 [0.09]
	outlet median (mg/L)	0.53	0.46	0.15	0.05
	Peto & Peto mod. of Gehsan-Wilcoxon test p-values	0.0002[b]	<0.001	0.0974	0.0299
EMC Percent Removal (all storms)	n	33	33	33	33
	mean	33%	43%	-97%	13%
	median	35%	44%	-53%	39%
	std. dev.	34%	29%	213%	92%
	Bootstrapped 95% Conf. Int.	21% - 44%	34% - 53%	-168% to -26%	-17% - 44%
EMC Percent Removal (storms with no bypass only)	n	12	12	12	12
	mean	28%	38%	-88%	-1%
	median	30%	40%	-50%	18%
	std. dev.	39%	36%	159%	128%
Individual Load Reductions (all storms)	n	33	33	33	33
	mean	40%	47%	-51%	22%
	median	45%	50%	-1%	39%
	std. dev.	32%	29%	151%	88%
	Bootstrapped 95% Conf. Int.	29% - 50%	38% - 57%	-100% to -1%	-6% - 50%
Individual Load Reductions (storms with no bypass only)	n	12	12	12	12
	mean	45%	53%	-49%	18%
	median	55%	65%	-35%	53%
	std. dev.	40%	38%	147%	133%
Cumulative Load Reduction (all storms)		39%	46%	-1%	39%
Cumulative Load Reduction (all storms without censored data)		37%	44%	-10%	42%
Cumulative Load Reduction (only storms with no bypass)		45%	54%	-40%	40%

[a] Calculation of total nitrogen assumed ½ the detection limit when TKN or $NO_{2,3}$-N data were censored
[b] Unpaired t-test of log-transformed values performed

Figure 17 shows the distribution of various nitrogen species and the proportion of data which were below the minimum detection limit.

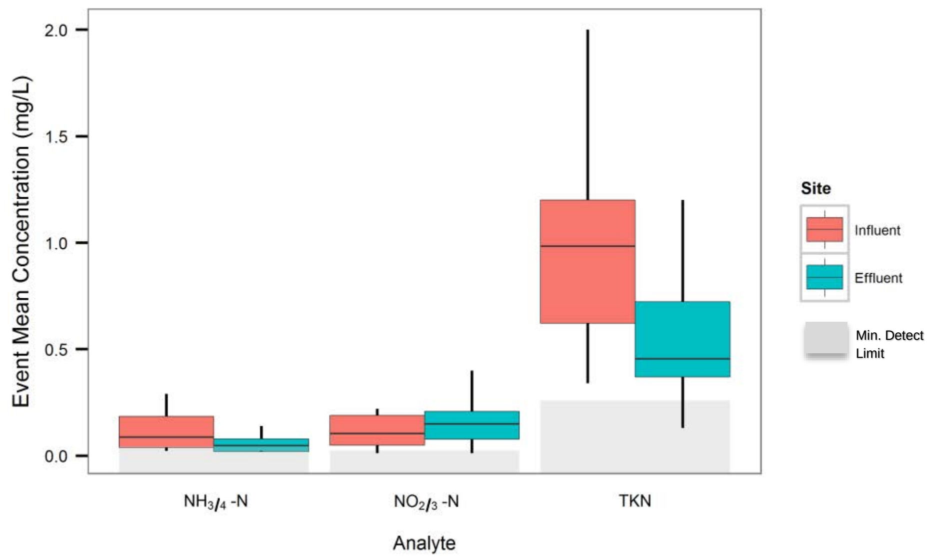


Figure 17. Boxplot of measured nitrogen species event mean concentrations with each respective minimum detection limit (MDL) shown in gray bar.

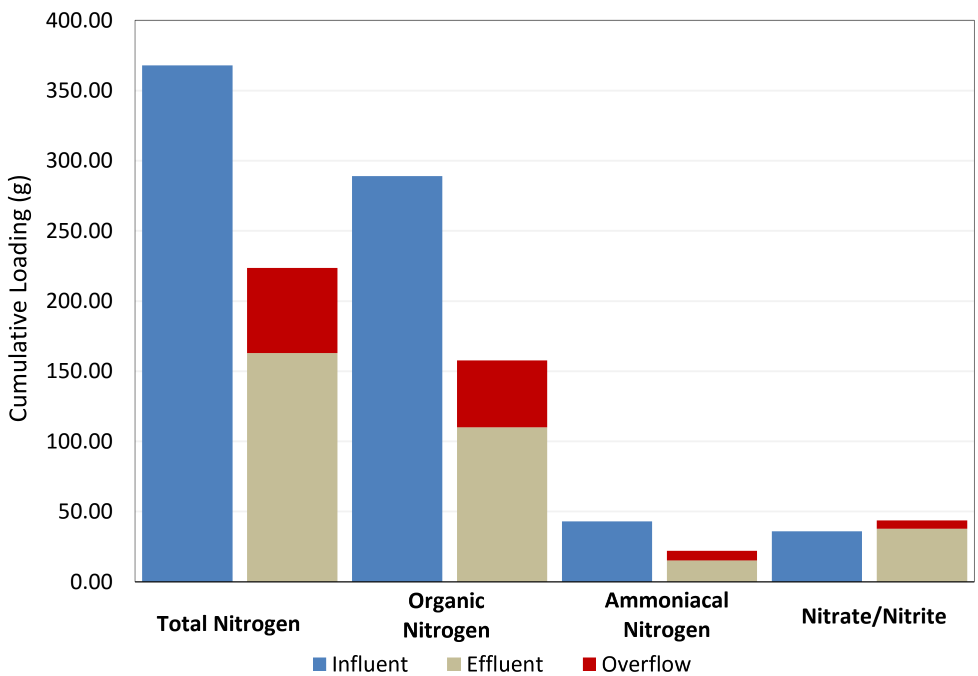


Figure 18. Cumulative loading for total nitrogen and nitrogen species (n = 34).

Metals

A summary of metal removal performance is given in Table 30. It is cautioned that the sample size for metals analysis was much smaller than other analytes due to most data falling below detection limits, especially for dissolved metals, and thus further testing is needed to confirm results. Generally speaking, the majority of the influent metals data collected were below TAPE screening criteria for enhanced metals treatment, which are designed to address pollutant irreducible concentrations. TAPE requires an influent range of 0.005 to 0.02 mg/L for dissolved copper and 0.02 to 0.30 mg/L for dissolved zinc; median dissolved concentrations of copper and zinc were 0.003 mg/L and 0.02 mg/L, respectively. After it became clear the study site was unable to produce influent concentrations of metals within the acceptable range, the research team chose not to analyze water quality samples for metals for the remainder of the study. The last water quality samples analyzed for metals were collected on June 12, 2014, approximately seven months prior to the study conclusion.

Of the data collected,total zinc was significantly reduced, with a median storm-by-storm removal efficiency of 74%. While dissolved zinc was also reduced, it was not significant at the $\alpha = 0.05$-level ($p=0.0663$). Inconclusive performance of dissolved zinc removal indicates the total zinc removal is most likely from sediment-bound metals, since that metric is similar to TSS and SSC. The mean influent total copper concentration of 0.008 mg/L (median of 0.0073 mg/L) was reduced to a mean effluent EMC of 0.0062 mg/L (median of 0.0049 mg/L), but results were not statistically significant. Dissolved copper measurements only resulted in a sample size of 5, disallowing statistical comparison. Dissolved copper concentrations were also close to the minimum detection limit (0.002 mg/L) at both the inlet (0.0043 mg/L) and outlet (mean: 0.0055 mg/L); the negative efficiency ratio observed is thus confounded by these very low influent concentrations. Due to the irreducible concentration levels, as illustrated by the majority of the metals influent data being below the TAPE screening criteria, the metals data presented have limited value and applicability. For these reasons, more robust analytics were not performed and metals monitoring concluded prior to the end of the study.

Table 30. Summary statistics of all metal performance metrics evaluated in the study.

Evaluation Metric	Statistical Parameter	Cu (Tot.)	Cu (Diss.)	Zn (Tot.)	Zn (Diss.)
Event Mean Concentration (EMC)	n	13	5	13	5
	inlet mean [std. dev.] (mg/L)	0.0080 [0.0069]	0.0043 [0.0055]	0.059 [0.047]	0.060 [0.008]
	inlet median (mg/L)	0.0073	0.0044	0.049	0.049
	outlet mean [std. dev.] (mg/L)	0.0062 [0.0034]	0.0055 [0.0028]	0.018 [0.010]	0.020 [2.5E-17]
	outlet median (mg/L)	0.0049	0.0048	0.013	0.026
	Peto & Peto mod. of Gehsan-Wilcoxon test p-values	0.5954	0.251	0.0019	0.0663
EMC Percent Removal (all storms)	n	13	5	13	5
	mean	-10%	-204%	66%	32%
	median	28%	-51%	74%	62%
	std. dev.	81%	366%	25%	67%
	Bootstrapped 95% Conf. Int.	-54% - 31%	-528% to 139%	53% - 79%	-28% to 95%
EMC Percent Removal (storms with no bypass only)	n	3	2	3	2
	mean	-51%	-421%	67%	4%
	median	29%	-421%	82%	4%
	std. dev.	141%	606%	30%	110%
Individual Load Reductions (all storms)	n	13	5	13	5
	mean	-6%	0%	58%	31%
	median	25%	-12%	62%	47%
	std. dev.	76%	374%	19%	63%
	Bootstrapped 95% Conf. Int.	-46% - 35%	-517% - 139%	48% to 68%	-21% to 85%
Individual Load Reductions (storms with no bypass only)	n	3	2	3	2
	mean	-48%	-415%	67%	6%
	median	29%	-415%	82%	6%
	std. dev.	144%	615%	30%	112%
Cumulative Load Reduction (all storms)		14%	-50%	63%	48%
Cumulative Load Reduction (all storms without censored data)		18%	7%	61%	-14%
Cumulative Load Reduction (only storms with no bypass)		-11%	-193%	10%	74%

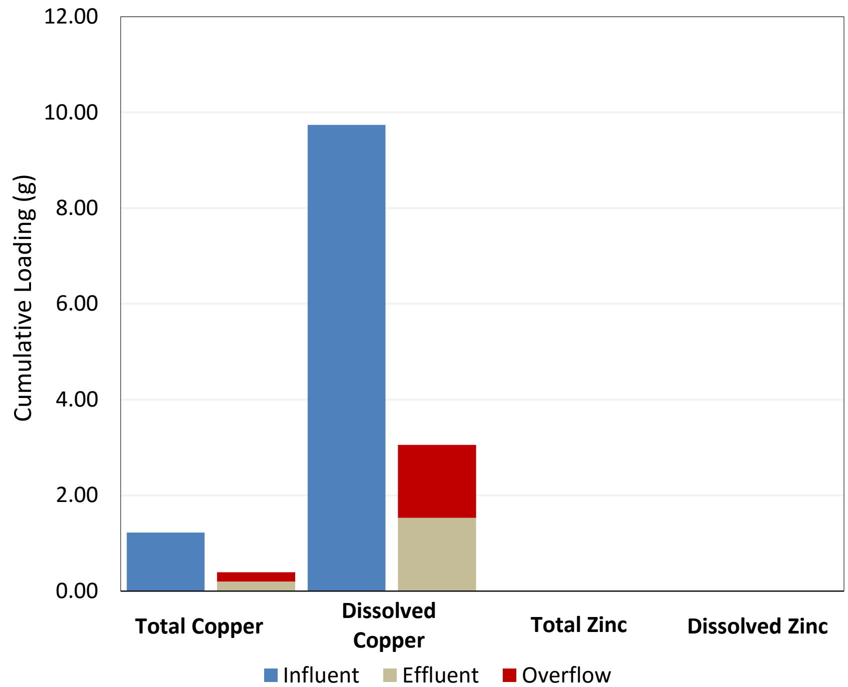


Figure 19. Cumulative loading for total metals species (n = 13) and dissolved metals species (n = 5).

Conclusions and Recommendations

The purpose of this study was to quantify the hydrologic and water quality treatment capabilities of a Filterra® Bioretention System to obtain performance data that supports approval by the North Carolina Department of Environmental and Natural Resources (NCDENR). This monitoring was performed in accordance with the Preliminary Evaluation Period (PEP) guidelines described in the 2007 NCDENR Stormwater BMP Manual and the Quality Assurance Project Plan (NC State 2013) previously submitted to NCDENR. Assessments were also conducted using the state of Washington's Technology Assessment Protocol – Ecology (TAPE).

North Carolina State University conducted a third-party analysis of the pollutant removal performance and hydrologic mitigation of a Filterra® Bioretention System. For removal of total suspended solids (TSS), guidelines set forth by TAPE target either (a) TSS removal greater than 80% (influent TSS range: > 200 mg/L), (b) TSS removal greater than or equal to 80% (influent TSS range: 100 – 200 mg/L), or (c) effluent TSS concentration less than or equal to 20 mg/L (influent TSS range: 20 – 100 mg/L). As a whole, the Filterra® system met these criteria. The bootstrapped 95% confidence interval of the mean TSS removal efficiency and mean effluent concentration were 90% - 94% and 3.9 – 6.6 mg/L, respectively. This also meets NCDENR's criterion of 85% TSS removal. While the cumulative loading reduction (76%) was lower due to bypass, when storms that generated bypass were excluded from the analysis, cumulative load reduction increased to 96%, indicating adequate treatment of smaller storms.

The Filterra® system also met TAPE's target of 50% removal of total phosphorus. The mean EMC removal efficiency for TAPE-qualified events was 66% with a 95% confidence interval of 57% - 75%. The mean load reduction was 65%, with a 95% confidence interval of 56% - 76%. Overall load reduction was 54%, indicating excellent removal of phosphorus that is on par and/or above the 45% pollutant removal credit awarded by NCDENR for bioretention without internal water storage (NCDENR 2009). When storms generating bypass were excluded, TP load reduction increased to 75%. The studied Filterra® system was slightly undersized and not maintained on the recommended biannual schedule; were the Filterra® system properly sized and maintained, it is expected less bypass would have occurred, and perhaps greater load reduction achieved as a result. Concentrations of both total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) were very low. Despite a cumulative load reduction of 66% for TDP, reduction of TDP concentrations was not significant. This is partially due to very low influent concentrations, and indicates the removal mechanisms for aqueous phosphorus species were more variable than the filtration and sedimentation removal mechanisms responsible for sediment-bound phosphorus removal.

While total nitrogen is not a pollutant targeted for TAPE approval, total nitrogen was also reduced, with the 95% confidence interval of the mean loading reduction ranging from 29% - 50%. Although total nitrogen was reduced, likely due to filtration of particulate-bound N, nitrate export was witnessed. This finding was expected, and is typical in systems that do not have apparent mechanisms for denitrification.

When looking at effluent concentrations as a benchmark, water quality of discharged and treated stormwater was generally better than "good" and "excellent" water quality thresholds found in the published literature. Over 80% of all measured TP effluent event mean concentrations met the 0.06 mg/L "excellent" threshold, with a median effluent concentration of 0.038 mg/L. 65% of the measured TN effluent samples (median: 0.53 mg/L) met or exceeded the “excellent” benthic threshold of 0.69 mg/L for the Piedmont of North Carolina. The 0.53 mg/L TN median effluent concentration meant that the “excellent” benthic threshold of 0.69 mg/L determined for this specific eco-region was met or exceeded for 65% of measured events.

Hydrologic mitigation was primarily provided via peak flow reduction. Despite bypass occurring for larger and high-intensity events, peak flow was reduced by a median value of 56%, with effluent peak flows mimicking pre-development conditions. While 22% of runoff bypassed the system, data from Smolek et al. (2015) show that this is within the expected overflow from traditional stormwater BMPs following NCDENR design guidance, such as a wetland or wet pond, suggesting that the Filterra® behaved similarly to widely-used and approved BMPs in North Carolina. In 2013, significant bypass did not occur before 0.70 inches (Figure 5 and Table 15). The system also treated rainfall intensities up to 0.90 in/hr in 2013, which meets new minimum design criteria established by NCDENR (2015) for non-storage based SCMs.

Future studies with higher nutrient concentrations entering the Filterra® (perhaps from watersheds with a high gross solids and leaf litter loading) will provide a better assessment of soluble phosphorus species.

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Appendices

Site and Monitoring Photos

Figure 20. Filterra Site with overflow bypass pipe

Figure 21. Planted tree species in the spring of 2013.

Figure 22. Inflow compound weir for flow measurement

Figure 23. Primary measuring device on the outlet pipe (Cipolleti-style weir)

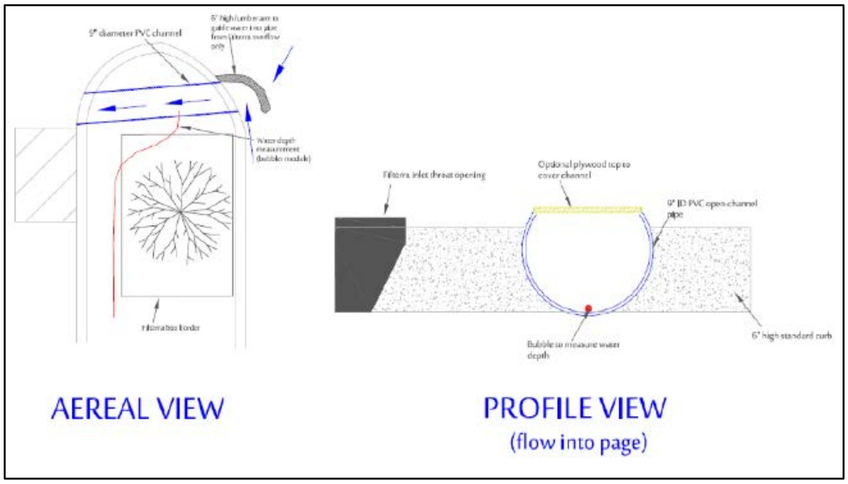


Figure 24. Plan and cross section of the overflow pipe for bypass monitoring

Additional Tables

Table 31. Summary of all hydrologic storms (n = 125). Sampled storms are marked by an asterisk.

Storm	Date	Rainfall	Duration	Intensity	Antecedent Dry Period	Inflow	Outflow	Overflow	Instrumentation Error/Other Abstraction
#		in	hr	in/hr	days	ft^3	ft^3	ft^3	ft^3
1	2/22/2013	0.58	26.1	0.02	-	376.8	354.0	0.0	22.8
2	2/26/2013*	1.12	14.5	0.08	2.1	846.9	741.4	122.1	-16.6
3	3/5/2013	0.10	14.7	0.01	6.7	24.0	24.0	0.0	0.0
4	3/12/2013	0.42	8.0	0.05	5.9	244.8	244.8	0.0	0.0
5	3/18/2013	0.14	1.3	0.11	6.5	44.4	44.4	0.0	0.0
6	3/24/2013	0.70	12.1	0.06	5.2	479.0	423.8	0.0	55.3
7	3/31/2013	0.10	2.7	0.04	6.5	24.0	24.0	0.0	0.0
8	4/1/2013	0.69	4.6	0.15	0.8	470.5	354.6	0.0	115.9
9	4/4/2013*	0.81	12.7	0.06	3.2	198.6	172.0	0.0	26.7
10	4/12/2013	0.32	2.8	0.11	7.2	126.0	139.8	15.0	-28.8
11	4/19/2013*	0.60	8.1	0.07	7.5	393.7	383.8	9.9	0.0
12	4/28/2013*	1.95	29.7	0.07	8.5	1590.5	1034.2	143.0	413.3
13	5/6/2013*	0.38	5.4	0.07	6.3	213.0	161.9	0.0	51.0
14	5/19/2013	0.62	11.2	0.06	0.5	410.7	427.7	0.0	-17.0
15	5/20/2013	0.45	14.9	0.03	0.3	269.0	269.0	0.0	0.0
16	5/23/2013	0.28	1.4	0.20	2.9	136.7	144.1	0.0	-7.4
17	6/3/2013	0.12	4.4	0.03	0.3	33.7	33.7	0.0	0.0
18	6/6/2013	4.94	27.1	0.18	2.8	4301.9	3118.9	1183.0	0.0
19	6/7/2013	0.30	2.8	0.11	0.4	151.5	138.6	8.5	4.4
20	6/9/2013	0.35	0.2	2.10	1.7	189.5	125.4	62.0	2.2
21	6/10/2013*	0.55	3.9	0.14	0.8	351.6	281.7	70.0	0.0
22	6/13/2013*	0.17	2.8	0.06	3.0	61.9	43.0	0.0	18.9
23	6/17/2013	0.20	1.4	0.14	4.0	80.9	74.7	0.0	6.3
24	6/19/2013*	0.19	1.0	0.19	1.0	74.5	64.9	0.0	9.6
25	6/22/2013	0.29	9.4	0.03	3.3	144.0	121.0	0.0	23.1
26	6/23/2013	0.11	1.9	0.06	0.3	28.7	28.7	0.0	0.0
27	6/23/2013*	0.35	11.0	0.03	0.7	189.5	189.5	0.0	0.0
28	6/25/2013	0.41	3.6	0.11	1.0	236.8	194.9	0.0	41.9
29	6/26/2013*	1.71	9.3	0.18	0.9	1374.4	1052.6	321.8	0.0
30	6/28/2013	0.47	4.2	0.11	1.9	173.9	172.3	0.0	1.6
31	6/30/2013	0.62	1.5	0.41	1.8	410.7	396.9	13.8	0.0
32	7/1/2013*	0.60	1.3	0.47	0.4	393.7	368.0	98.9	-73.2
33	7/1/2013	0.46	5.8	0.08	0.4	203.2	176.6	13.3	13.3
34	7/2/2013*	0.87	5.5	0.16	0.5	626.5	478.1	103.9	44.5
35	7/3/2013	0.98	4.2	0.24	1.0	723.1	617.6	105.5	0.0
36	7/8/2013	1.64	6.1	0.27	4.8	1311.5	932.8	378.7	0.0

37	7/9/2013	0.17	4.9	0.03	0.6	61.9	35.4	0.0	26.5
38	7/11/2013	0.37	9.7	0.04	1.9	205.1	156.5	0.0	48.6
39	7/12/2013	0.60	2.8	0.22	0.4	393.7	329.0	64.7	0.0
40	7/13/2013	0.40	9.3	0.04	0.7	228.8	205.9	0.0	22.9
41	7/14/2013	0.23	4.2	0.06	0.7	101.1	80.1	0.0	21.0
42	7/18/2013	0.13	0.2	0.56	1.4	63.4	77.1	0.0	-13.7
43	7/24/2013	0.13	1.2	0.11	5.9	39.6	43.4	9.0	-12.8
44	7/25/2013	0.43	1.4	0.31	0.4	284.8	223.7	0.0	61.1
45	7/27/2013	0.17	5.3	0.03	2.7	61.9	61.9	0.0	0.0
46	7/29/2013	0.75	2.1	0.35	1.8	522.2	408.0	51.8	62.3
47	8/2/2013	0.34	6.3	0.05	3.7	181.8	141.6	0.0	40.2
48	8/12/2013	0.16	3.7	0.04	10.1	55.9	49.7	0.0	6.2
49	8/13/2013*	0.78	5.5	0.14	0.6	548.1	371.0	118.7	58.4
50	8/16/2013	0.20	14.9	0.01	2.6	80.9	80.9	0.0	0.0
51	8/17/2013	1.23	4.2	0.30	0.3	944.6	746.4	198.2	0.0
52	8/19/2013	1.56	14.5	0.11	1.5	1239.7	1020.9	126.8	92.0
53	8/21/2013	1.93	6.3	0.31	1.9	1572.5	1156.8	415.7	0.0
54	9/1/2013*	0.37	6.1	0.06	11.0	205.1	179.6	0.0	25.5
55	9/16/2013	0.12	3.3	0.04	14.3	18.4	20.9	0.0	-2.5
56	9/21/2013*	0.95	8.0	0.12	1.5	696.7	603.0	93.7	0.0
57	10/7/2013	0.34	11.0	0.03	15.3	132.4	65.5	0.0	66.9
58	10/8/2013	0.18	3.1	0.06	0.6	82.2	20.1	0.0	62.2
59	10/13/2013*	0.10	3.2	0.03	2.4	36.5	0.0	0.0	36.5
60	11/1/2013*	0.71	7.2	0.10	13.4	368.2	368.2	0.0	0.0
61	11/7/2013	0.20	15.7	0.01	5.0	80.9	70.0	0.0	10.9
62	11/26/2013*	1.24	27.7	0.04	8.0	369.3	324.3	45.0	0.0
63	12/4/2013	0.13	4.7	0.03	6.4	9.9	0.0	0.0	9.9
64	12/8/2013	0.19	12.9	0.01	0.9	74.5	74.5	0.0	0.0
65	12/9/2013*	0.53	16.8	0.03	1.1	334.9	334.9	0.0	0.0
66	12/14/2013	1.09	10.5	0.10	3.9	820.3	501.1	319.2	0.0
67	12/23/2013	0.35	15.8	0.02	8.5	189.5	189.5	0.0	0.0
68	12/29/2013	1.58	12.8	0.12	4.9	1257.6	1018.9	238.7	0.0
69	1/2/2013	0.30	17.1	0.02	3.6	151.5	68.8	29.1	53.6
70	1/10/2014	2.84	18.6	0.15	7.3	2395.3	2366.2	29.1	0.0
71	1/11/2014	1.00	8.1	0.12	0.5	740.7	560.8	179.9	0.0
72	1/14/2014*	0.20	11.2	0.02	2.32	84.5	50.4	4.0	30.1
73	1/21/2014	0.13	2.7	0.05	7.22	15.2	14.5	0.0	0.7
74	1/30/2014	0.14	5.2	0.03	8.58	39.0	0.4	0.0	38.7
75	1/31/2014	0.10	4.8	0.02	0.73	30.0	0.5	0.0	29.5
76	2/1/2014	0.26	8.5	0.03	0.93	115.4	34.4	0.0	81.0
77	2/4/2014	0.20	2.8	0.07	2.65	33.1	24.1	0.0	9.0
78	2/5/2014*	0.28	12.3	0.02	0.26	78.2	64.4	0.0	13.8
79	2/13/2014	0.40	12.2	0.03	1.90	264.6	120.5	0.0	144.1
80	2/15/2014	0.35	5.2	0.07	1.29	97.2	50.5	0.0	46.7

81	2/19/2014*	0.46	2.4	0.19	3.72	277.2	173.0	50.2	53.9
82	2/21/2014	0.19	1.5	0.13	2.23	91.1	52.7	0.0	38.4
83	3/3/2014*	0.35	7.6	0.05	9.90	71.9	58.6	0.0	13.3
84	3/5/2015	0.10	5.2	0.02	1.40	5.1	5.1	0.0	0.0
85	3/6/2014	1.50	26.2	0.06	1.32	1004.5	920.9	83.6	0.0
86	3/16/2014	0.22	15.0	0.01	8.65	28.1	28.1	0.0	0.0
87	3/17/2014	0.68	10.0	0.07	0.56	650.8	650.8	0.0	0.0
88	3/28/2014	1.11	22.3	0.05	9.03	482.4	478.4	4.0	0.0
89	3/29/2014	0.32	9.9	0.03	0.31	166.5	94.4	24.9	47.2
90	4/7/2014	0.22	10.3	0.02	8.24	94.3	25.1	15.5	53.7
91	4/15/2014*	0.81	0.8	1.01	7.35	574.2	386.2	188.0	0.0
92	4/15/2014	0.82	1.9	0.42	0.46	556.8	361.0	195.8	0.0
93	4/18/2014*	1.08	23.6	0.05	3.03	811.4	804.5	6.9	0.0
94	4/28/2014	1.48	2.2	0.66	8.80	1167.9	800.3	367.6	0.0
95	4/29/2014	2.36	4.6	0.52	0.89	1960.8	1069.0	891.7	0.0
96	4/30/2014	0.27	2.3	0.12	0.67	129.4	120.8	8.6	0.1
97	5/15/2014	3.64	16.0	0.23	14.87	3120.9	1418.9	1595.1	106.9
98	5/29/2014	0.32	0.2	1.92	13.02	166.5	115.5	51.1	0.0
99	6/10/2014	0.11	0.2	0.66	11.89	28.7	23.7	4.8	0.2
100	6/12/2014*	0.22	0.1	2.20	2.39	94.3	62.8	30.0	1.5
101	6/17/2014	0.19	3.3	0.06	5.26	17.0	16.2	0.7	0.1
102	6/19/2014*	0.61	1.2	0.51	1.94	402.2	239.9	135.2	27.1
103	6/21/2014	0.57	2.8	0.20	1.91	368.4	246.4	118.7	3.3
104	6/22/2014	0.14	0.2	0.84	0.95	44.4	28.0	10.6	5.8
105	7/3/2014	0.29	3.3	0.09	5.97	144.0	143.6	0.4	0.0
106	7/10/2014	0.50	4.7	0.11	6.73	310.0	289.6	20.5	0.0
107	7/21/2014	0.88	9.2	0.10	10.59	635.3	407.1	228.2	0.0
108	8/9/2014	2.93	6.6	0.45	18.61	2476.8	1281.5	1195.3	0.0
109	8/10/2014	0.83	11.1	0.07	0.35	591.6	591.6	0.0	0.0
110	8/11/2014*	0.59	10.3	0.06	0.97	385.3	272.1	113.2	0.0
111	8/18/2014	0.51	5.0	0.10	6.80	318.3	229.7	88.6	0.0
112	8/19/2014	0.11	1.4	0.08	0.86	7.0	13.0	2.3	-8.3
113	8/23/2014	0.89	4.4	0.20	3.91	644.0	419.8	224.2	0.0
114	9/24/2014	0.33	10.1	0.03	31.32	84.5	40.7	0.0	43.9
115	9/25/2014	0.15	9.5	0.02	0.45	50.1	27.3	0.0	22.8
116	9/29/2014	0.12	10.0	0.01	4.12	33.7	33.7	0.0	0.0
117	10/11/2014*	0.43	4.0	0.11	11.65	252.9	89.6	0.0	163.3
118	10/14/2014*	0.72	3.4	0.21	2.49	496.3	163.0	77.8	255.4
119	10/15/2014	0.50	7.9	0.06	0.67	310.0	96.7	55.2	158.2
120	11/1/2014	0.21	14.6	0.01	16.62	55.2	7.1	5.1	43.0
121	11/23/2014	0.75	13.8	0.05	21.73	570.2	168.2	217.5	184.5
122	11/24/2014*	1.94	48.1	0.04	0.65	1581.5	488.5	1295.0	-202.0
123	12/6/2014*	0.21	13.4	0.02	9.93	43.4	24.0	3.2	16.2
124	12/16/2014	0.10	13.4	0.01	9.39	33.1	3.6	4.4	25.0

125	12/22/2014*	0.97	13.4	0.07	5.09	398.4	135.1	32.6	230.6
	SUM	**80.18**				**53953**	**38973**	**11920**	**3061**
	% of Inflow						**72%**	**22%**	**6%**

Table 32. Peak flow summary of all hydrologic storms (n = 125). Sampled storms are marked by an asterisk.

Storm Event	Date	Peak Rainfall Intensity	Peak Inflow	Peak Outflow (NOUT + Bypass)	NOUT Flow		Bypass Flow
		in/hr	cfs	cfs	cfs	in/hr	cfs
1	2/22/2013	1.02	0.243	0.065	0.065	117.0	0
2	2/26/2013*	1.86	0.443	0.125	0.124	223.2	0.001
3	3/5/2013	0.12	0.029	0.051	0.051	91.8	0.000
4	3/12/2013	0.30	0.071	0.094	0.094	169.2	0.000
5	3/18/2013	0.30	0.071	0.079	0.079	142.2	0.000
6	3/24/2013	0.42	0.100	0.085	0.085	153.0	0.000
7	3/31/2013	0.30	0.071	0.038	0.038	68.4	0.000
8	4/1/2013	1.14	0.272	0.059	0.059	106.2	0.000
9	4/4/2013*	0.36	0.086	0.038	0.038	68.4	0.000
10	4/12/2013	0.72	0.066	0.041	0.040	72.0	0.001
11	4/19/2013*	1.80	0.429	0.101	0.097	174.6	0.004
12	4/28/2013*	1.20	0.286	0.115	0.088	158.4	0.027
13	5/6/2013*	1.32	0.315	0.086	0.086	154.8	0.000
14	5/19/2013	1.98	0.472	0.240	0.240	432.0	0.000
15	5/20/2013	0.84	0.200	0.091	0.091	163.8	0.000
16	5/23/2013	1.74	0.415	0.165	0.165	297.0	0.000
17	6/3/2013	0.30	0.071	0.038	0.038	68.4	0.000
18	6/6/2013	2.40	0.572	0.375	0.247	444.6	0.128
19	6/7/2013	1.50	0.357	0.064	0.061	109.8	0.003
20	6/9/2013	3.00	0.715	0.316	0.115	207.0	0.201
21	6/10/2013*	1.98	0.472	0.152	0.027	48.6	0.125
22	6/13/2013*	0.54	0.038	0.034	0.034	61.2	0.000
23	6/17/2013	0.30	0.071	0.067	0.067	120.6	0.000
24	6/19/2013*	0.78	0.186	0.059	0.059	106.2	0.000
25	6/22/2013	1.32	0.315	0.132	0.132	237.6	0.000
26	6/23/2013	0.66	0.031	0.027	0.027	48.6	0.000
27	6/23/2013*	0.42	0.100	0.069	0.069	124.2	0.000
28	6/25/2013	1.44	0.129	0.123	0.123	221.4	0.000
29	6/26/2013*	5.64	1.344	0.403	0.296	532.8	0.107
30	6/28/2013	1.38	0.143	0.130	0.130	234.0	0.000
31	6/30/2013	1.92	0.458	0.162	0.129	232.2	0.033
32	7/1/2013*	2.70	0.643	0.342	0.137	246.6	0.205
33	7/1/2013	0.30	0.071	0.052	0.052	93.6	0.000

34	7/2/2013*	1.86	0.443	0.224	0.077	138.6	0.147
35	7/3/2013	2.82	0.672	0.189	0.096	172.8	0.092
36	7/8/2013	4.26	1.015	0.571	0.207	372.6	0.364
37	7/9/2013	1.20	0.286	0.074	0.074	133.2	0.000
38	7/11/2013	1.02	0.243	0.090	0.090	162.0	0.000
39	7/12/2013	2.76	0.658	0.262	0.106	190.8	0.156
40	7/13/2013	0.30	0.071	0.058	0.058	104.4	0.000
41	7/14/2013	1.02	0.243	0.064	0.063	113.4	0.001
42	7/18/2013	0.84	0.080	0.122	0.122	219.6	0.000
43	7/24/2013	0.84	0.080	0.075	0.075	135.0	0.000
44	7/25/2013	1.32	0.254	0.155	0.155	279.0	0.000
45	7/27/2013	0.24	0.057	0.120	0.120	216.0	0.000
46	7/29/2013	3.54	0.844	0.339	0.186	334.8	0.153
47	8/2/2013	1.74	0.415	0.133	0.133	239.4	0.000
48	8/12/2013	0.48	0.114	0.111	0.111	199.8	0.000
49	8/13/2013*	3.54	0.844	0.396	0.154	277.2	0.241
50	8/16/2013	1.50	0.357	0.074	0.074	133.2	0.000
51	8/17/2013	2.76	0.658	0.346	0.135	243.0	0.211
52	8/19/2013	2.16	0.515	0.206	0.120	216.0	0.086
53	8/21/2013	5.52	1.315	0.449	0.100	180.0	0.349
54	9/1/2013*	1.56	0.372	0.142	0.142	255.6	0.000
55	9/16/2013	1.26	0.073	0.039	0.039	70.2	0.000
56	9/21/2013*	1.20	0.286	0.156	0.032	57.6	0.124
57	10/7/2013	0.96	0.183	0.048	0.048	86.4	0.000
58	10/8/2013	0.30	0.033	0.008	0.008	14.4	0.000
59	10/13/2013*	0.30	0.174	0.000	0.000	0.0	0.000
60	11/1/2013*	1.38	0.526	0.077	0.077	138.6	0.000
61	11/7/2013	0.24	0.057	0.004	0.004	7.2	0.000
62	11/26/2013*	0.72	0.089	0.051	0.049	88.2	0.002
63	12/4/2013	0.30	0.004	0.000	0.000	0.0	0.000
64	12/8/2013	0.42	0.013	0.016	0.016	28.8	0.000
65	12/9/2013*	0.54	0.043	0.035	0.035	63.0	0.000
66	12/14/2013	1.62	0.386	0.213	0.027	48.6	0.186
67	12/23/2013	0.60	0.050	0.026	0.026	46.8	0.000
68	12/29/2013	2.52	0.601	0.406	0.083	149.4	0.322
69	1/2/2013	0.24	0.015	0.014	0.009	16.2	0.005
70	1/10/2014	2.52	0.601	0.405	0.080	144.0	0.325
71	1/11/2014	2.28	0.543	0.241	0.051	91.8	0.190
72	1/14/2014*	0.42	0.047	0.017	0.015	27.0	0.002
73	1/21/2014	0.30	0.008	0.006	0.006	10.8	0.000
74	1/30/2014	0.24	0.003	0.000	0.000	0.0	0.000
75	1/31/2014	0.24	0.003	0.001	0.001	1.8	0.000
76	2/1/2014	0.30	0.047	0.014	0.014	25.2	0.000
77	2/4/2014	0.24	0.017	0.008	0.008	14.4	0.000

78	2/5/2014*	0.90	0.120	0.046	0.046	82.8	0.000
79	2/13/2014	0.30	0.026	0.014	0.014	25.2	0.000
80	2/15/2014	0.30	0.017	0.008	0.008	14.4	0.000
81	2/19/2014*	1.56	0.372	0.231	0.083	149.4	0.148
82	2/21/2014	0.96	0.105	0.046	0.046	82.8	0.000
83	3/3/2014*	0.66	0.045	0.026	0.026	46.8	0.000
84	3/5/2015	0.24	0.003	n/a	n/a	n/a	0.000
85	3/6/2014	0.24	0.096	n/a	n/a	n/a	0.010
86	3/16/2014	0.24	0.044	n/a	n/a	n/a	0.000
87	3/17/2014	0.30	0.380	n/a	n/a	n/a	0.000
88	3/28/2014	0.78	0.097	0.042	0.042	75.6	0.000
89	3/29/2014	2.10	0.500	0.135	0.083	149.4	0.051
90	4/7/2014	0.42	0.100	0.009	0.003	5.4	0.005
91	4/15/2014*	4.32	1.029	0.452	0.083	149.4	0.369
92	4/15/2014	1.80	0.429	0.138	0.025	45.0	0.113
93	4/18/2014*	0.54	0.129	0.023	0.023	41.4	0.000
94	4/28/2014	4.74	1.130	0.430	0.083	149.4	0.347
95	4/29/2014	3.96	0.944	0.554	0.083	149.4	0.471
96	4/30/2014	0.84	0.200	0.032	0.032	57.6	0.000
97	5/15/2014	3.60	0.858	0.411	0.083	149.4	0.327
98	5/29/2014	3.06	0.729	0.177	0.083	149.4	0.094
99	6/10/2014	0.84	0.200	0.050	0.050	90.0	0.000
100	6/12/2014*	2.16	0.515	0.106	0.038	68.4	0.068
101	6/17/2014	0.60	0.020	0.015	0.015	27.0	0.000
102	6/19/2014*	1.38	0.329	0.140	0.039	70.2	0.101
103	6/21/2014	3.00	0.715	0.094	0.018	32.4	0.076
104	6/22/2014	0.90	0.214	0.025	0.009	16.2	0.016
105	7/3/2014	1.20	0.286	0.039	0.039	70.2	0.000
106	7/10/2014	0.60	0.143	0.033	0.033	59.4	0.000
107	7/21/2014	3.30	0.786	0.342	0.083	149.4	0.259
108	8/9/2014	2.10	0.500	0.268	0.014	25.2	0.254
109	8/10/2014	1.50	0.357	0.018	0.018	32.4	0.000
110	8/11/2014*	2.52	0.601	0.193	0.003	5.4	0.190
111	8/18/2014	3.54	0.844	0.285	0.000	0.0	0.285
112	8/19/2014	0.78	0.014	0.006	0.006	10.8	0.000
113	8/23/2014	4.92	1.172	0.464	0.012	21.6	0.452
114	9/24/2014	6.36	1.516	0.015	0.015	27.0	0.000
115	9/25/2014	0.54	0.129	0.008	0.008	14.4	0.000
116	9/29/2014	0.30	0.071	n/a	n/a	n/a	n/a
117	10/11/2014*	3.54	0.844	0.083	0.083	149.4	0.000
118	10/14/2014*	1.92	0.458	0.203	0.083	149.4	0.102
119	10/15/2014	1.62	0.386	0.185	0.070	126.0	0.115
120	11/1/2014	0.24	0.014	0.003	0.003	5.4	0.000
121	11/23/2014	1.92	0.458	0.543	0.083	149.4	0.460

122	11/24/2014*	0.60	0.143	0.301	0.051	91.8	0.250
123	12/6/2014*	0.90	0.069	0.043	0.043	77.4	0.000
124	12/16/2014	0.24	0.057	0.003	0.003	5.4	0.000
125	12/22/2014*	0.60	0.143	0.076	0.020	36.0	0.056

Table 33. Water quality results for total suspended solids, suspended sediment concentration, total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus.

Date	Rainfall (in)	Total Suspended Solids (mg/L)		Suspended Sediment Concentration (mg/L)		Total Phosphorus (mg/L) MDL: 0.024 mg/L		Total Dissolved Phosphorus (mg/L) MDL: 0.024 mg/L		Soluble Reactive Phosphorus (mg/L) MDL: 0.055 mg/L	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
2/26/2013	1.12	50.00	4.40	62.25	2.90	0.07	*<MDL*	0.74	*<MDL*	0.12	*<MDL*
4/4/2013	0.81	37.00	2.80	57.34	1.51	0.03	*<MDL*	0.03	*<MDL*	*<MDL*	*<MDL*
4/19/2013	0.60	51.00	6.80	48.94	6.44	0.11	0.09	0.05	0.05	*<MDL*	*<MDL*
4/29/2013	1.95	20.00	4.00	12.30	3.54	0.04	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
5/6/2013	0.38	68.00	5.20	0.00	0.00	0.06	0.04	0.03	*<MDL*	*<MDL*	*<MDL*
6/10/2013	0.55	32.00	4.00	43.38	3.40	0.03	0.06	0.14	*<MDL*	*<MDL*	*<MDL*
6/13/2013	0.17	0.00	0.00	0.00	0.00	0.21	0.07	0.00	0.00	0.00	0.00
6/19/2013	0.30	0.00	0.00	0.00	0.00	0.22	0.04	0.00	0.00	*<MDL*	*<MDL*
6/24/2013	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/26/2013	1.71	66.00	6.80	95.77	7.03	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
7/1/2013	0.60	30.00	6.80	39.10	4.27	0.05	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
7/2/2013	0.87	30.00	2.90	19.51	2.30	0.05	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
8/13/2013	0.78	190.00	2.80	226.41	3.33	0.21	0.07	0.09	*<MDL*	*<MDL*	*<MDL*
9/2/2013	0.37	220.00	8.00	353.17	12.09	0.10	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
9/21/2013	0.95	40.00	3.60	79.09	3.09	0.04	*<MDL*	*<MDL*	0.03	*<MDL*	*<MDL*
10/13/2013	0.10	55.00	1.60	0.00	0.00	0.07	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
11/1/2013	0.71	94.00	4.00	71.84	3.05	0.05	0.05	*<MDL*	*<MDL*	0.08	*<MDL*
11/26/2013	1.24	0.00	0.00	0.00	0.00	0.20	0.04	0.03	0.04	0.00	0.00
12/10/2013	0.53	270.00	9.20	0.00	0.00	0.12	0.03	*<MDL*	0.03	*<MDL*	*<MDL*
12/14/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*<MDL*	*<MDL*
1/14/2014	0.20	0.00	0.00	0.00	0.00	0.12	0.05	*<MDL*	*<MDL*	*<MDL*	*<MDL*
2/5/2014	0.29	170.00	16.00	0.00	0.00	0.06	0.03	*<MDL*	*<MDL*	*<MDL*	*<MDL*
2/19/2014	0.46	120.00	3.20	86.67	2.07	0.06	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
3/3/2014	0.35	54.00	14.00	0.00	0.00	0.59	0.05	0.39	0.02	*<MDL*	*<MDL*
4/15/2014	0.81	730.00	8.80	194.72	8.39	0.29	0.14	0.06	0.04	*<MDL*	*<MDL*
4/19/2014	1.08	43.00	1.60	39.37	0.74	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*	*<MDL*
6/12/2014	0.25	220.00	3.60	309.03	1.57	0.30	0.09	0.14	0.06	*<MDL*	*<MDL*
6/19/2014	0.61	100.00	1.20	111.87	1.01	0.09	0.04	*<MDL*	*<MDL*	*<MDL*	*<MDL*
8/11/2014	0.51	200.00	2.40	230.13	2.39	0.17	0.04	*<MDL*	0.02	*<MDL*	*<MDL*

10/11/2014	0.43	150.00	7.60	219.75	6.49	0.27	0.13	0.14	0.08	<MDL	<MDL
10/14/2014	0.72	62.00	2.80	85.66	1.78	0.06	<MDL	<MDL	<MDL	<MDL	<MDL
11/24/2014	0.75	160.00	2.00	133.10	3.03	0.17	0.09	0.07	0.08	<MDL	<MDL
12/6/2014	0.20	82.00	11.00	0.00	0.00	0.12	0.06	<MDL	0.04	<MDL	<MDL
12/22/2014	0.97	33.00	3.60	0.00	0.00	0.12	0.03	<MDL	<MDL	<MDL	<MDL

Table 34. Water quality results for total nitrogen and nitrogen species.

Date	Rainfall (in)	Total Nitrogen		Total Ammoniacal Nitrogen (mg/L) MDL: 0.045 mg/L		Nitrate/Nitrite (mg/L) MDL: 0.025 mg/L		Total Kjedhal Nitrogen (mg/L) MDL: 0.26 mg/L	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT
2/26/2013	1.12	1.25	0.54	0.14	0.06	0.05	0.08	1.20	0.46
4/4/2013	0.81	0.87	0.44	0.29	0.11	0.16	0.17	0.71	0.27
4/19/2013	0.60	1.41	1.14	0.07	0.06	0.11	0.18	1.30	0.96
4/29/2013	1.95	0.35	0.51	<MDL	<MDL	<MDL	0.15	0.34	0.36
5/6/2013	0.38	0.94	0.68	0.27	0.24	0.07	0.13	0.87	0.55
6/10/2013	0.55	0.73	0.89	0.05	<MDL	0.11	0.39	0.62	0.50
6/13/2013	0.17	2.39	1.60	0.28	<MDL	0.19	0.40	2.20	1.20
6/19/2013	0.30	2.51	0.89	0.02	<MDL	0.11	0.22	2.40	0.67
6/24/2013	0.35	1.55	0.26	0.46	<MDL	0.45	0.13	1.10	<MDL
6/26/2013	1.71	0.77	0.31	0.14	<MDL	0.21	0.18	0.56	<MDL
7/1/2013	0.60	0.67	0.51	0.17	0.08	0.04	0.05	0.63	0.46
7/2/2013	0.87	0.58	0.43	<MDL	<MDL	0.07	0.06	0.51	0.37
8/13/2013	0.78	1.39	0.62	0.10	0.07	0.19	0.20	1.20	0.42
9/2/2013	0.37	1.25	1.05	0.13	0.14	0.15	0.22	1.10	0.83
9/21/2013	0.95	1.10	0.52	0.13	0.06	0.20	0.11	0.90	0.41
10/13/2013	0.10	0.93	0.46	<MDL	<MDL	0.13	<MDL	0.80	0.45
11/1/2013	0.71	0.40	0.64	<MDL	0.11	<MDL	0.07	0.39	0.57
11/26/2013	1.24	2.01	0.31	<MDL	<MDL	<MDL	<MDL	2.00	0.30
12/10/2013	0.53	1.07	0.42	0.07	<MDL	0.10	0.15	0.97	0.27
12/14/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/14/2014	0.20	1.27	0.44	0.05	<MDL	0.07	0.07	1.20	0.37
2/5/2014	0.29	0.58	0.53	0.08	0.08	0.14	0.15	0.44	0.38
2/19/2014	0.46	0.81	0.33	0.11	0.07	0.20	0.20	0.61	<MDL
3/3/2014	0.35	1.51	1.39	0.56	0.42	0.41	0.51	1.10	0.88
4/15/2014	0.81	1.91	1.01	<MDL	0.05	<MDL	<MDL	1.90	1.00
4/19/2014	1.08	0.46	0.44	<MDL	0.06	<MDL	<MDL	0.45	0.43
6/12/2014	0.25	2.62	1.76	0.57	0.31	0.22	0.36	2.40	1.40
6/19/2014	0.61	1.30	1.06	0.17	0.08	0.20	0.32	1.10	0.74
8/11/2014	0.51	1.60	0.62	0.25	<MDL	0.10	0.17	1.50	0.45

10/11/2014	0.43	1.90	2.10	0.19	0.11	0.20	0.80	1.70	1.30
10/14/2014	0.72	0.99	0.45	0.56	*<MDL*	0.05	0.08	0.94	0.37
11/24/2014	0.75	0.90	0.59	*<MDL*	*<MDL*	0.05	0.09	0.85	0.50
12/6/2014	0.20	1.06	0.99	*<MDL*	0.05	0.06	0.21	1.00	0.78
12/22/2014	0.97	0.55	*0.26*	0.07	*<MDL*	0.06	0.13	0.49	*<MDL*

Table 35. Water quality results for metals species.

Date	Rainfall (in)	Total Copper (microg/L) MDL: 2 µg/L		Dissolved Copper (µg/L) MDL: 2 µg/L		Total Zinc (microg/L) MDL: 10 µg/L		Dissolved Zinc (µg/L) MDL: 10 µg/L	
		IN	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
2/26/2013	1.12	7.80	3.20	4.40	3.80	66.00	*<MDL*	30.00	*<MDL*
4/4/2013	0.81	7.30	4.90	5.20	4.80	35.00	*<MDL*	28.00	*<MDL*
4/19/2013	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4/29/2013	1.95	3.30	4.10	0.00	0.00	5.00	*<MDL*	0.00	0.00
5/6/2013	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/10/2013	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/13/2013	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/19/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/24/2013	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/26/2013	1.71	*<MDL*	2.50	*<MDL*	2.40	19.00	*<MDL*	13.00	*<MDL*
7/1/2013	0.60	3.00	3.20	0.00	0.00	22.00	*<MDL*	0.00	0.00
7/2/2013	0.87	2.10	2.10	0.00	0.00	18.00	*<MDL*	0.00	0.00
8/13/2013	0.78	7.60	5.40	0.00	0.00	82.00	19.00	0.00	0.00
9/2/2013	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9/21/2013	0.95	6.70	4.80	0.00	0.00	49.00	12.00	0.00	0.00
10/13/2013	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11/1/2013	0.71	3.50	11.00	0.00	0.00	37.00	25.00	0.00	0.00
11/26/2013	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/10/2013	0.53	14.00	10.00	*<MDL*	9.50	180.00	32.00	15.00	26.00
12/14/2013	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/14/2014	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2/5/2014	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2/19/2014	0.46	12.00	7.60	4.50	6.80	87.00	24.00	28.00	26.00
3/3/2014	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4/15/2014	0.81	9.00	9.50	0.00	0.00	71.00	35.00	0.00	0.00
4/19/2014	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/12/2014	0.25	27.00	12.00	0.00	0.00	99.00	31.00	0.00	0.00
6/19/2014	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8/11/2014	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/11/2014	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/14/2014	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11/24/2014	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/6/2014	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12/22/2014	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 36. Individual storm loading for total suspended solids and suspended sediment concentration.

Date	Rainfall (in)	Total Suspended Solids (mg)			Suspended Sediment Concentration (mg)		
		IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	1199011.40	92371.32	172817.43	1492769.19	60881.09	215157.70
4/4/2013	0.81	208116.28	13635.39	0.00	322523.98	7353.37	0.00
4/19/2013	0.60	568607.23	73908.01	14297.15	545639.96	69995.23	13719.66
4/29/2013	1.95	900761.14	117140.94	80986.05	553968.10	103669.73	49806.42
5/6/2013	0.38	410068.40	23842.29	0.00			
6/10/2013	0.55	318636.66	31904.96	63397.01	431951.82	27119.21	85942.57
6/13/2013	0.17						
6/19/2013	0.30						
6/24/2013	0.35						
6/26/2013	1.71	2568615.05	202681.23	601414.85	3727216.11	209536.63	872689.40
7/1/2013	0.60	334474.84	70859.96	84052.47	435932.21	44495.89	109548.39
7/2/2013	0.87	532249.48	39260.39	88271.96	346139.58	31137.55	57406.20
8/13/2013	0.78	2949105.76	29413.91	638806.34	3514247.55	34981.54	761221.80
9/2/2013	0.37	1277727.21	40682.86	0.00	2051158.72	61481.97	0.00
9/21/2013	0.95	789128.00	61473.77	106086.06	1560303.34	52764.99	209758.66
10/13/2013	0.10	56791.47	0.00	0.00			
11/1/2013	0.71	980152.28	41708.61	0.00	749086.59	31802.81	0.00
11/26/2013	1.24						
12/10/2013	0.53	2560791.18	87256.59	0.00			
12/14/2013	0.30						
1/14/2014	0.20						
2/5/2014	0.29	376520.56	29182.16	0.00			
2/19/2014	0.46	941910.82	15679.81	170685.74	680295.09	10142.87	123277.78
3/3/2014	0.35	109889.29	23230.31	0.00			
4/15/2014	0.82	11869534.94	96237.49	3886197.63	3166076.50	91753.70	1036603.29
4/19/2014	1.08	987994.60	36449.97	8401.59	904589.48	16858.11	7692.34
6/12/2014	0.25	587278.70	6398.40	186623.00	824939.72	2790.41	262145.94
6/19/2014	0.61	1138895.30	8151.43	382894.11	1274082.17	6860.79	428343.64
8/11/2014	0.51	2181965.01	18489.25	641194.29	2510678.04	18412.21	737790.21
10/11/2014	0.43	1073995.23	19272.28	0.00	1573403.01	16457.51	0.00
10/14/2014	0.72	871253.70	12926.56	136664.41	1203735.35	8217.60	188817.31
11/24/2014	0.75	2583262.38	9525.04	985510.72	2148951.39	14430.43	819821.73
12/6/2014	0.20	100739.00	7469.72	7411.75			
12/22/2014	0.97	372282.90	13775.52	30486.57			

Table 37. Individual storm loading for total phosphorus, total dissolved phosphorus, and soluble reactive phosphorus. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Phosphorus (mg)			Total Dissolved Phosphorus (mg)			Soluble Reactive Phosphorus (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	1774.54	*251.92*	255.77	17745.37	*251.92*	2557.70	2877.63	*577.32*	414.76
4/4/2013	0.81	168.74	*58.44*	0.00	168.74	*58.44*	0.00	*154.68*	*133.92*	0.00
4/19/2013	0.60	1226.41	999.93	30.84	524.01	532.57	13.18	*306.60*	*298.89*	*7.71*
4/29/2013	1.95	1891.60	1200.69	170.07	*540.46*	*351.42*	*48.59*	*1238.55*	*805.34*	*111.36*
5/6/2013	0.38	367.86	201.74	0.00	150.76	*55.02*	0.00	*165.84*	*126.09*	0.00
6/10/2013	0.55	338.55	438.69	67.36	1394.04	*95.71*	277.36	*273.83*	*219.35*	*54.48*
6/13/2013	0.17	368.26	79.13	0.00						
6/19/2013	0.30	463.88	64.31	0.00				*57.99*	*50.53*	0.00
6/24/2013	0.35									
6/26/2013	1.71	1323.23	*357.67*	309.82	*467.02*	*357.67*	*109.35*	*1070.26*	*819.67*	*250.59*
7/1/2013	0.60	501.71	343.88	126.08	*133.79*	*125.05*	*33.62*	*306.60*	*286.57*	*77.05*
7/2/2013	0.87	798.37	514.45	132.41	*212.90*	*162.46*	*35.31*	*487.90*	*372.30*	*80.92*
8/13/2013	0.78	3259.54	703.83	706.05	1443.51	*126.06*	312.68	*426.84*	*288.89*	*92.46*
9/2/2013	0.37	580.79	*61.02*	0.00	*69.69*	*61.02*	0.00	*159.72*	*139.85*	0.00
9/21/2013	0.95	789.13	*204.91*	106.09	*236.74*	478.13	*31.83*	*542.53*	*469.59*	*72.93*
10/13/2013	0.10	68.15	0.00	0.00	*12.39*	0.00	0.00	*28.40*	0.00	0.00
11/1/2013	0.71	542.21	542.21	0.00	*125.13*	*125.13*	0.00	865.45	*286.75*	0.00
11/26/2013	1.24	2091.65	330.62	254.85	292.83	394.91	35.68			
12/10/2013	0.53	1138.13	303.50	0.00	*113.81*	294.02	0.00	*260.82*	*260.82*	0.00
12/14/2013	0.30							*638.75*	*390.20*	*248.55*
1/14/2014	0.20	287.11	68.48	13.59	*28.71*	*17.12*	*1.36*	*65.80*	*39.23*	*3.11*
2/5/2014	0.29	121.82	52.89	0.00	*26.58*	*21.89*	0.00	*60.91*	*50.16*	0.00
2/19/2014	0.46	463.11	*58.80*	83.92	*94.19*	*58.80*	*17.07*	*215.85*	*134.75*	*39.12*
3/3/2014	0.35	1200.64	76.33	0.00	793.64	39.82	0.00	*55.96*	*45.63*	0.00
4/15/2014	0.82	4715.29	1531.05	1543.83	910.54	470.25	298.12	*447.14*	*300.74*	*146.40*
4/19/2014	1.08	1010.97	*273.37*	8.60	*275.72*	*273.37*	*2.34*	*631.86*	*626.48*	*5.37*
6/12/2014	0.25	800.83	158.18	254.49	373.72	108.42	118.76	*73.41*	*48.88*	*23.33*
6/19/2014	0.61	979.45	285.30	329.29	*136.67*	*81.51*	*45.95*	*313.20*	*186.80*	*105.30*
8/11/2014	0.51	1854.67	338.97	545.02	*130.92*	184.89	*38.47*	*300.02*	*211.86*	*88.16*
10/11/2014	0.43	1933.19	329.66	0.00	1002.40	205.40	0.00	*196.90*	*69.74*	0.00
10/14/2014	0.72	786.94	*55.40*	123.44	*168.63*	*55.40*	*26.45*	*386.44*	*126.96*	*60.62*
11/24/2014	0.75	2744.72	447.68	1047.11	1049.45	361.95	400.36	*444.00*	*130.97*	*169.38*
12/6/2014	0.20	147.42	38.03	10.85	*14.74*	25.13	*1.08*	*33.78*	*18.67*	*2.49*
12/22/2014	0.97	1353.76	95.66	110.86	*135.38*	*45.92*	*11.09*	*310.24*	*105.23*	*25.41*

Table 38. Individual storm loading for total nitrogen and nitrogen species. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Nitrogen (mg)			Total Ammoniacal Nitrogen (mg)			Nitrate/Nitrite (mg)			Total Kjedhal Nitrogen (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	29903.34	11315.49	4310.07	3357.23	1280.60	483.89	1127.07	1658.48	162.45	28776.27	9657.00	4147.62
4/4/2013	0.81	4893.54	2142.70	*0.00*	1631.18	535.68	*0.00*	899.96	827.86	*0.00*	3993.58	1314.84	*0.00*
4/19/2013	0.60	15720.32	12390.46	395.27	735.84	630.39	18.50	1226.41	1956.39	30.84	14493.91	10434.07	364.44
4/29/2013	1.95	*15875.92*	14935.47	*1427.38*	*1013.36*	*658.92*	*91.11*	*562.98*	4392.79	*50.62*	15312.94	10542.68	1376.76
5/6/2013	0.38	5656.53	3117.84	*0.00*	1628.21	1100.41	*0.00*	410.07	596.06	*0.00*	5246.46	2521.78	*0.00*
6/10/2013	0.55	7268.90	7098.85	1446.24	517.78	*179.47*	103.02	1095.31	3110.73	217.93	6173.59	3988.12	1228.32
6/13/2013	0.17	4191.12	1947.83	*0.00*	491.01	*27.39*	*0.00*	333.19	486.96	*0.00*	3857.94	1460.88	*0.00*
6/19/2013	0.30	5292.46	1635.23	*0.00*	47.44	*41.34*	*0.00*	231.94	404.21	*0.00*	5060.51	1231.01	*0.00*
6/24/2013	0.35	145.50	*24.41*	*0.00*	43.18	*2.11*	*0.00*	42.24	12.20	*0.00*	103.26	*12.20*	*0.00*
6/26/2013	1.71	29967.18	*9239.88*	7016.51	5448.58	*670.64*	1275.73	8172.87	5365.09	1913.59	21794.31	*3874.79*	5102.91
7/1/2013	0.60	7514.53	5356.18	1888.38	1895.36	844.07	476.30	490.56	562.71	123.28	7023.97	4793.47	1765.10
7/2/2013	0.87	10361.12	5821.37	1718.36	*399.19*	*304.61*	*66.20*	1312.88	812.28	217.74	9048.24	5009.08	1500.62
8/13/2013	0.78	21575.04	6513.08	4673.37	1552.16	745.85	336.21	2949.11	2100.99	638.81	18625.93	4412.09	4034.57
9/2/2013	0.37	7259.81	5339.63	*0.00*	755.02	711.95	*0.00*	871.18	1118.78	*0.00*	6388.64	4220.85	*0.00*
9/21/2013	0.95	21701.02	8879.55	2917.37	2564.67	990.41	344.78	3945.64	1878.37	530.43	17755.38	7001.18	2386.94
10/13/2013	0.10	960.29	*0.00*	*0.00*	*23.23*	*0.00*	*0.00*	134.23	*0.00*	*0.00*	826.06	*0.00*	*0.00*
11/1/2013	0.71	*4196.93*	6704.66	*0.00*	*234.61*	1146.99	*0.00*	*130.34*	761.18	*0.00*	4066.59	5943.48	*0.00*
11/26/2013	1.24	*21047.22*	*2870.00*	*2564.44*	*235.31*	*206.64*	*28.67*	*130.73*	*114.80*	*15.93*	20916.49	2755.20	2548.51
12/10/2013	0.53	10129.35	3983.45	*0.00*	663.91	*213.40*	*0.00*	929.47	1422.66	*0.00*	9199.88	2560.79	*0.00*
12/14/2013	0.30												
1/14/2014	0.20	3038.57	623.42	143.85	117.24	*32.10*	5.55	167.48	95.58	7.93	2871.09	527.84	135.92
2/5/2014	0.29	1284.60	966.66	*0.00*	168.33	145.91	*0.00*	310.08	273.58	*0.00*	974.52	693.08	*0.00*
2/19/2014	0.46	6357.90	*1616.98*	1152.13	863.42	328.30	156.46	1569.85	979.99	284.48	4788.05	*636.99*	867.65
3/3/2014	0.35	3072.83	2306.44	*0.00*	1139.59	696.91	*0.00*	834.34	846.25	*0.00*	2238.49	1460.19	*0.00*
4/15/2014	0.82	*31096.56*	*11072.78*	*10181.31*	*365.84*	535.87	*119.78*	*203.25*	*136.70*	*66.54*	30893.31	10936.08	10114.76
4/19/2014	1.08	*10626.69*	*10080.70*	*90.37*	*516.97*	1252.97	*4.40*	*287.21*	*284.77*	*2.44*	10339.48	9795.93	87.92
6/12/2014	0.25	6993.96	3128.10	2222.51	1521.59	550.97	483.52	587.28	639.84	186.62	6406.68	2488.27	2035.89
6/19/2014	0.61	14805.64	7200.43	4977.62	1936.12	529.84	650.92	2277.79	2173.72	765.79	12527.85	5026.72	4211.84
8/11/2014	0.51	17455.72	4776.39	5129.55	2727.46	*173.34*	801.49	1090.98	1309.66	320.60	16364.74	3466.73	4808.96
10/11/2014	0.43	13603.94	5325.23	*0.00*	1360.39	278.94	*0.00*	1431.99	2028.66	*0.00*	12171.95	3296.57	*0.00*
10/14/2014	0.72	13855.74	2063.63	2173.40	7869.39	*103.87*	1234.39	646.41	355.48	101.40	13209.33	1708.15	2072.01
11/24/2014	0.75	14579.29	2800.36	5561.98	*363.27*	*107.16*	*138.59*	855.71	419.10	326.45	13723.58	2381.26	5235.53
12/6/2014	0.20	1301.01	672.27	95.72	*27.64*	30.56	*2.03*	72.48	142.60	5.33	1228.52	529.67	90.39
12/22/2014	0.97	6182.15	*994.90*	506.26	733.28	*86.10*	60.05	654.32	497.45	53.58	5527.84	*497.45*	452.68

Table 39. Individual storm loading for metal species. Italicized values were estimated using half the minimum detection limit.

Date	Rainfall (in)	Total Copper (mg)			Dissolved Copper (mg)			Total Zinc (mg)			Dissolved Zinc (mg)		
		IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER	IN	OUT	OVER
2/26/2013	1.12	187.05	67.18	26.96	105.51	79.78	15.21	1582.70	*104.97*	228.12	719.41	*104.97*	103.69
4/4/2013	0.81	41.06	23.86	*0.00*	29.25	23.37	*0.00*	196.87	*24.35*	*0.00*	157.49	*24.35*	*0.00*
4/19/2013	0.60												
4/29/2013	1.95	148.63	120.07	13.36				225.19	*146.43*	20.25			
5/6/2013	0.38												
6/10/2013	0.55												
6/13/2013	0.17												
6/19/2013	0.30												
6/24/2013	0.35												
6/26/2013	1.71	*38.92*	74.52	*9.11*	*38.92*	71.53	*9.11*	739.45	*149.03*	173.13	505.94	*149.03*	118.46
7/1/2013	0.60	33.45	33.35	8.41				245.28	*52.10*	61.64			
7/2/2013	0.87	37.26	28.43	6.18				319.35	*67.69*	52.96			
8/13/2013	0.78	117.96	56.73	25.55				1272.77	199.59	275.70			
9/2/2013	0.37												
9/21/2013	0.95	132.18	81.97	17.77				966.68	204.91	129.96			
10/13/2013	0.10												
11/1/2013	0.71	36.50	114.70	*0.00*				385.80	260.68	*0.00*			
11/26/2013	1.24												
12/10/2013	0.53	132.78	94.84	*0.00*	*9.48*	90.10	*0.00*	1707.19	303.50	*0.00*	142.27	246.59	*0.00*
12/14/2013	0.30												
1/14/2014	0.20												
2/5/2014	0.29												
2/19/2014	0.46	94.19	37.24	17.07	35.32	33.32	6.40	682.89	117.60	123.75	219.78	127.40	39.83
3/3/2014	0.35												
4/15/2014	0.82	146.34	103.89	47.91				1154.43	382.76	377.97			
4/19/2014	1.08												
6/12/2014	0.25	72.08	21.33	22.90				264.28	55.10	83.98			
6/19/2014	0.61												
8/11/2014	0.51												
10/11/2014	0.43												
10/14/2014	0.72												
11/24/2014	0.75												
12/6/2014	0.20												
12/22/2014	0.97												

Statistical Analyses

Bootstrapping Methodology

```
> boot.TSS1 <- boot(data=stand$TSS1,statistic=mymean.func,R=1000)
> boot.ci(boot.TSS1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSS1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.8974,  0.9445 )   ( 0.8989,  0.9471 )

Level     Percentile            BCa
95%   ( 0.8962,  0.9445 )   ( 0.8880,  0.9396 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TSS1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TSS2 <- boot(data=stand$TSS2,statistic=mymean.func,R=1000)
> boot.ci(boot.TSS2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSS2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.7653,  0.8575 )   ( 0.7659,  0.8563 )

Level     Percentile            BCa
95%   ( 0.7676,  0.8580 )   ( 0.7628,  0.8550 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TSS2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.SSC1 <- boot(data=stand$SSC1,statistic=mymean.func,R=1000)
> boot.ci(boot.SSC1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSC1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.9156,  0.9712 )   ( 0.9203,  0.9741 )

Level     Percentile            BCa
95%   ( 0.9130,  0.9668 )   ( 0.8933,  0.9631 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.SSC1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.SSC2 <- boot(data=stand$SSC2,statistic=mymean.func,R=1000)
```

```
> boot.ci(boot.SSC2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSC2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.7397,  0.8454 )   ( 0.7427,  0.8456 )

Level     Percentile            BCa
95%   ( 0.7379,  0.8408 )   ( 0.7390,  0.8421 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.SSC2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TP1 <- boot(data=stand$TP1,statistic=mymean.func,R=1000)
> boot.ci(boot.TP1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TP1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.4285,  0.6515 )   ( 0.4396,  0.6592 )

Level     Percentile            BCa
95%   ( 0.4211,  0.6407 )   ( 0.4050,  0.6297 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TP1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TP2 <- boot(data=stand$TP2,statistic=mymean.func,R=1000)
> boot.ci(boot.TP2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TP2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.4400,  0.6598 )   ( 0.4523,  0.6681 )

Level     Percentile            BCa
95%   ( 0.4323,  0.6482 )   ( 0.4210,  0.6414 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TP2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TDP1 <- boot(data=stand$TDP1,statistic=mymean.func,R=1000)
 > boot.ci(boot.TDP1,conf=0.95)
 BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
 Based on 1000 bootstrap replicates

 CALL :
 boot.ci(boot.out = boot.TDP1, conf = 0.95)

 Intervals :
 Level      Normal              Basic
```

```
95%   (-0.2553,  0.2117 )   (-0.2478,  0.2299 )

Level     Percentile            BCa
95%   (-0.2865,  0.1912 )   (-0.2856,  0.1918 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TDP1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TDP2 <- boot(data=stand$TDP2,statistic=mymean.func,R=1000)
> boot.ci(boot.TDP2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TDP2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.0692,  0.3627 )   (-0.0465,  0.3912 )

Level     Percentile            BCa
95%   (-0.0963,  0.3413 )   (-0.1339,  0.3133 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TDP2, conf = 0.95) :
  bootstrap variances needed for studentized intervals


> boot.TN1 <- boot(data=stand$TN1,statistic=mymean.func,R=1000)
> boot.ci(boot.TN1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TN1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.2113,  0.4426 )   ( 0.2145,  0.4509 )

Level     Percentile            BCa
95%   ( 0.2038,  0.4402 )   ( 0.1977,  0.4307 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TN1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TN2 <- boot(data=stand$TN2,statistic=mymean.func,R=1000)
> boot.ci(boot.TN2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TN2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.2886,  0.5061 )   ( 0.2926,  0.5056 )

Level     Percentile            BCa
95%   ( 0.2917,  0.5048 )   ( 0.2815,  0.4976 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TN2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
```

```
> boot.TKN1 <- boot(data=stand$TKN1,statistic=mymean.func,R=1000)
> boot.ci(boot.TKN1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TKN1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.3357,  0.5307 )   ( 0.3369,  0.5366 )

Level     Percentile            BCa
95%   ( 0.3327,  0.5323 )   ( 0.3229,  0.5280 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TKN1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TKN2 <- boot(data=stand$TKN2,statistic=mymean.func,R=1000)
> boot.ci(boot.TKN2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TKN2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.3799,  0.5712 )   ( 0.3807,  0.5776 )

Level     Percentile            BCa
95%   ( 0.3688,  0.5658 )   ( 0.3659,  0.5623 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TKN2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.ci(boot.NH31,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NH31, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.1763,  0.4418 )   (-0.1347,  0.4828 )

Level     Percentile            BCa
95%   (-0.2268,  0.3907 )   (-0.3321,  0.3452 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NH31, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NH32 <- boot(data=stand$NH32,statistic=mymean.func,R=1000)
> boot.ci(boot.NH32,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NH32, conf = 0.95)

Intervals :
Level      Normal              Basic
```

```
95%   (-0.0638,  0.5032 )   (-0.0206,  0.5387 )

Level     Percentile            BCa
95%   (-0.0957,  0.4637 )   (-0.2284,  0.4191 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NH32, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NO31<- boot(data=stand$NO31,statistic=mymean.func,R=1000)
> boot.ci(boot.NO31,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NO31, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-1.6872, -0.2675 )   (-1.5447, -0.1889 )

Level     Percentile            BCa
95%   (-1.7509, -0.3951 )   (-2.1262, -0.4928 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NO31, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.NO32 <- boot(data=stand$NO32,statistic=mymean.func,R=1000)
> boot.ci(boot.NO32,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.NO32, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-1.0024, -0.0102 )   (-0.9357,  0.0462 )

Level     Percentile            BCa
95%   (-1.0578, -0.0760 )   (-1.3071, -0.1388 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.NO32, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.DissCu1<- boot(data=stand$DissCu1,statistic=mymean.func,R=1000)
> boot.ci(boot.DissCu1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 999 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissCu1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-5.288,  1.391 )   (-4.176,  2.262 )

Level     Percentile            BCa
95%   (-6.341,  0.097 )   (-8.500, -0.079 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
```

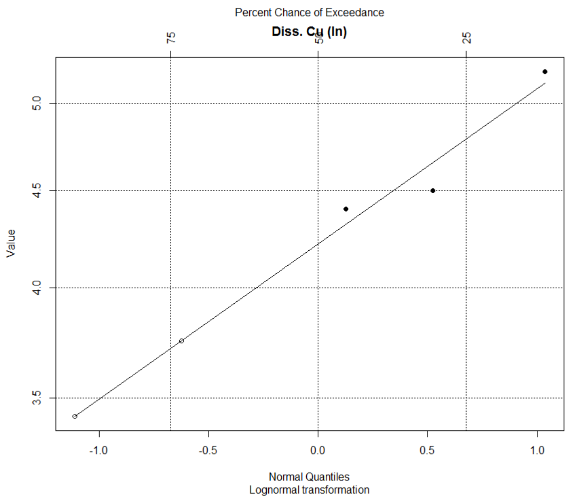
```
In boot.ci(boot.DissCu1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.DissCu2 <- boot(data=stand$DissCu2,statistic=mymean.func,R=1000)
> boot.ci(boot.DissCu2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 993 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissCu2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-5.170,  1.392 )   (-3.909,  1.950 )

Level     Percentile            BCa
95%   (-5.708,  0.150 )   (-8.500,  0.059 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.DissCu2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.DissZn1<- boot(data=stand$DissZn1,statistic=mymean.func,R=1000)
> boot.ci(boot.DissZn1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 995 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissZn1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.2878,  0.9538 )   (-0.1841,  1.0699 )

Level     Percentile            BCa
95%   (-0.4266,  0.8274 )   (-0.7333,  0.8214 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.DissZn1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.DissZn2 <- boot(data=stand$DissZn2,statistic=mymean.func,R=1000)
> boot.ci(boot.DissZn2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 997 bootstrap replicates

CALL :
boot.ci(boot.out = boot.DissZn2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.2115,  0.8536 )   (-0.1516,  0.8645 )

Level     Percentile            BCa
95%   (-0.2515,  0.7646 )   (-0.4615,  0.6868 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.DissZn2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotCu1<- boot(data=stand$TotCu1,statistic=mymean.func,R=1000)
> boot.ci(boot.TotCu1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
```

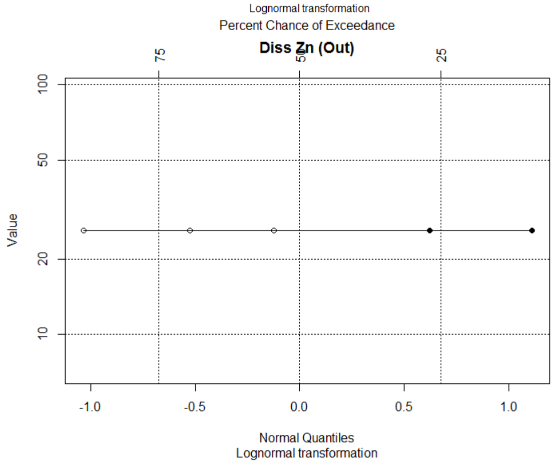
```
boot.ci(boot.out = boot.TotCu1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.5378,  0.3114 )   (-0.4811,  0.3591 )

Level     Percentile            BCa
95%   (-0.5603,  0.2798 )   (-0.7453,  0.2121 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotCu1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotCu2 <- boot(data=stand$TotCu2,statistic=mymean.func,R=1000)
> boot.ci(boot.TotCu2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotCu2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   (-0.4602,  0.3473 )   (-0.4024,  0.3971 )

Level     Percentile            BCa
95%   (-0.5271,  0.2724 )   (-0.6670,  0.2307 )
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotCu2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotZn2 <- boot(data=stand$TotZn2,statistic=mymean.func,R=1000)
> boot.ci(boot.TotZn2,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotZn2, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.4776,  0.6829 )   ( 0.4856,  0.6916 )

Level     Percentile            BCa
95%   ( 0.4679,  0.6738 )   ( 0.4670,  0.6734 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TotZn2, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.TotZn1<- boot(data=stand$TotZn1,statistic=mymean.func,R=1000)
> boot.ci(boot.TotZn1,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TotZn1, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.5319,  0.7881 )   ( 0.5420,  0.7997 )

Level     Percentile            BCa
95%   ( 0.5236,  0.7813 )   ( 0.4742,  0.7593 )
```

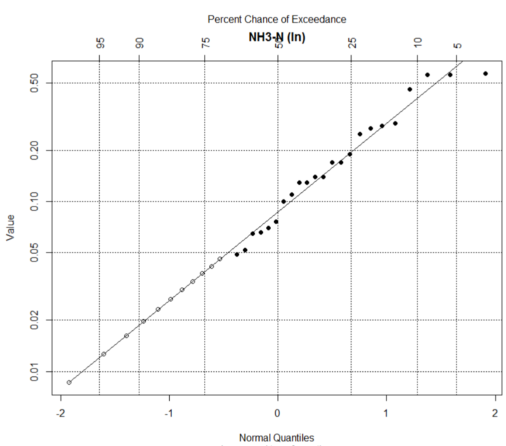
```
Calculations and Intervals on Original Scale
Some BCa intervals may be unstable
Warning message:
In boot.ci(boot.TotZn1, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> stand <- read.csv("C:/Users/Alessandra/Dropbox/R/stand.csv")
>   View(stand)
> boot.TSSOut <- boot(data=stand$TSSOut,statistic=mymean.func,R=1000)
> boot.ci(boot.TSSOut,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.TSSOut, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 3.904,  6.579 )   ( 3.802,  6.486 )

Level     Percentile            BCa
95%   ( 4.045,  6.729 )   ( 4.093,  6.891 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.TSSOut, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> stand <- read.csv("C:/Users/Alessandra/Dropbox/R/stand.csv")
>   View(stand)
> boot.SSCOut <- boot(data=stand$SSCOut,statistic=mymean.func,R=1000)
> boot.ci(boot.SSCOut,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.SSCOut, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 2.758,  5.024 )   ( 2.717,  4.894 )

Level     Percentile            BCa
95%   ( 2.942,  5.119 )   ( 3.024,  5.325 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.SSCOut, conf = 0.95) :
  bootstrap variances needed for studentized intervals
```

```
> boot.tapeEMC <- boot(data=tpstand$emc.tp.tape,statistic=mymean.func,R
=1000)
> boot.ci(boot.tapeEMC,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.tapeEMC, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.5691,  0.7522 )   ( 0.5754,  0.7516 )

Level     Percentile            BCa
95%   ( 0.5713,  0.7475 )   ( 0.5507,  0.7409 )
Calculations and Intervals on Original Scale
```

```
Warning message:
In boot.ci(boot.tapeEMC, conf = 0.95) :
  bootstrap variances needed for studentized intervals
> boot.tapeLOAD <- boot(data=tpstand$load.tp.tape,statistic=mymean.func
,R=1000)
> boot.ci(boot.tapeLOAD,conf=0.95)
BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
Based on 1000 bootstrap replicates

CALL :
boot.ci(boot.out = boot.tapeLOAD, conf = 0.95)

Intervals :
Level      Normal              Basic
95%   ( 0.5566,  0.7578 )   ( 0.5618,  0.7644 )

Level     Percentile            BCa
95%   ( 0.5514,  0.7540 )   ( 0.5447,  0.7506 )
Calculations and Intervals on Original Scale
Warning message:
In boot.ci(boot.tapeLOAD, conf = 0.95) :
  bootstrap variances needed for studentized intervals
```


Percent Chance of Exceedance
Diss. Cu (In)
Value
Normal Quantiles
Lognormal transformation


Percent Chance of Exceedance
Diss Zn (Out)
Value
Normal Quantiles
Lognormal transformation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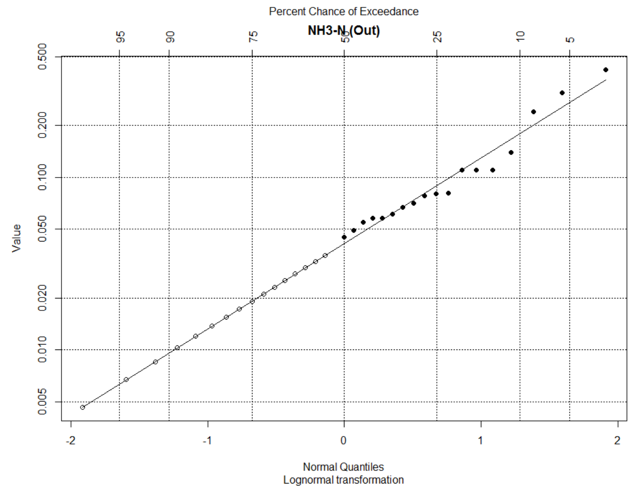
NH3-N (In)
Value
Normal Quantiles
Lognormal transformation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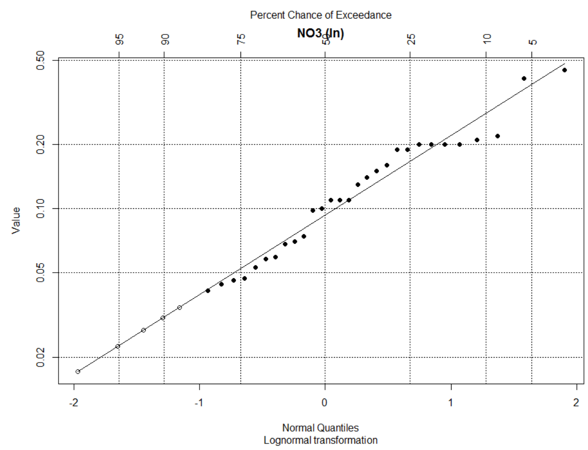
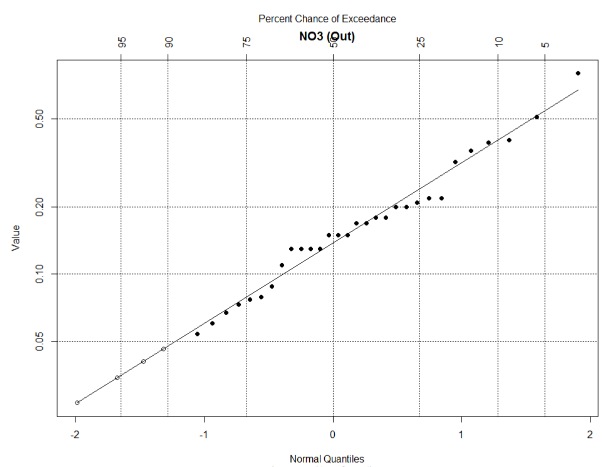
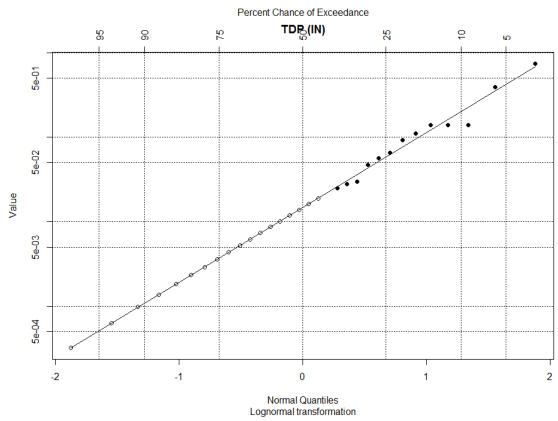
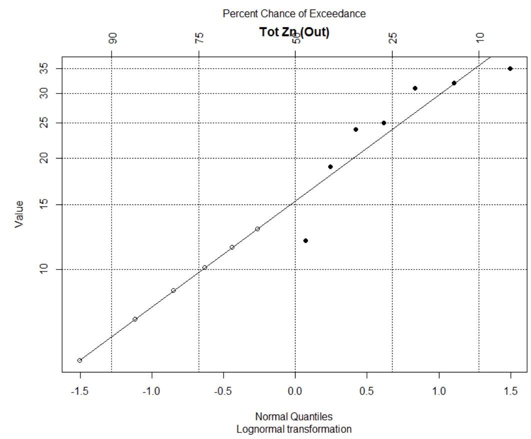
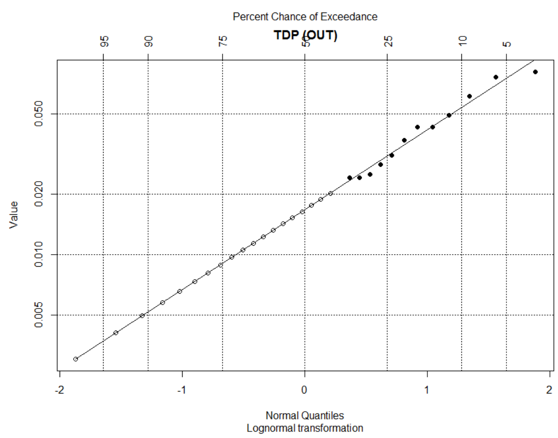
Lognormal transformation

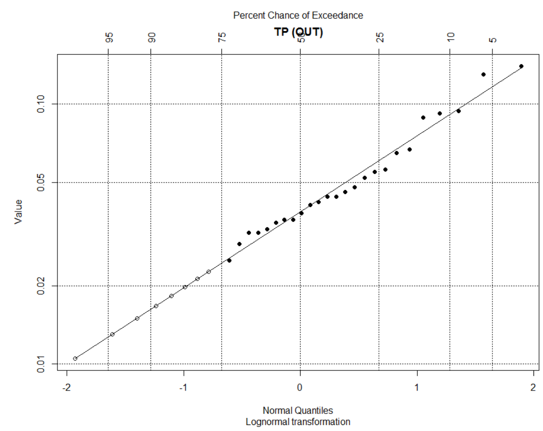

Percent Chance of Exceedance
NO3 (In)
Value
Normal Quantiles
Lognormal transformation

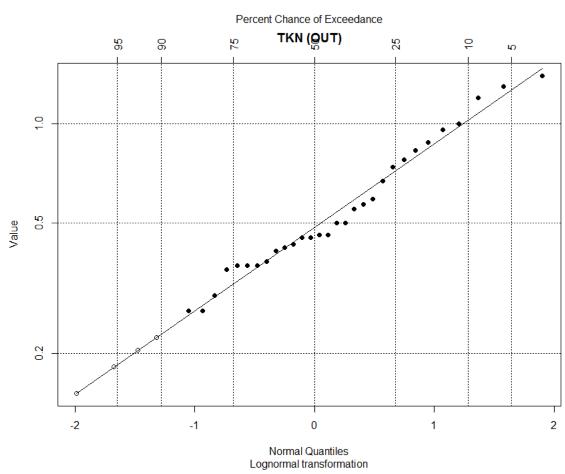

Percent Chance of Exceedance
NO3 (Out)
Value
Normal Quantiles
Lognormal transformation


Percent Chance of Exceedance
TDP (IN)
Value
Normal Quantiles
Lognormal transformation


Percent Chance of Exceedance
Tot Zn (Out)
Value
Normal Quantiles
Lognormal transformation


Percent Chance of Exceedance
TDP (OUT)
Value
Normal Quantiles
Lognormal transformation

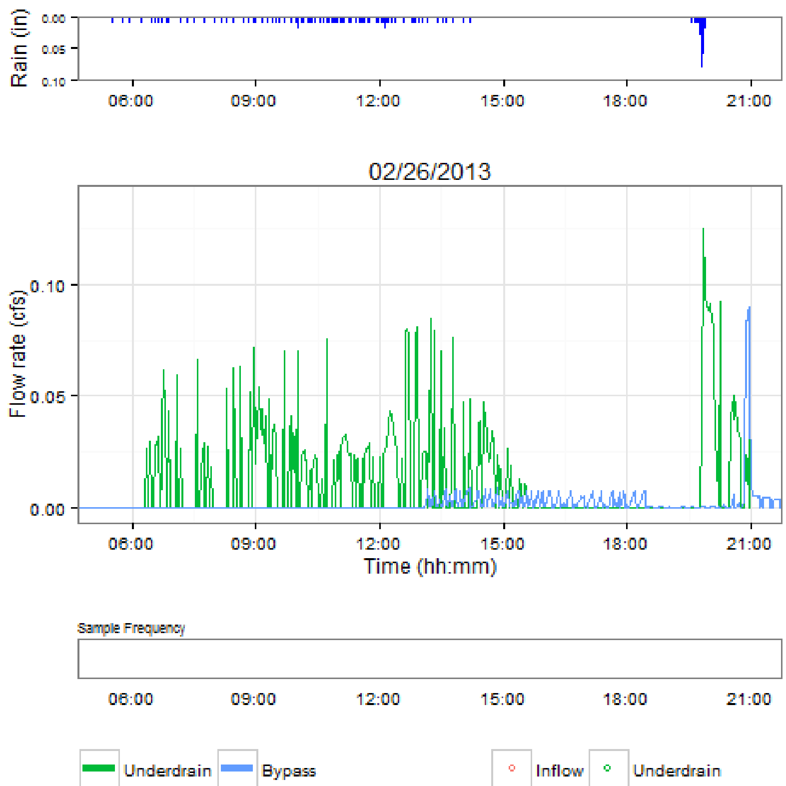

Percent Chance of Exceedance
TP (OUT)
Value
Normal Quantiles
Lognormal transformation


Percent Chance of Exceedance
TKN (OUT)
Value
Normal Quantiles
Lognormal transformation

Individual Storm Hydrographs Sampled for Water Quality Parameters

Notes on hydrograph data set:

- Plots are of underdrain and bypass flow time series only. Inflow often had inundation that rendered the visualization unusable, at which point peak flows and volumes were estimated using engineering methods (see report). Inflow aliquot sampling frequency is shown in the "Sample Frequency" time series plot for comparison to underdrain.
- Time-stamped aliquot data (circle points in graphs below) are available for storms sampled after August 2013.
- EMC values in bold font were below the minimum detection limit reported by the laboratory. The numbers reported in the EMC chart are ½ of the minimum detection limit.
- Because total nitrogen (TN) is the sum of Total Kjehldahl Nitrogen and nitrate/nitrate-nitrogen, in some cases one of these analytes were below detection limits. In no case were both TKN and $NO_{2/3}$-N below detection limit for the same storm. When one was below detection limit, half of the minimum detection limit (MDL) was taken as the value, and it was added to the complimentary analyte. In such cases, the TN value will be shown in italics in the appendices that follow.
- The average underdrain flow rate was determined by dividing the total underdrain volume by the duration of drainage. Volumetric flux (or flow rate divided by area of media) was then calculated in inches per hour.

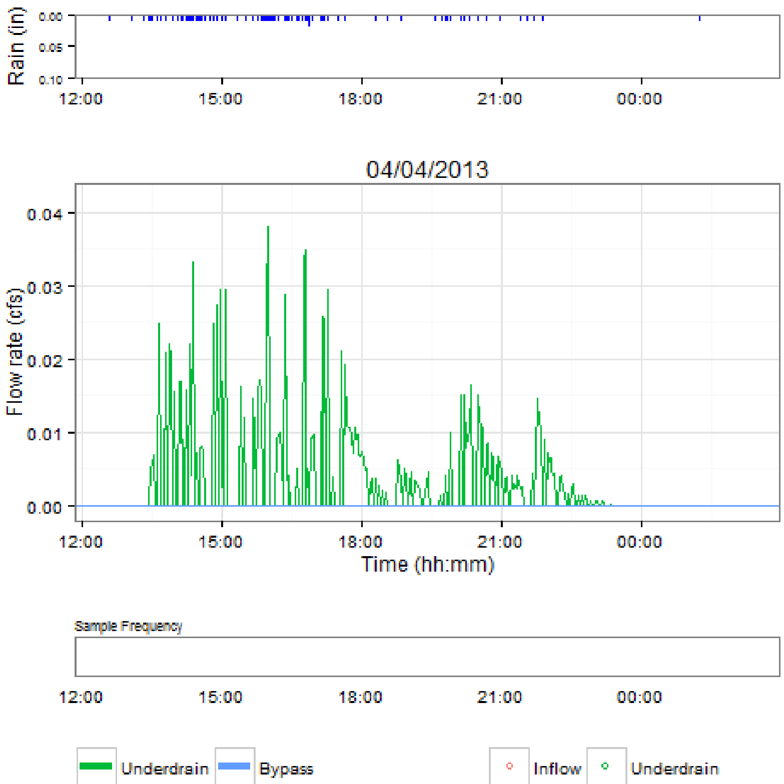


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.12		
Rainfall duration (h)	14.4		
Max 5-min intensity (in/h)	0.22		
Mean intensity (in/h)	0.08		
Antecedent dry period (h)	62		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	50.0		4.40		0.91
SSC	mg L^{-1}	62.25		2.90		0.95
TP	mg L^{-1}	0.074		**0.012**	0.024	0.84
Ortho-P	mg L^{-1}	0.120		**0.0275**	0.055	0.77
TDP	mg L^{-1}	0.74		**0.012**	0.460	0.98
TKN	mg L^{-1}	1.20		0.460		0.62
$NH_{3/4}$-N	mg L^{-1}	0.140		0.061		0.56
TN	mg L^{-1}	1.247		0.539		0.57
$NO_{2/3}$-N	mg L^{-1}	0.047		0.079		-0.68
Cu	µg L^{-1}	7.80		3.20		0.59
Zn	µg L^{-1}	66.0		**5.0**	10.0	0.92

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1095.5	Y[a]	846.9	0.443	-	-	Y
UNDERDRAIN	751.4	N	741.4	0.124	0.014	25.1	Y
BYPASS	122.1	N	122.1	0.001	-	-	-

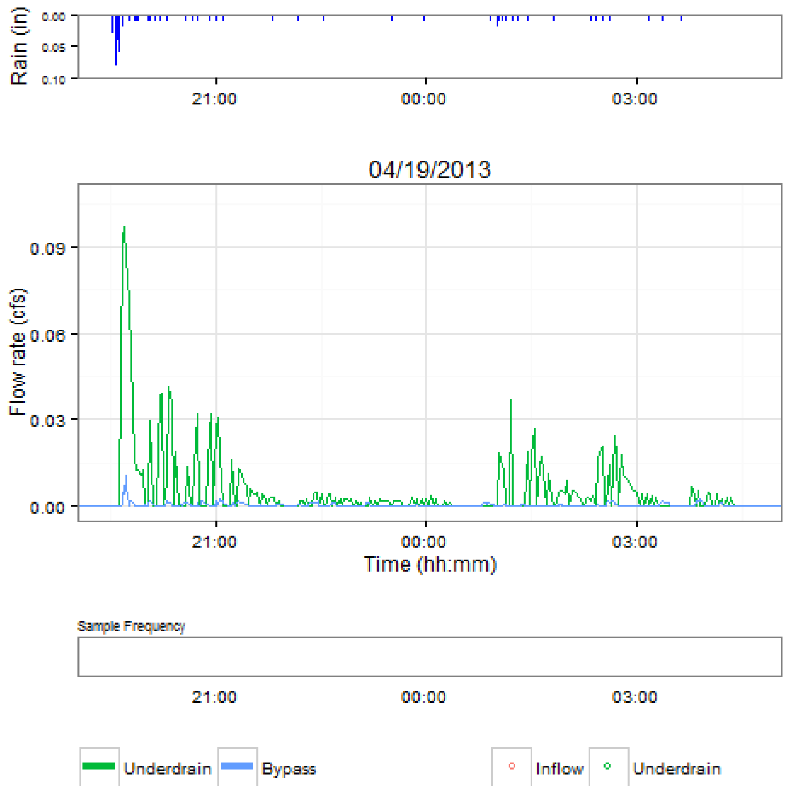
[a]Backwater in weir observed.



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.81		
Rainfall duration (h)	12.7		
Max 5-min intensity (in/h)	0.19		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	76		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	37.0		2.80		0.92
SSC	mg L^{-1}	57.34		1.510		0.97
TP	mg L^{-1}	0.03		**0.012**	0.024	0.60
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.030		**0.012**	0.024	0.60
TKN	mg L^{-1}	0.710		0.270		0.62
$NH_{3/4}$-N	mg L^{-1}	0.290		0.11		0.62
TN	mg L^{-1}	0.87		0.44		0.49
$NO_{2/3}$-N	mg L^{-1}	0.160		0.17		-0.06
Cu	µg L^{-1}	7.3		4.9		0.33
Zn	µg L^{-1}	35.0		**5.0**	10.0	0.86

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	198.6	N	198.6	0.086	-	-	Y
UNDERDRAIN	172.0	N	172.0	0.038	0.005	9.05	Y
BYPASS	0.0	-	0.0	0.000	-	-	-

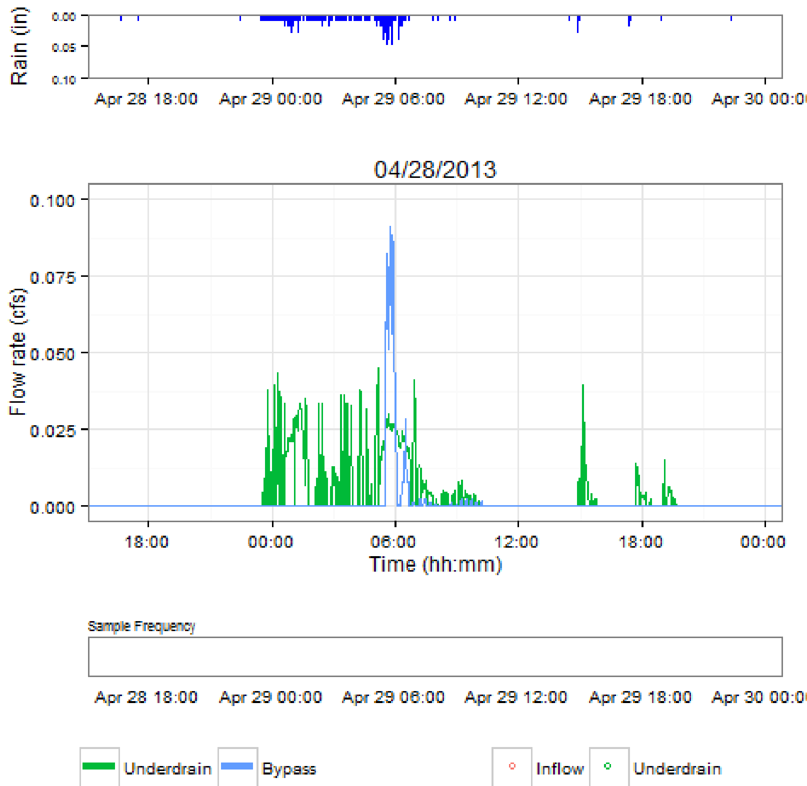


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.60		
Rainfall duration (h)	8.1		
Max 5-min intensity (in/h)	0.32		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	180		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	51.0		6.8		0.87
SSC	mg L^{-1}	48.94		6.44		0.87
TP	mg L^{-1}	0.11		0.092		0.16
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.0470		0.049		-0.04
TKN	mg L^{-1}	1.30		0.960		0.26
$NH_{3/4}$-N	mg L^{-1}	0.066		0.058		0.12
TN	mg L^{-1}	1.41		1.14		0.19
$NO_{2/3}$-N	mg L^{-1}	0.11		0.18		-0.64
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	590.8	Y[a]	393.7	0.101	-	-	Y
UNDERDRAIN	81.0	Y[b]	383.8	0.097	0.011	19.2	Y
BYPASS	9.9	N	9.9	0.004	-	-	-

[a]Backwater in weir observed.
[b]Weir readings low.

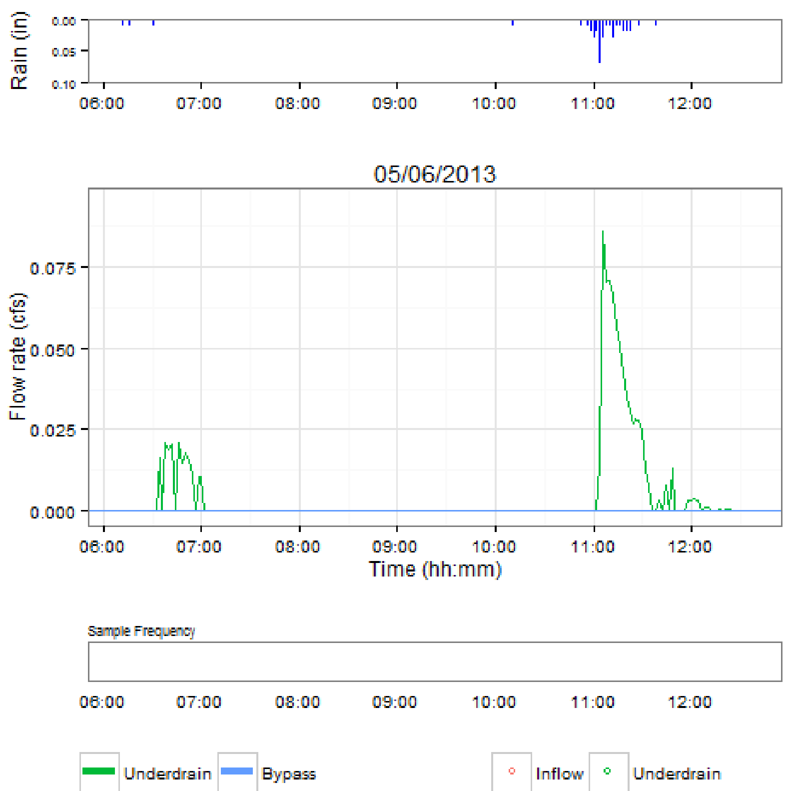


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.95		
Rainfall duration (h)	29.7		
Max 5-min intensity (in/h)	0.58		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	205		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	20.0		4.0		0.80
SSC	mg L^{-1}	12.3		3.54		0.71
TP	mg L^{-1}	0.042		0.041		0.02
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.0120**	0.024	NA
TKN	mg L^{-1}	0.34		0.360		-0.06
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	*0.3525*		0.51		-0.45
$NO_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	0.15		-11.00
Cu	µg L^{-1}	3.3		4.1		-0.24
Zn	µg L^{-1}	5.0		5.0		0.00

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	5627.1	Y[a]	1590.5	0.286	-	-	Y
UNDERDRAIN	1034.2	N	1034.2	0.088	0.013	23.5	Y
BYPASS	143.0	N	143.0	0.027	-	-	-

[a]Backwater in weir observed.

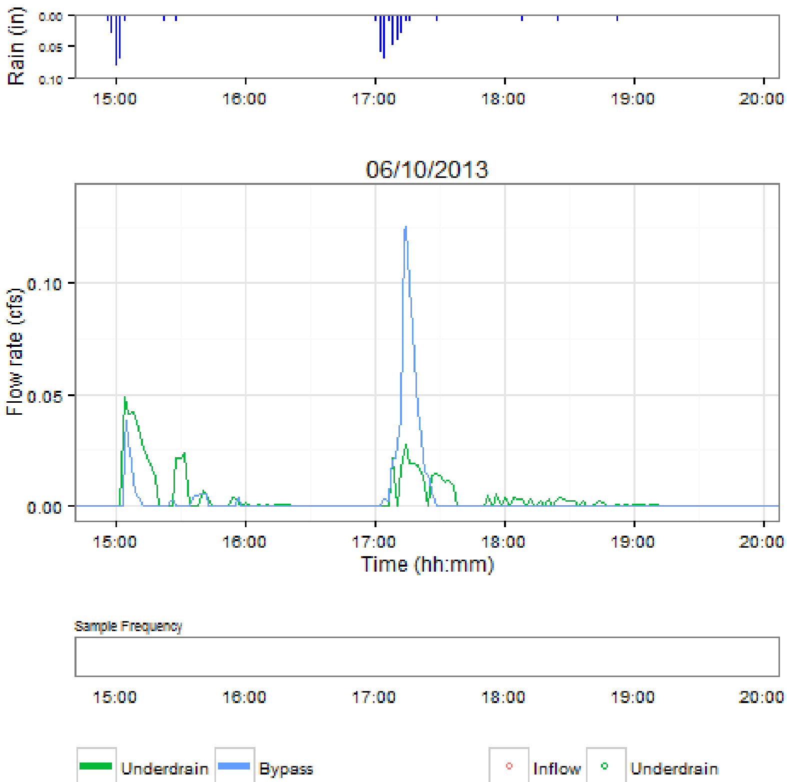


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.38		
Rainfall duration (h)	5.4		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	152		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	68.0		5.20		0.92
SSC	mg L^{-1}					
TP	mg L^{-1}	0.0610		0.044		0.28
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.025		**0.012**	0.024	0.52
TKN	mg L^{-1}	0.87		0.55		0.37
$NH_{3/4}$-N	mg L^{-1}	0.27		0.24		0.11
TN	mg L^{-1}	0.938		0.68		0.28
$NO_{2/3}$-N	mg L^{-1}	0.068		0.13		-0.91
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	519.1	Y[a]	213.0	0.315	-	-	Y
UNDERDRAIN	161.9	N	161.9	0.086	0.007	13.5	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Backwater in weir observed.

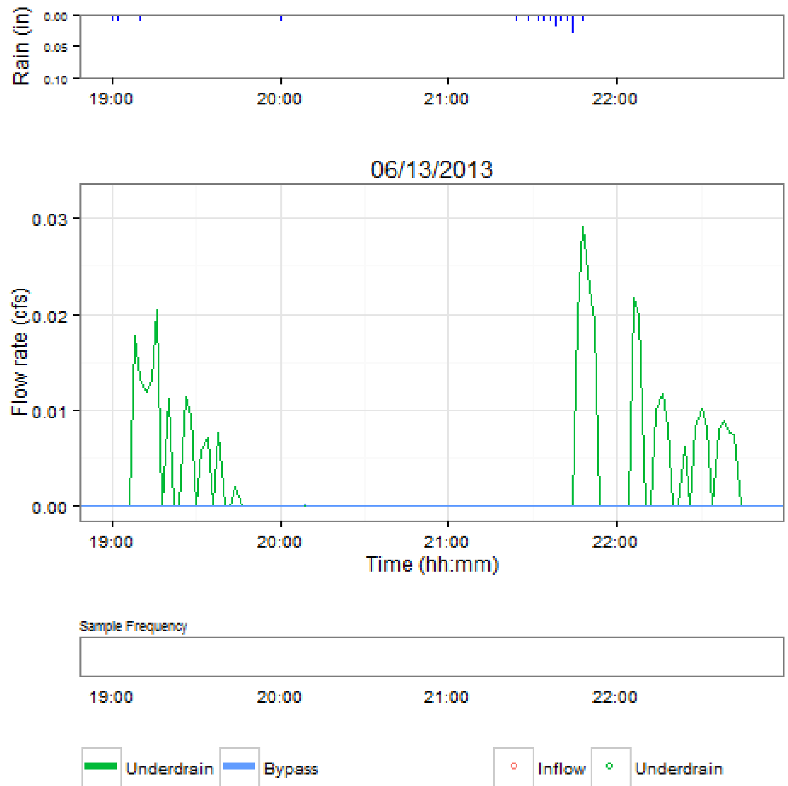


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.55		
Rainfall duration (h)	3.9		
Max 5-min intensity (in/h)	0.30		
Mean intensity (in/h)	0.14		
Antecedent dry period (h)	19.9		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	32.0		4.0		0.88
SSC	mg L^{-1}	43.38		3.4		0.92
TP	mg L^{-1}	0.034		0.055		-0.62
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.14		**0.012**	0.024	0.91
TKN	mg L^{-1}	0.62		0.50		0.19
$NH_{3/4}$-N	mg L^{-1}	0.052		**0.0225**	0.045	0.57
TN	mg L^{-1}	0.73		0.890		-0.22
$NO_{2/3}$-N	mg L^{-1}	0.11		0.390		-2.55
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	2677.2	Y[a]	351.6	0.472	-	-	Y
UNDERDRAIN	73.28	Y[b]	281.7	0.027	0.018	33.1	Y
BYPASS	70.0	N	70.0	0.125	-	-	-

[a]Backwater in weir observed.
[b]Weir readings low

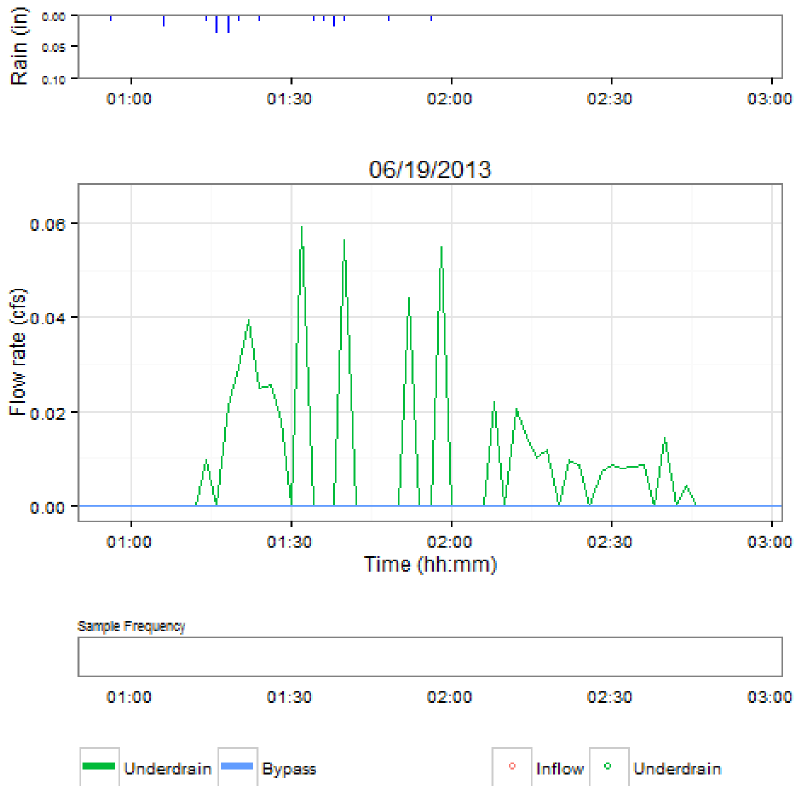


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.17		
Rainfall duration (h)	2.8		
Max 5-min intensity (in/h)	0.12		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	72.1		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.21		0.0650		0.69
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}					
TKN	mg L^{-1}	2.20		1.20		0.45
$NH_{3/4}$-N	mg L^{-1}	0.28		**0.0225**	0.045	0.92
TN	mg L^{-1}	2.39		1.60		0.33
$NO_{2/3}$-N	mg L^{-1}	0.19		0.40		-1.11
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	25.2	Y[a]	61.9	0.038	-	-	Y
UNDERDRAIN	43.0	N	43.0	0.034	0.003	6.14	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Weir readings low

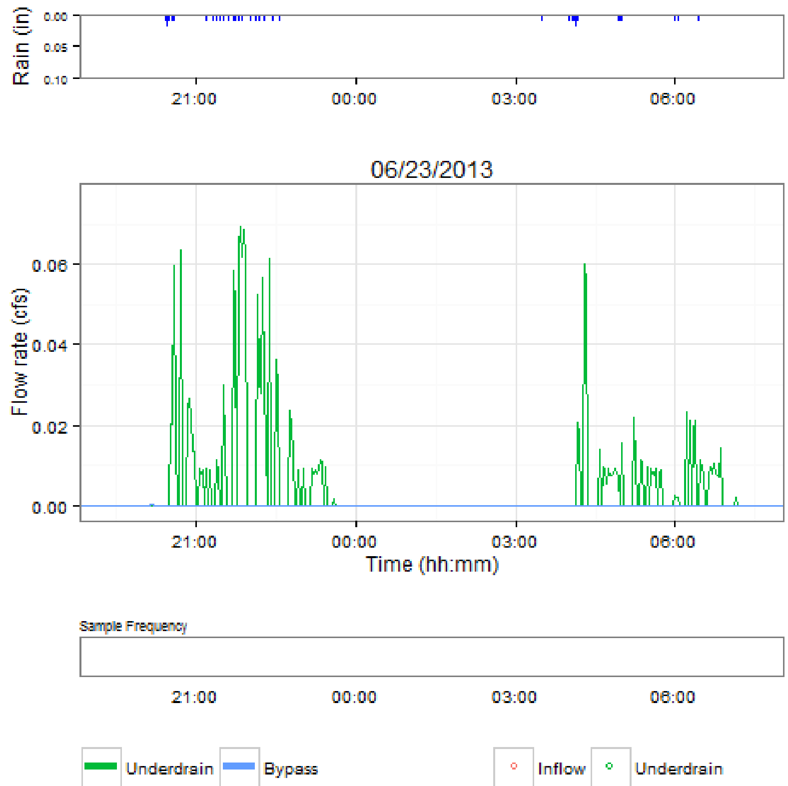


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.19		
Rainfall duration (h)	1.0		
Max 5-min intensity (in/h)	0.18		
Mean intensity (in/h)	0.19		
Antecedent dry period (h)	25.0		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.220		0.035		0.84
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}					
TKN	mg L^{-1}	2.40		0.67		0.72
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	2.51		0.89		0.58
$NO_{2/3}$-N	mg L^{-1}	0.11		0.22		-1.0
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	37.5	Y[a]	74.5	0.186	-	-	Y
UNDERDRAIN	64.9	N	64.9	0.059	0.012	21.6	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Weir readings low

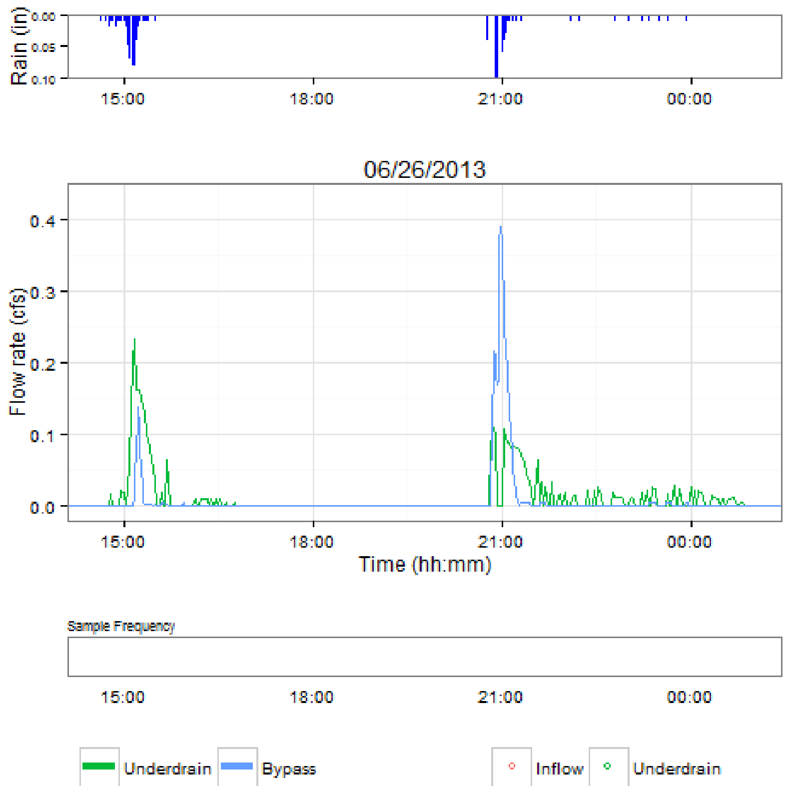


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.35		
Rainfall duration (h)	10		
Max 5-min intensity (in/h)	0.12		
Mean intensity (in/h)	0.035		
Antecedent dry period (h)	16.9		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}					
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}					
TKN	mg L^{-1}	1.10		**0.13**	0.26	0.88
$NH_{3/4}$-N	mg L^{-1}	0.46		**0.0225**	0.045	0.95
TN	mg L^{-1}	1.55		0.26		0.83
$NO_{2/3}$-N	mg L^{-1}	0.45		0.13		0.71
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	50.6	Y[a]	189.5	0.100	-	-	Y
UNDERDRAIN	221.5	Y[b]	189.5	0.069	0.003	4.9	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Weir readings low
[a]Weir readings high

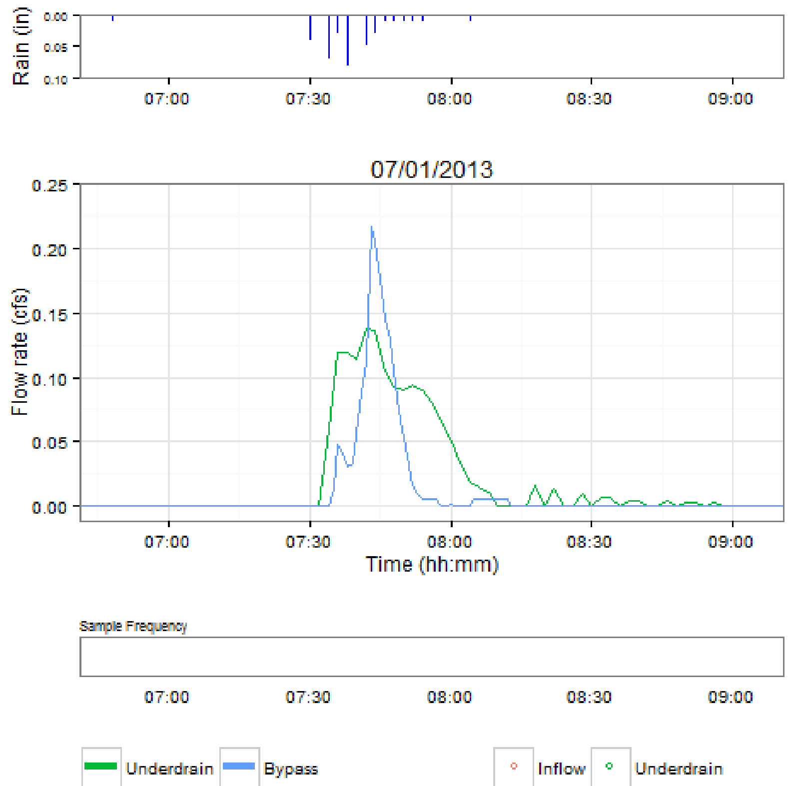


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.71		
Rainfall duration (h)	9.3		
Max 5-min intensity (in/h)	1.08		
Mean intensity (in/h)	0.18		
Antecedent dry period (h)	20.9		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	66.0		6.8		0.90
SSC	mg L^{-1}	95.77		7.03		0.93
TP	mg L^{-1}	0.034		0.012		0.65
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.56		**0.13**	0.26	0.77
$NH_{3/4}$-N	mg L^{-1}	0.14		**0.0225**	0.045	0.84
TN	mg L^{-1}	0.77		0.31		0.60
$NO_{2/3}$-N	mg L^{-1}	0.21		*0.18*		0.14
Cu	µg L^{-1}	**1.0**	2.0	2.5		-1.50
Zn	µg L^{-1}	19.0		**5.0**	10	0.74

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	3006.2	Y[a]	1374.4	1.344	-	-	Y
UNDERDRAIN	477.3	Y[b]	1052.6	0.296	0.029	51.4	Y
BYPASS	321.8	N	321.8	0.107	-	-	-

[a]Backwater in weir observed
[a]Weir readings low

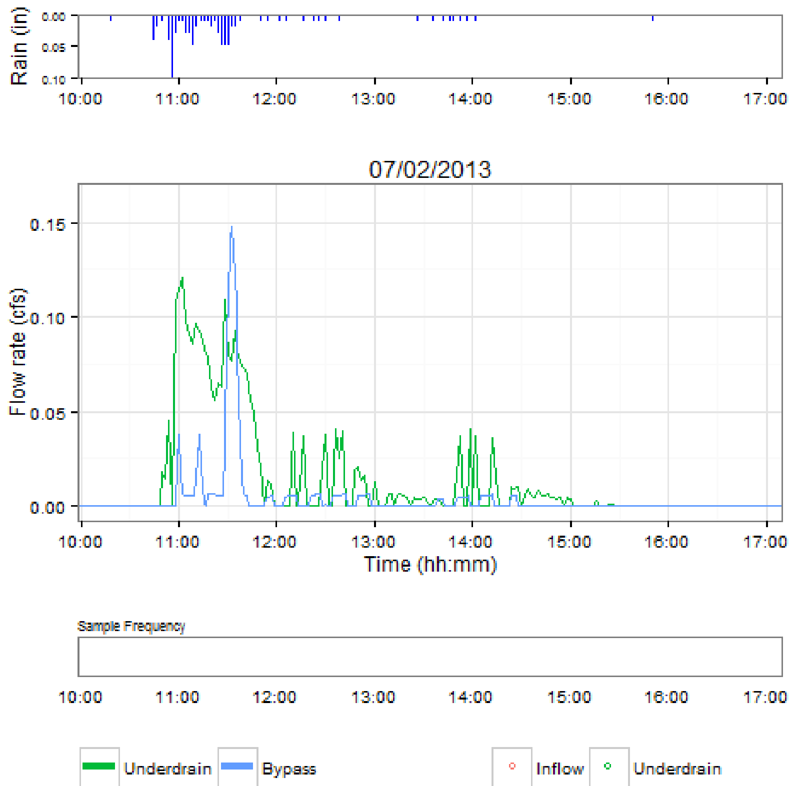


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.6		
Rainfall duration (h)	1.27		
Max 5-min intensity (in/h)	0.58		
Mean intensity (in/h)	0.47		
Antecedent dry period (h)	9.3		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	30.0		6.8		0.77
SSC	mg L^{-1}	39.1		4.27		0.89
TP	mg L^{-1}	0.045		0.033		0.27
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.63		0.46		0.27
$NH_{3/4}$-N	mg L^{-1}	0.17		0.081		0.52
TN	mg L^{-1}	0.674		1.0		-0.48
$NO_{2/3}$-N	mg L^{-1}	0.044		0.54		-0.23
Cu	µg L^{-1}	3.0		3.2		-0.07
Zn	µg L^{-1}	22.0		**5.0**	10.0	0.77

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1639.8	Y[a]	393.7	0.643	-	-	Y
UNDERDRAIN	368.0	N	368.0	0.137	0.068	122.7	Y
BYPASS	98.9	N	98.9	0.205	-	-	-

[a]Backwater in weir observed

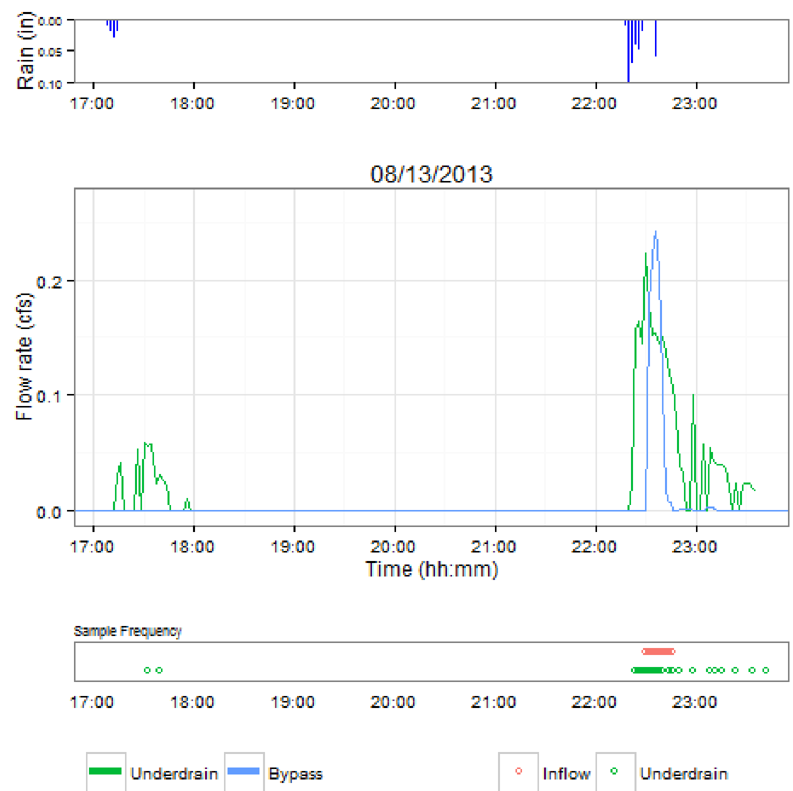


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.87		
Rainfall duration (h)	5.53		
Max 5-min intensity (in/h)	0.68		
Mean intensity (in/h)	0.16		
Antecedent dry period (h)	11.4		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	30.0		2.9		0.90
SSC	mg L^{-1}	19.51		2.3		0.88
TP	mg L^{-1}	0.045		0.038		0.16
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.51		0.37		0.27
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	0.584		0.43		0.26
$NO_{2/3}$-N	mg L^{-1}	0.0740		0.06		0.19
Cu	µg L^{-1}	2.1		2.1		0
Zn	µg L^{-1}	18.0		**5.0**	10.	0.72

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	2094.7	Y[a]	626.5	0.443	-	-	Y
UNDERDRAIN	478.1	N	478.1	0.077	0.028	51.2	Y
BYPASS	103.9	N	103.9	0.147	-	-	-

[a]Backwater in weir observed

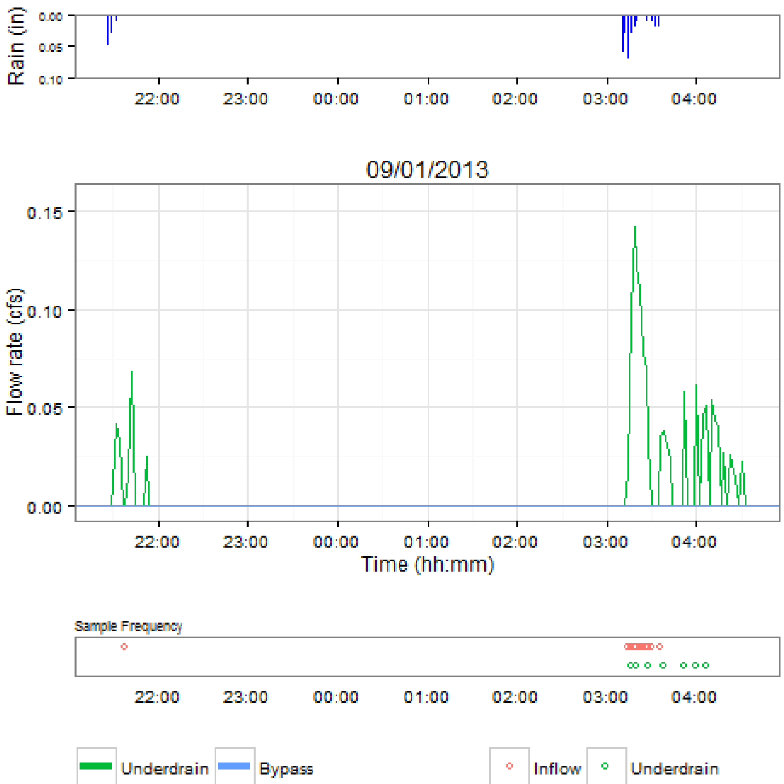


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.78		
Rainfall duration (h)	5.5		
Max 5-min intensity (in/h)	0.64		
Mean intensity (in/h)	0.14		
Antecedent dry period (h)	13.6		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	190.0		2.80		0.99
SSC	mg L^{-1}	226.4		3.33		0.99
TP	mg L^{-1}	0.21		0.067		0.68
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.093		**0.012**	0.024	0.87
TKN	mg L^{-1}	1.2		0.42		0.65
$NH_{3/4}$-N	mg L^{-1}	0.10		0.071		0.29
TN	mg L^{-1}	1.39		0.62		0.55
$NO_{2/3}$-N	mg L^{-1}	0.19		0.2		-0.05
Cu	µg L^{-1}	7.6		5.4		0.29
Zn	µg L^{-1}	82.0		19.0		0.77

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1365.9	Y[a]	548.1	0.844	-	-	Y
UNDERDRAIN	371.0	N	371.0	0.154	0.088	159.0	Y
BYPASS	118.7	N	118.7	0.241	-	-	-

[a]Backwater in weir observed

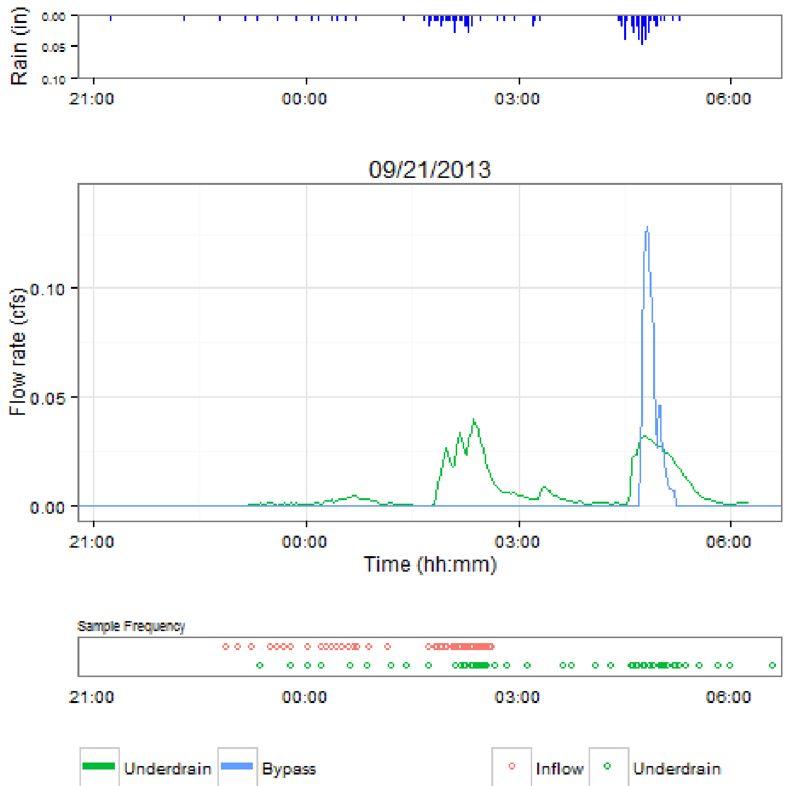


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.37		
Rainfall duration (h)	6.1		
Max 5-min intensity (in/h)	0.24		
Mean intensity (in/h)	0.06		
Antecedent dry period (h)	264		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	220		8.0		0.96
SSC	mg L^{-1}	353.17		12.09		0.97
TP	mg L^{-1}	0.10		0.012		0.88
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.10		0.83		0.25
$NH_{3/4}$-N	mg L^{-1}	0.13		0.14		-0.08
TN	mg L^{-1}	1.25		1.05		0.16
$NO_{2/3}$-N	mg L^{-1}	0.15		0.22		-0.47
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	515.3	Y[a]	205.1	0.372	-	-	Y
UNDERDRAIN	179.6	N	179.6	0.142	0.007	11.7	Y
BYPASS	0.0	N	0.0	0.000	-	-	-

[a]Backwater in weir observed

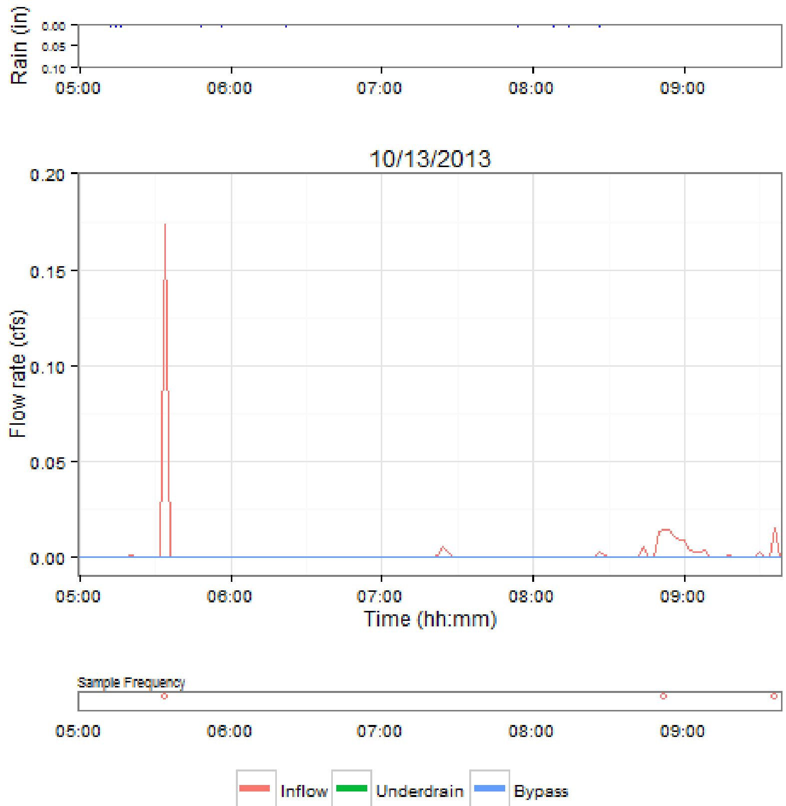


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.95		
Rainfall duration (h)	8.0		
Max 5-min intensity (in/h)	0.43		
Mean intensity (in/h)	0.12		
Antecedent dry period (h)	128		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	$mg\ L^{-1}$	40.0		3.6		0.91
SSC	$mg\ L^{-1}$	79.09		3.09		0.96
TP	$mg\ L^{-1}$	0.04		**0.012**	0.024	0.70
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	$mg\ L^{-1}$	**0.0120**	0.024	0.028		-1.33
TKN	$mg\ L^{-1}$	0.90		0.041		0.54
$NH_{3/4}$-N	$mg\ L^{-1}$	0.13		0.058		0.55
TN	$mg\ L^{-1}$	1.1		0.151		0.86
$NO_{2/3}$-N	$mg\ L^{-1}$	0.20		0.11		0.45
Cu	$\mu g\ L^{-1}$	6.7		4.8		0.28
Zn	$\mu g\ L^{-1}$	49.0		12.0		0.76

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	3220.8	Y[a]	696.7	0.286	-	-	Y
UNDERDRAIN	197.0	Y[b]	603.0	0.032	0.024	43.1	Y
BYPASS	93.7	N	93.7	0.124	-	-	-

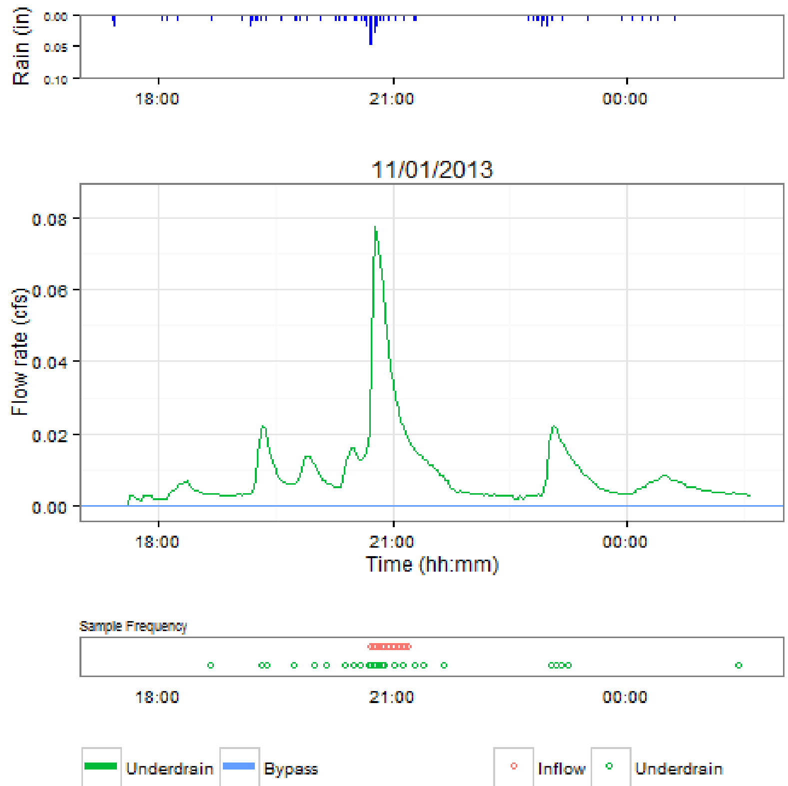
[a]Backwater in weir observed
[b]Weir readings low



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.1		Underdrain hydrograph not available, sample filled 12 bottles
Rainfall duration (h)	3.2		
Max 5-min intensity (in/h)	0.05		
Mean intensity (in/h)	0.04		
Antecedent dry period (h)	108		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	55.0		1.6		0.97
SSC	mg L^{-1}					
TP	mg L^{-1}	0.066		0.032		0.52
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.80		0.45		0.44
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	0.93		0.4625		0.50
$NO_{2/3}$-N	mg L^{-1}	0.13		**0.0125**	0.025	0.90
Cu	µg L^{-1}					
Zn	µg L^{-1}					

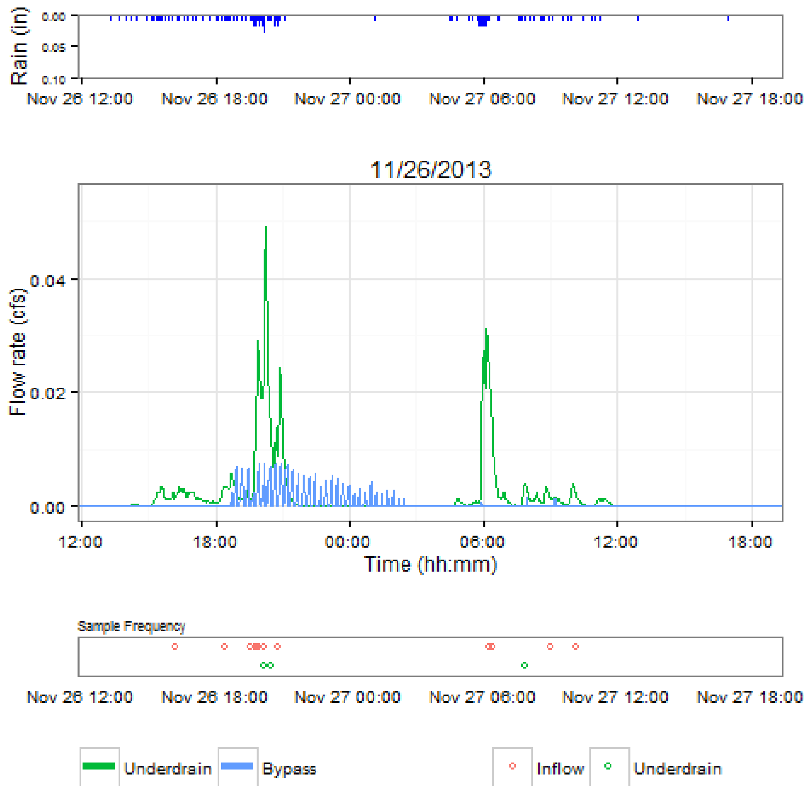
Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	36.5	N	36.5	0.174	-	-	Y
UNDERDRAIN	-	-	-	-	-	-	Y
BYPASS	0.0	N	0.0	0.0	-	-	-



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.71		
Rainfall duration (h)	7.2		
Max 5-min intensity (in/h)	0.30		
Mean intensity (in/h)	0.10		
Antecedent dry period (h)	465		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	94.0		4.0		0.96
SSC	mg L^{-1}	71.84		3.05		0.96
TP	mg L^{-1}	0.052		0.052		0.0
Ortho-P	mg L^{-1}	0.083		**0.0275**	0.055	0.67
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.39		0.57		-0.46
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.11		-3.89
TN	mg L^{-1}	0.4025		0.643		-0.60
$NO_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	0.0730		-4.84
Cu	µg L^{-1}	3.5		11.0		-2.14
Zn	µg L^{-1}	37.0		25.0		0.32

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	368.2	N	368.2	0.526	-	-	Y
UNDERDRAIN	335.1	N	335.1	0.077	0.012	21.0	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

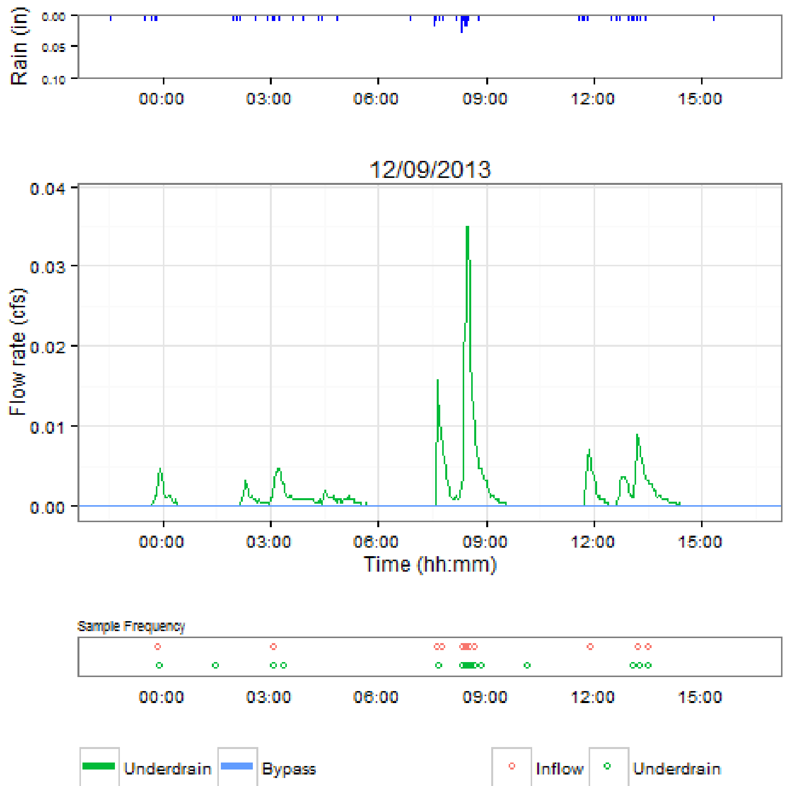


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.24		
Rainfall duration (h)	27.7		
Max 5-min intensity (in/h)	0.29		
Mean intensity (in/h)	0.04		
Antecedent dry period (h)	462		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.20		0.036		0.82
Ortho-P	mg L^{-1}					
TDP	mg L^{-1}	0.028		0.0430		-0.54
TKN	mg L^{-1}	2.0		0.30		0.85
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	**0.0225**	0.045	NA
TN	mg L^{-1}	*2.0125*		*0.3125*		0.84
$NO_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	369.3	N	369.3	0.089	-	-	Y
UNDERDRAIN	197.2	Y[a]	324.3	0.049	0.004	7.72	Y
BYPASS	45.0	N	45.0	0.002	-	-	-

[a]Weir readings low

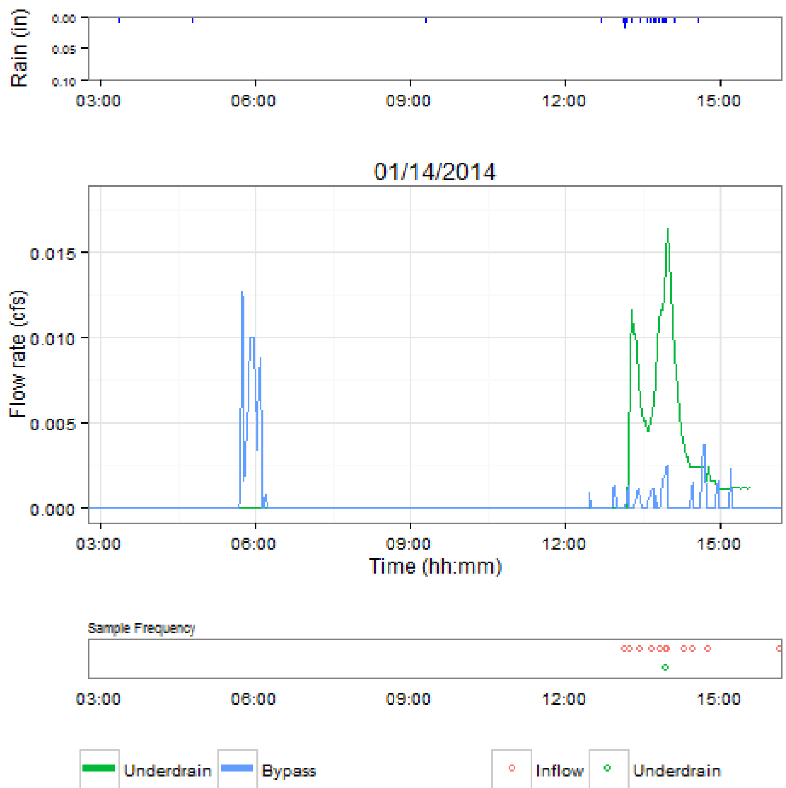


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.53		
Rainfall duration (h)	16.8		
Max 5-min intensity (in/h)	0.18		
Mean intensity (in/h)	0.03		
Antecedent dry period (h)	25.6		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	$mg\ L^{-1}$	270		9.2		0.97
SSC	$mg\ L^{-1}$					
TP	$mg\ L^{-1}$	0.12		0.032		0.73
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	
TDP	$mg\ L^{-1}$	**0.0120**	0.024	0.031		-1.58
TKN	$mg\ L^{-1}$	0.97		0.27		0.72
$NH_{3/4}$-N	$mg\ L^{-1}$	0.07		**0.0225**	0.045	0.68
TN	$mg\ L^{-1}$					
$NO_{2/3}$-N	$mg\ L^{-1}$	0.098		0.15		-0.53
Cu	$\mu g\ L^{-1}$	14		10		0.29
Zn	$\mu g\ L^{-1}$	180		32		0.82

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	50.9	Y[a]	334.9	0.043	-	-	Y
UNDERDRAIN	85.0	Y[a]	334.9	0.035	0.006	11.2	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

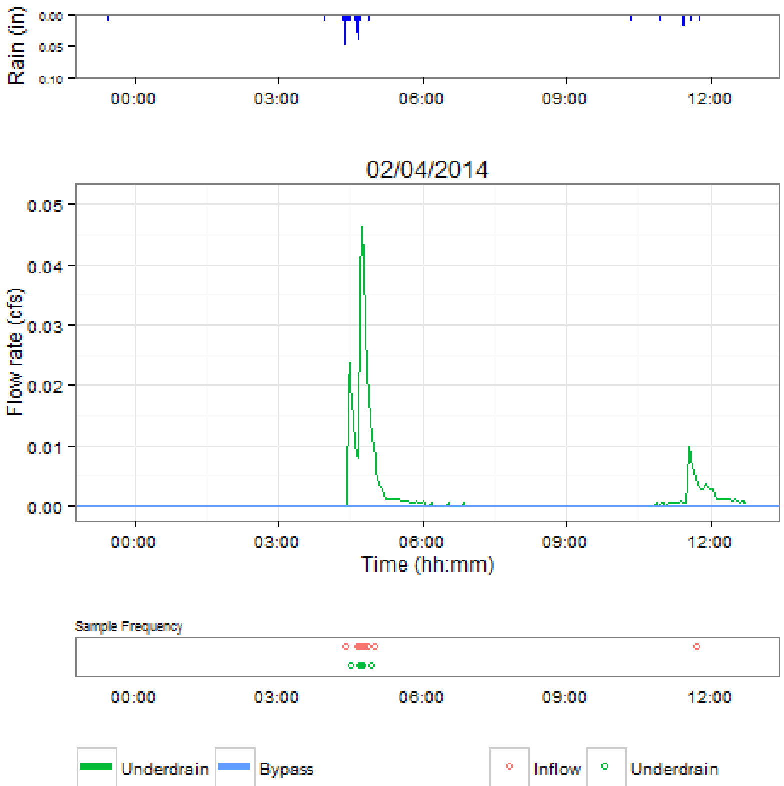
[a]Weir readings low



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.2		
Rainfall duration (h)	11.2		
Max 5-min intensity (in/h)	0.14		
Mean intensity (in/h)	0.02		
Antecedent dry period (h)	50.5		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}					
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.048		0.60
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.20		0.37		0.69
$NH_{3/4}$-N	mg L^{-1}	0.049		**0.0225**	0.045	0.54
TN	mg L^{-1}	1.27		0.437		0.66
$NO_{2/3}$-N	mg L^{-1}	0.07		0.0670		0.04
Cu	µg L^{-1}					
Zn	µg L^{-1}					

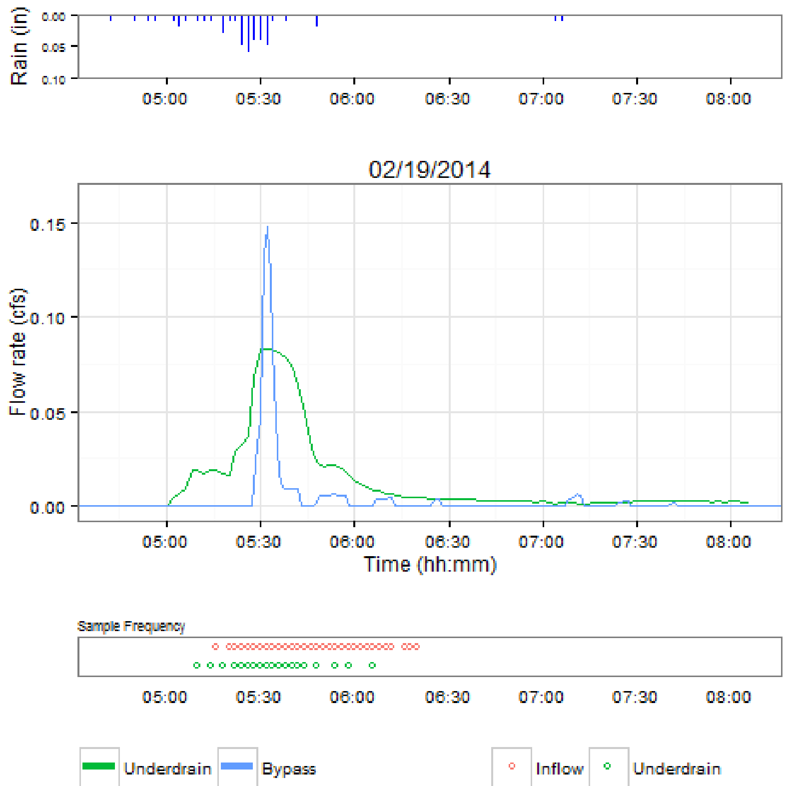
Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	84.5	N	84.5	0.047	-	-	Y
UNDERDRAIN	50.4	N	50.4	0.015	0.007	12.6	Y
BYPASS	4.0	N	4.0	0.002	-	-	-



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.29		
Rainfall duration (h)	12.3		
Max 5-min intensity (in/h)	0.2		
Mean intensity (in/h)	0.02		
Antecedent dry period (h)	6.3		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	170.0		16.0		0.91
SSC	mg L^{-1}					
TP	mg L^{-1}	0.055		0.029		0.47
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.44		0.38		0.14
$NH_{3/4}$-N	mg L^{-1}	0.076		0.08		-0.05
TN	mg L^{-1}	0.58		0.53		0.09
$NO_{2/3}$-N	mg L^{-1}	0.14		0.15		-0.07
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	78.2	N	78.2	0.120	-	-	Y
UNDERDRAIN	64.4	N	64.4	0.046	0.002	3.9	Y
BYPASS	0.0	N	0.0	0.046	-	-	-

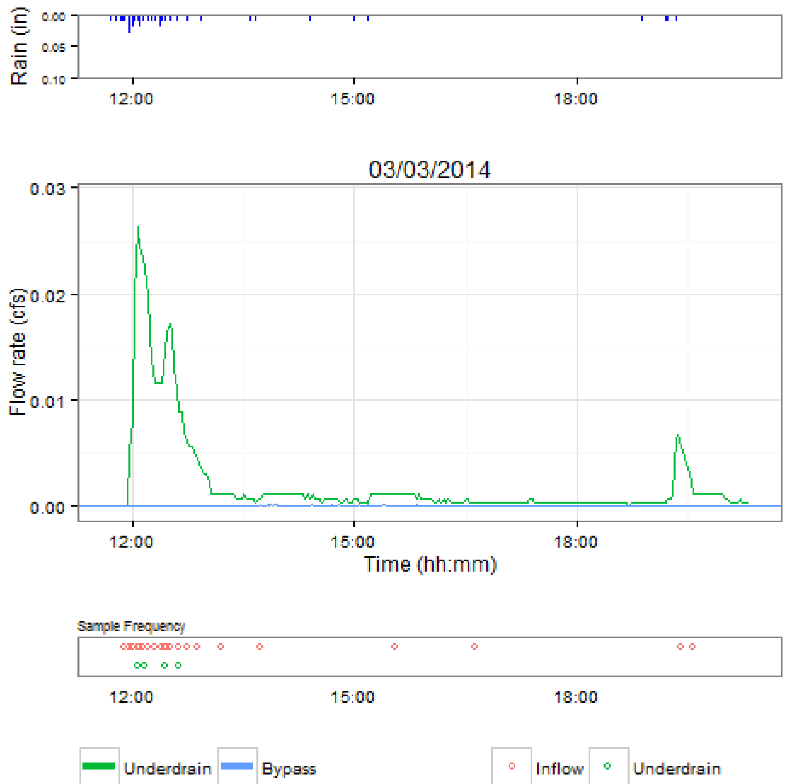


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.46		
Rainfall duration (h)	2.4		
Max 5-min intensity (in/h)	0.42		
Mean intensity (in/h)	0.19		
Antecedent dry period (h)	89.2		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	120.0		3.20		0.97
SSC	mg L^{-1}	86.67		2.07		0.98
TP	mg L^{-1}	0.059		**0.012**	0.024	0.80
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.61		**0.13**	0.26	0.79
$NH_{3/4}$-N	mg L^{-1}	0.11		0.067		0.39
TN	mg L^{-1}	0.81		0.33		0.59
$NO_{2/3}$-N	mg L^{-1}	0.20		0.20		0
Cu	µg L^{-1}	12.0		7.60		0.37
Zn	µg L^{-1}	87.0		24.0		0.72

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	953.7	Y[a]	277.2	0.372	-	-	Y
UNDERDRAIN	173.0	N	173.0	0.083	0.016	28.9	Y
BYPASS	50.2	N	50.2	0.148	-	-	-

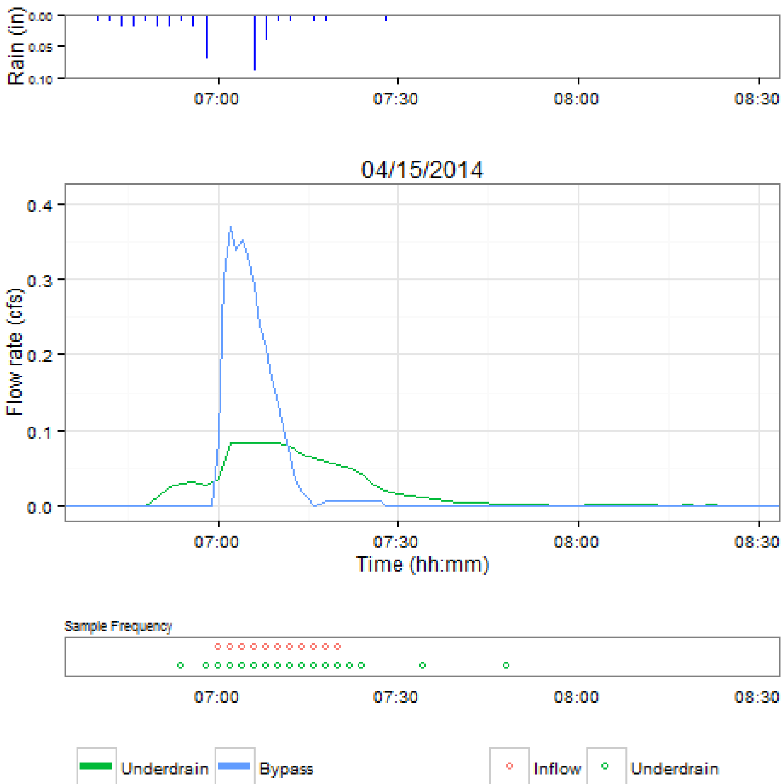
[a]Backwater in weir observed



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.35		
Rainfall duration (h)	7.6		
Max 5-min intensity (in/h)	0.24		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	238		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	54.0		14.0		0.74
SSC	mg L^{-1}					
TP	mg L^{-1}	0.59		0.046		0.92
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.39		0.024		0.94
TKN	mg L^{-1}	1.10		0.88		0.20
$NH_{3/4}$-N	mg L^{-1}	0.56		0.42		0.25
TN	mg L^{-1}	1.51		1.39		0.08
$NO_{2/3}$-N	mg L^{-1}	0.41		0.51		-0.24
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	71.9	N	71.9	0.045	-	-	Y
UNDERDRAIN	58.6	N	58.6	0.026	0.002	3.5	Y
BYPASS	0.0	N	0.0	0.0	-	-	-

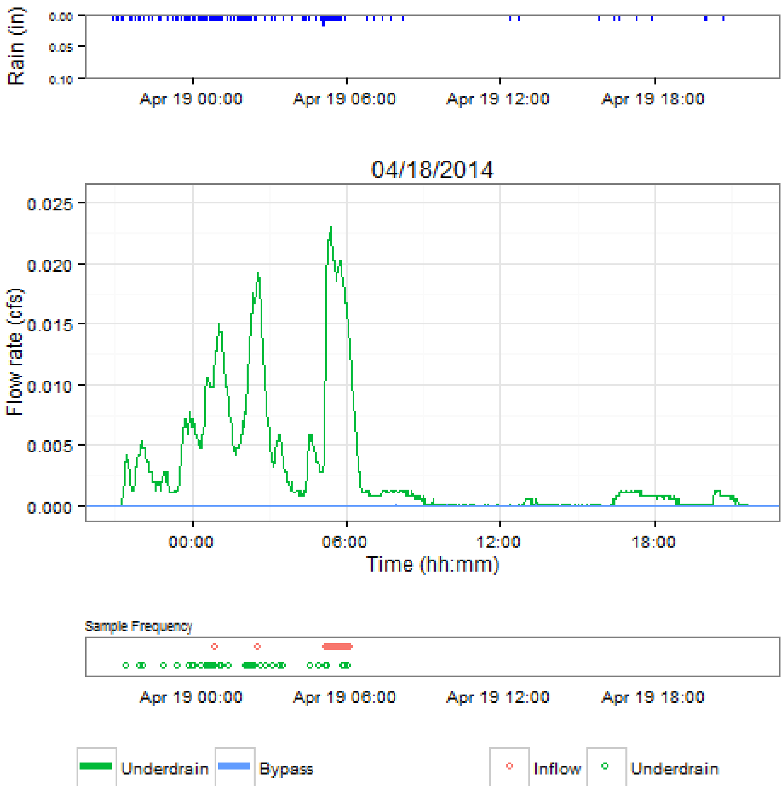


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.81		
Rainfall duration (h)	0.8		
Max 5-min intensity (in/h)	0.8		
Mean intensity (in/h)	1.0		
Antecedent dry period (h)	172		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	$mg\ L^{-1}$	730		8.80		0.99
SSC	$mg\ L^{-1}$	194.7		8.39		0.96
TP	$mg\ L^{-1}$	0.29		0.14		0.52
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	$mg\ L^{-1}$	0.0560		0.043		0.23
TKN	$mg\ L^{-1}$	1.90		1.0		0.47
$NH_{3/4}$-N	$mg\ L^{-1}$	**0.0225**	0.045	0.049		-1.18
TN	$mg\ L^{-1}$	*1.913*		*1.013*		0.47
$NO_{2/3}$-N	$mg\ L^{-1}$	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	$\mu g\ L^{-1}$	9.0		9.5		-0.06
Zn	$\mu g\ L^{-1}$	71.0		35.0		0.51

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1191.8	Y[a]	574.2	1.029	-	-	Y
UNDERDRAIN	139.7	Y[b]	386.2	0.083	0.068	122.0	Y
BYPASS	188.0	N	188.0	0.369	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

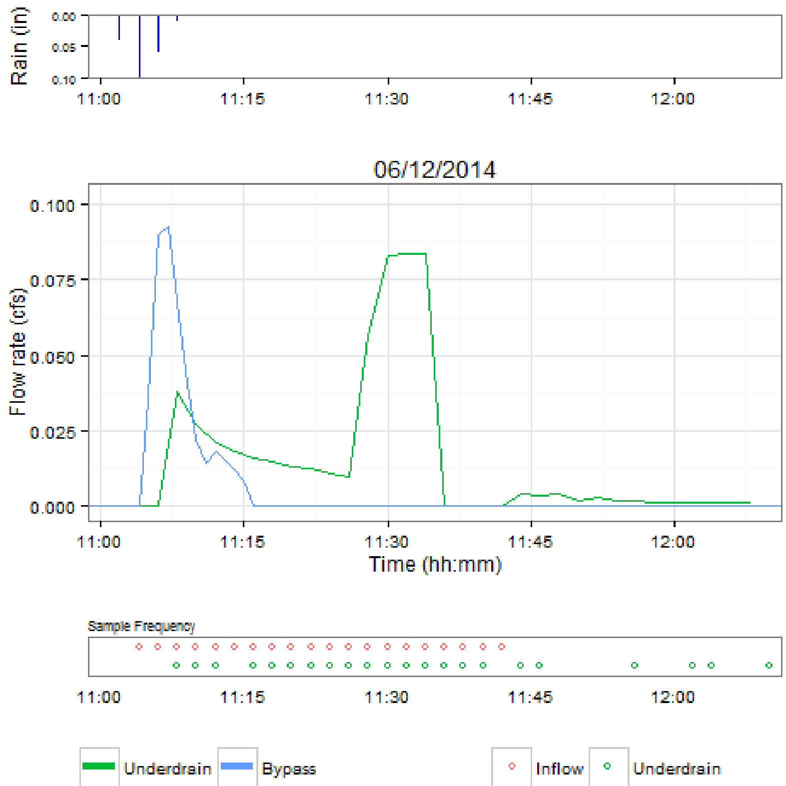


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.08		
Rainfall duration (h)	23.7		
Max 5-min intensity (in/h)	0.21		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	72.4		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	43.0		1.6		0.96
SSC	mg L^{-1}	39.37		0.74		0.98
TP	mg L^{-1}	0.044		**0.012**	0.0224	0.73
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.0120**	0.024	NA
TKN	mg L^{-1}	0.450		0.43		0.04
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.055		-1.44
TN	mg L^{-1}	*0.463*		*0.443*		0.04
$NO_{2/3}$-N	mg L^{-1}	**0.0125**	0.025	**0.0125**	0.025	NA
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1938.8	Y[a]	811.4	1.029	-	-	Y
UNDERDRAIN	263.2	Y[b]	804.5	0.083	0.009	16.1	Y
BYPASS	6.90	N	6.90	0.369	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

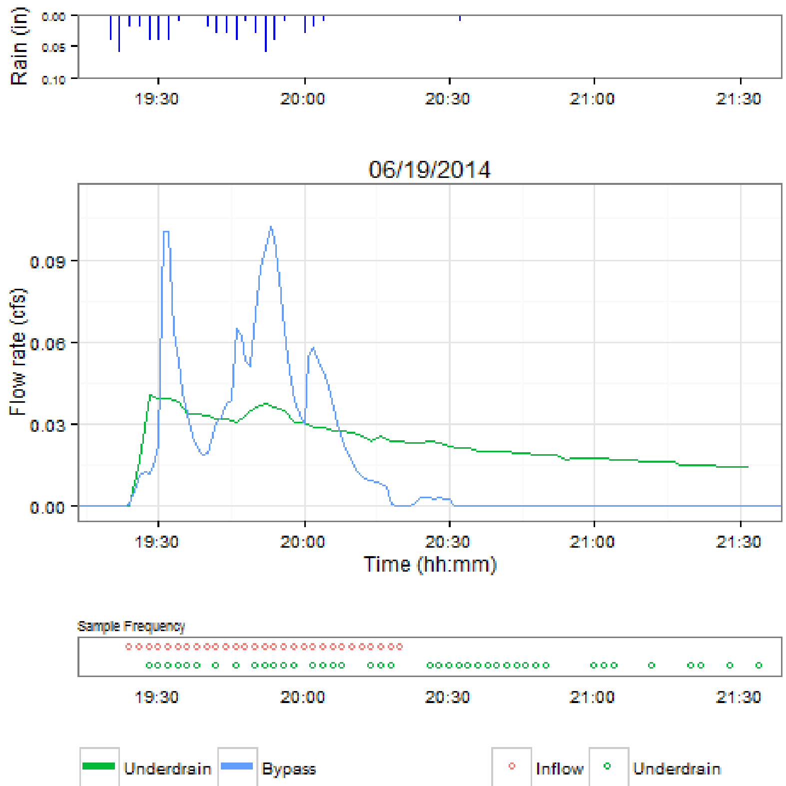


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.25		
Rainfall duration (h)	7.6		
Max 5-min intensity (in/h)	0.21		
Mean intensity (in/h)	0.03		
Antecedent dry period (h)	57.4		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	$mg\ L^{-1}$	220		3.60		0.98
SSC	$mg\ L^{-1}$	309		1.57		0.99
TP	$mg\ L^{-1}$	0.30		0.0890		0.70
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	$mg\ L^{-1}$	0.14		0.0610		0.56
TKN	$mg\ L^{-1}$	2.40		1.40		0.42
$NH_{3/4}$-N	$mg\ L^{-1}$	0.57		0.31		0.46
TN	$mg\ L^{-1}$	2.62		1.76		0.33
$NO_{2/3}$-N	$mg\ L^{-1}$	0.22		0.36		-0.64
Cu	$\mu g\ L^{-1}$	27		12		0.56
Zn	$\mu g\ L^{-1}$	99		31		0.69

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1459.1	Y[a]	94.3	0.515	-	-	Y
UNDERDRAIN	62.8	N	62.8	0.038	0.017	31.4	Y
BYPASS	30.0	N	30.0	0.068	-	-	-

[a]Backwater in weir observed

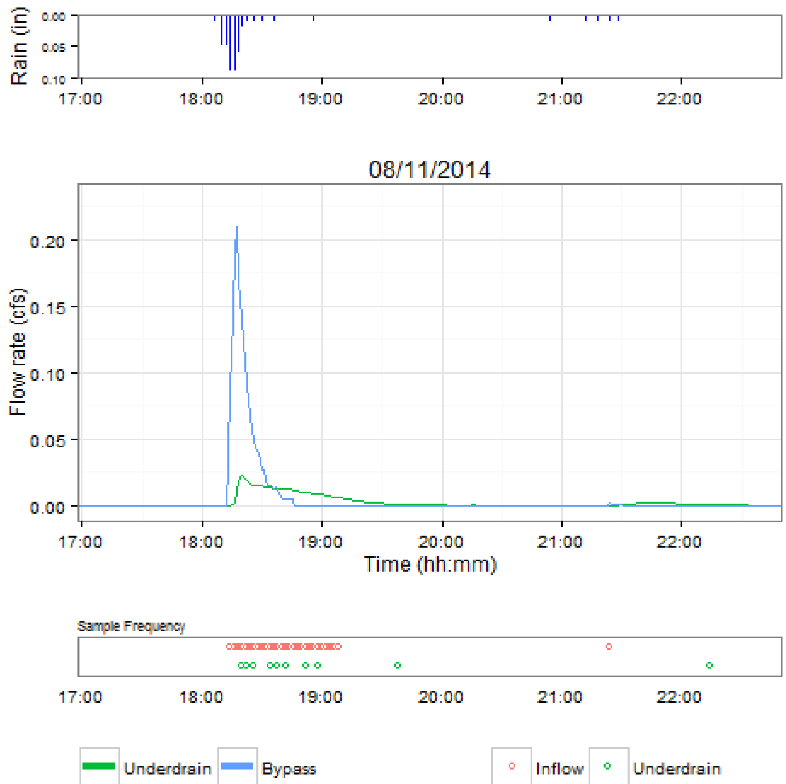


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.61		
Rainfall duration (h)	1.2		
Max 5-min intensity (in/h)	0.6		
Mean intensity (in/h)	0.51		
Antecedent dry period (h)	46.6		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	$mg\ L^{-1}$	100		1.2		0.99
SSC	$mg\ L^{-1}$	111.87		1.01		0.99
TP	$mg\ L^{-1}$	0.086		0.042		0.51
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	$mg\ L^{-1}$	**0.012**	0.024	**0.0120**	0.024	NA
TKN	$mg\ L^{-1}$	1.1		0.740		0.33
$NH_{3/4}$-N	$mg\ L^{-1}$	0.17		0.078		0.54
TN	$mg\ L^{-1}$	1.30		1.06		0.18
$NO_{2/3}$-N	$mg\ L^{-1}$	0.20		0.32		-0.60
Cu	$\mu g\ L^{-1}$					
Zn	$\mu g\ L^{-1}$					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	4928.6	Y[a]	402.2	0.329	-	-	Y
UNDERDRAIN	239.9	N	239.9	0.039	0.031	55.4	Y
BYPASS	135.2	N	135.2	0.101	-	-	-

[a]Backwater in weir observed

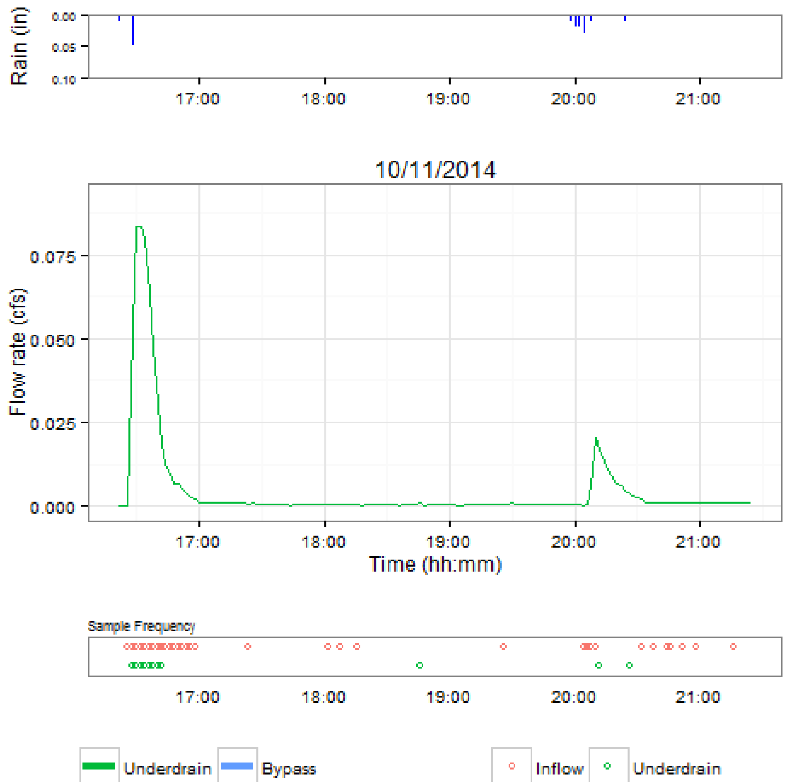


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.51		
Rainfall duration (h)	10.2		
Max 5-min intensity (in/h)	0.42		
Mean intensity (in/h)	0.05		
Antecedent dry period (h)	23.4		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	200		2.40		0.99
SSC	mg L^{-1}	230.13		2.39		0.99
TP	mg L^{-1}	0.17		0.044		0.51
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	1.5		0.45		0.33
$NH_{3/4}$-N	mg L^{-1}	0.25		**0.0225**		0.54
TN	mg L^{-1}	1.6		0.62		0.61
$NO_{2/3}$-N	mg L^{-1}	0.1		0.17		-0.60
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	2738.6	Y[a]	385.3	0.601	-	-	Y
UNDERDRAIN	46.1	Y[b]	272.1	0.003	0.015	27.2	Y
BYPASS	113.2	N	113.2	0.190	-	-	-

[a]Backwater in weir observed
[b]Weir readings low

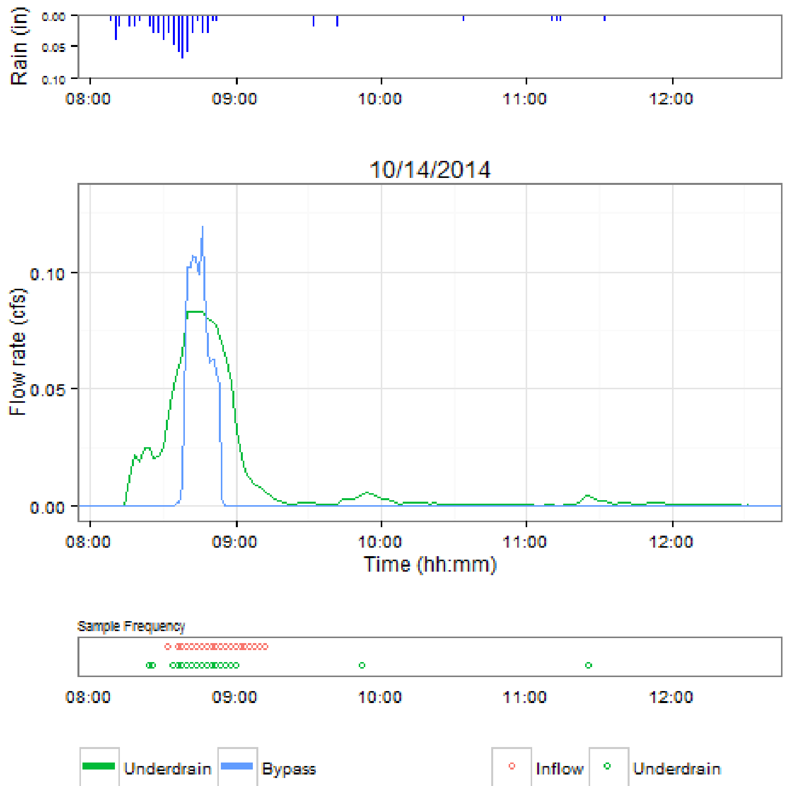


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.43		Bypass hydrograph unavailable
Rainfall duration (h)	4.0		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.11		
Antecedent dry period (h)	286.3		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	150.0		7.60		0.95
SSC	mg L^{-1}	219.75		6.49		0.97
TP	mg L^{-1}	0.27		0.13		0.52
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	0.014		0.0810		0.42
TKN	mg L^{-1}	1.7		1.30		0.24
$NH_{3/4}$-N	mg L^{-1}	0.19		0.11		0.42
TN	mg L^{-1}	1.90		2.10		-0.11
$NO_{2/3}$-N	mg L^{-1}	0.20		0.80		-3.0
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1489.8	Y[a]	252.8	0.844	-	-	Y
UNDERDRAIN	89.5	N	89.5	0.083	0.007	11.9	Y
BYPASS	-	-	-	-	-	-	-

[a]Backwater in weir observed

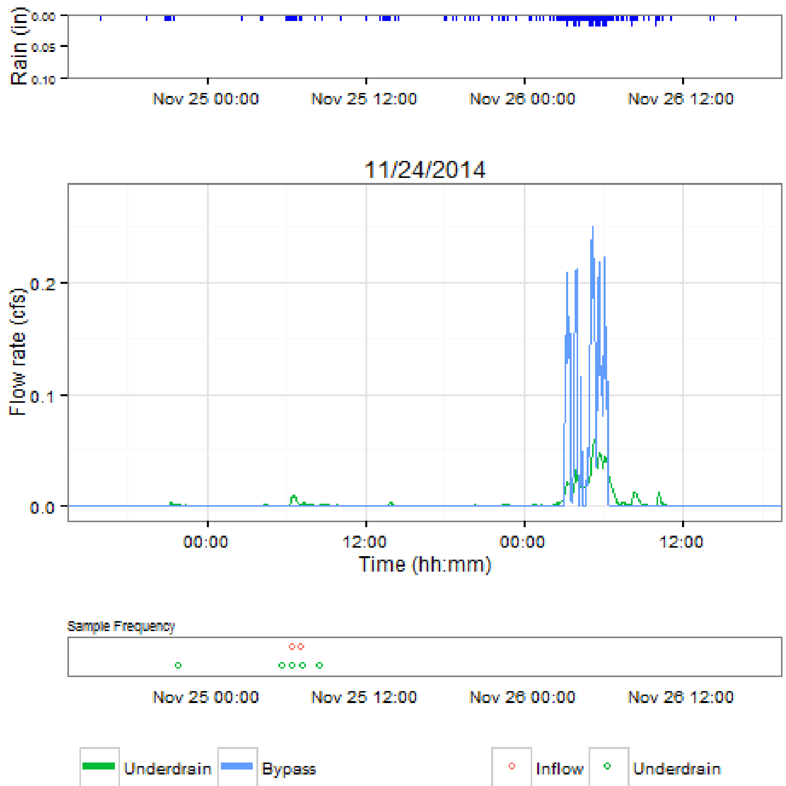


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.72		
Rainfall duration (h)	3.4		
Max 5-min intensity (in/h)	0.63		
Mean intensity (in/h)	0.21		
Antecedent dry period (h)	59.7		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	62		2.8		0.95
SSC	mg L^{-1}	85.66		1.78		0.98
TP	mg L^{-1}	0.0560		0.012		0.79
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.0120**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.94		0.37		0.61
$NH_{3/4}$-N	mg L^{-1}	0.56		0.0225		0.96
TN	mg L^{-1}	0.986		0.447		0.55
$NO_{2/3}$-N	mg L^{-1}	0.046		0.077		-0.67
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1096.8	Y[a]	496.3	0.458	-	-	Y
UNDERDRAIN	163.4	N	163.4	0.083	0.012	22.2	Y
BYPASS	77.8	N	77.8	0.102	-	-	-

[a]Backwater in weir observed

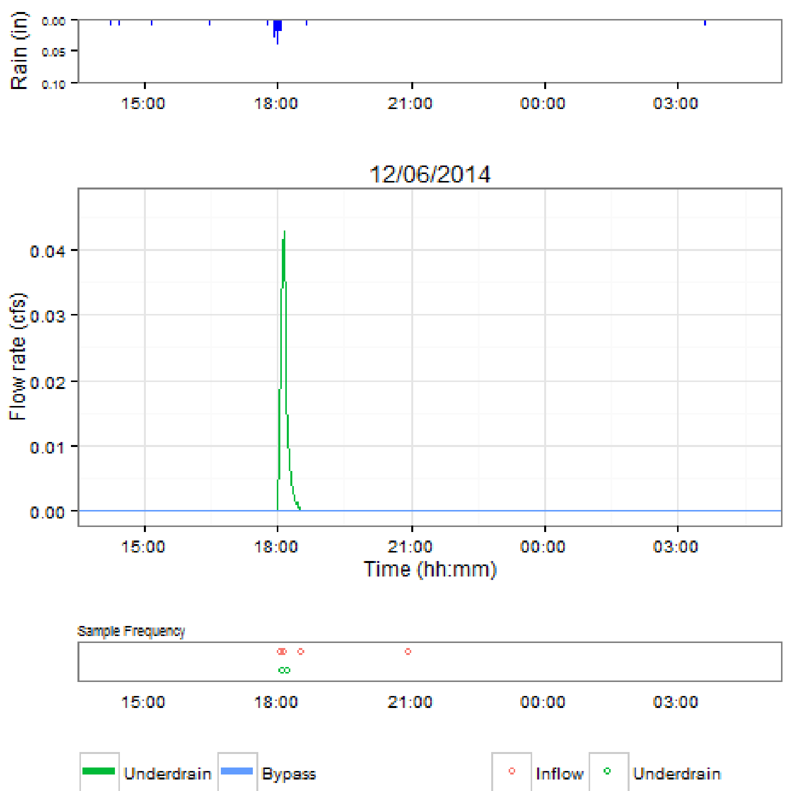


Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	1.94		Storm not included in statistical analysis in body of report because it was sampled before a majority of the runoff occurred. Sample personnel were on-site, and all available indication was that there would be no rain for at least six hours, which did not occur.
Rainfall duration (h)	48.1		
Max 5-min intensity (in/h)	0.41		
Mean intensity (in/h)	0.04		
Antecedent dry period (h)	15.5		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	$mg\ L^{-1}$	160.0		2.0		0.99
SSC	$mg\ L^{-1}$	133.1		3.03		0.98
TP	$mg\ L^{-1}$	0.17		0.094		0.45
Ortho-P	$mg\ L^{-1}$	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	$mg\ L^{-1}$	0.0650		0.076		-0.17
TKN	$mg\ L^{-1}$	0.85		0.50		0.41
$NH_{3/4}$-N	$mg\ L^{-1}$	**0.0225**	0.045	**0.0225**	0.045	NA
TN	$mg\ L^{-1}$	0.903		0.588		0.35
$NO_{2/3}$-N	$mg\ L^{-1}$	0.0530		0.088		-0.66
Cu	$\mu g\ L^{-1}$					
Zn	$\mu g\ L^{-1}$					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	1259.5	Y[a]	1581.5	0.143	-	-	N
UNDERDRAIN	488.5	N	488.5	0.051	0.004	6.60	N
BYPASS	1295.0	N	1295.0	0.250	-	-	-

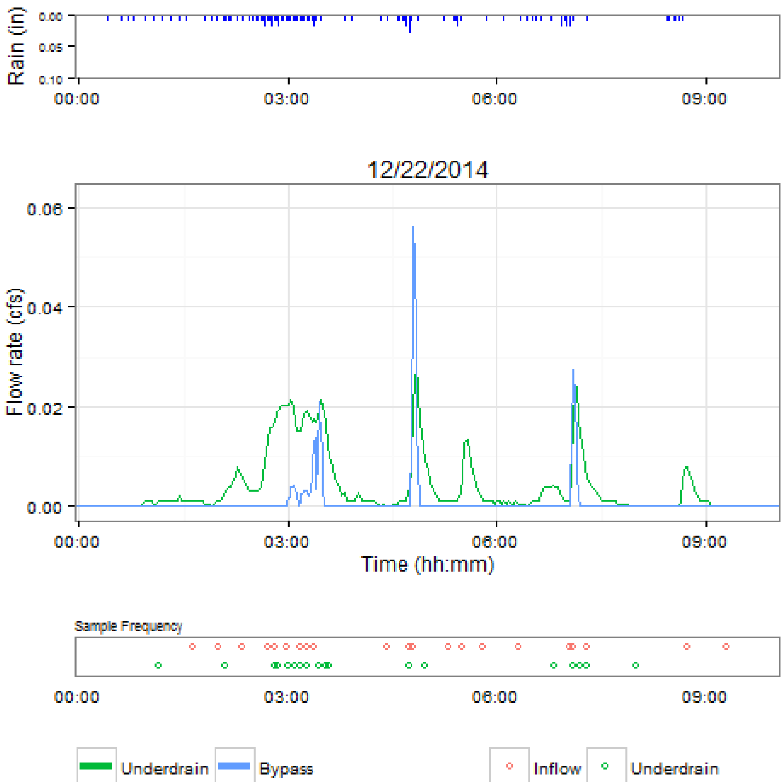
[a]Backwater in weir observed



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.2		
Rainfall duration (h)	4.4		
Max 5-min intensity (in/h)	0.15		
Mean intensity (in/h)	0.045		
Antecedent dry period (h)	238.2		

Analyte	Units	Inflow EMC	Inflow MDL	Underdrain EMC	Underdrain MDL	Efficiency Ratio
TSS	mg L^{-1}	82		11		0.87
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.0560		0.53
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	0.037		-2.08
TKN	mg L^{-1}	1.0		0.78		0.22
$NH_{3/4}$-N	mg L^{-1}	**0.0225**	0.045	0.045		-1.0
TN	mg L^{-1}	1.06		0.99		0.07
$NO_{2/3}$-N	mg L^{-1}	0.0590		0.21		-2.56
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	43.4	N	43.4	0.069	-	-	Y
UNDERDRAIN	24.0	N	24.0	0.043	0.007	12.0	Y
BYPASS	3.2	N	3.2	0.0	-	-	-



Rainfall Parameter	Value	QQ	Notes
Rainfall Total (in)	0.97		
Rainfall duration (h)	13.8		
Max 5-min intensity (in/h)	0.33		
Mean intensity (in/h)	0.07		
Antecedent dry period (h)	365.8		

		Inflow		Underdrain		Efficiency
Analyte	Units	EMC	MDL	EMC	MDL	Ratio
TSS	mg L^{-1}	33		3.60		0.89
SSC	mg L^{-1}					
TP	mg L^{-1}	0.12		0.025		0.79
Ortho-P	mg L^{-1}	**0.0275**	0.055	**0.0275**	0.055	NA
TDP	mg L^{-1}	**0.012**	0.024	**0.012**	0.024	NA
TKN	mg L^{-1}	0.490		**0.13**	0.26	0.73
$NH_{3/4}$-N	mg L^{-1}	0.065		**0.0225**	0.045	0.65
TN	mg L^{-1}	0.548		*0.26*		0.53
$NO_{2/3}$-N	mg L^{-1}	0.0580		0.13		-1.24
Cu	µg L^{-1}					
Zn	µg L^{-1}					

Location	Volume (cf)	Vol Corrected?	Corrected Volume (cf)	Peak Flow (cfs)	Average Flow (cfs)	Average Flow (in/hr)	>70% of Hydrograph Captured?
IN	398.4	N	398.4	0.143	-	-	Y
UNDERDRAIN	135.1	N	135.1	0.020	0.005	8.5	Y
BYPASS	32.6	N	32.6	0.056	-	-	-