Spring 2018

Water Infiltration and Pollutant Rentention Efficiencies in the Ballona Creek Rain Garden

Jamie Lynn Burkhard
Loyola Marymount University, jamie.burkhard@gmail.com

Recommended Citation

Burkhard, Jamie Lynn, "Water Infiltration and Pollutant Rentention Efficiencies in the Ballona Creek Rain Garden" (2018). *LMU/LLS Theses and Dissertations*. 523.
https://digitalcommons.lmu.edu/etd/523

WATER INFILTRATION AND POLLUTANT RENTENTION EFFICIENCIES IN THE BALLONA CREEK RAIN GARDEN

by

Jamie Lynn Burkhard

A thesis presented to the

Faculty of the
Department of Civil Engineering & Environmental Science
Loyola Marymount University

In partial fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

May, 2018

SIGNATURES OF APPROVAL

WATER INFILTRATION AND POLLUTANT RENTENTION EFFICIENCIES IN THE BALLONA CREEK RAIN GARDEN

[redacted]

May 4, 2018

John H. Dorsey, Ph.D. Department of Civil Engineering
And Environmental Science
Date

[redacted]

May 5 2018

Joseph C. Reichenberger, P.E. Department of Civil Engineering
And Environmental Science
Date

[redacted]

5-10-2018

Karina Johnston, Director of Watershed
Programs, The Bay Foundation
Date

[redacted]

May 3, 2018

Jamie L. Burkhard, M.S. Department of Civil Engineering
And Environmental Science
Date

Table of Contents

FIGURES

TABLES

ACKNOWLEDGMENTS

I would like to thank my thesis committee for their *invaluable* feedback and advice, and countless hours spent reading and editing on my behalf; I am tremendously grateful to Dr. John Dorsey, Karina Johnston, and Dr. Joseph Reichenberger. I appreciate the sounding board opportunities, technical expertise, drive to share this research with other people and agencies, and general encouragement. I truly couldn't have accomplished this without all of your support.

I would also like to sincerely thank the following people and organizations for their part in this project's success. Without their help, this project would not have been realized:

Tom Boughey for all his amazing carpentry work, physical labor, and technical expertise;
Stephanie Kawecki for all her hard work in the lab helping to analyze the samples and show me (and others) the ropes;
Dr. Don Kendall for all the calls, emails, and meetings about the mathematical equations, volume calculations, and general hydrological assistance;
Dr. Yong-Jun Li for his expertise with the ICP/MS for all of the metals analyses;
Dr. Jose Saez for his help with weir and flow calculations for all inlets and outlets as well as editing assistance;
LMU student volunteers for all the hours spent in the rain collecting samples and all the hours in the lab analyzing them;
The Bay Foundation for creating projects like this one, allowing me access to the site for this study, helping with sampling analyses and equipment, and promoting LID;
CURes for project promotion, student volunteers to sample during storms, and transportation;
Nikhil Vishwanath for his work on this project during the first season, background knowledge, and help to get me started;
Metropolitan Water District for the World Water Forum funding for this project and the opportunity to present the research;
IIRMES for their laboratory and technical support in the analyses of all the organics samples;
Los Angeles Center for Urban Natural Resources Sustainability for the fellowship that enabled me to better focus on this project as well as their financial support of similar projects that promote sustainability;
LMU Faculty and Staff for their sincere support of students and their desire to help us succeed.

I also want to thank my friends and family for their continual and unwavering support: Jan and Don, Julie and Jennifer, Jim and Jacque. Thank you for everything you've done.

ACRONYMS

BCRG- Ballona Creek Rain Garden
BMP- Best Management Practice
cfs- cubic feet per second
cm- centimeter
cms- cubic meters per second
CWA- Clean Water Act
FIB- Fecal Indicator Bacteria
gal- Gallons
GI- Green Infrastructure
ICP/MS- Inductively coupled plasma-mass spectrometry
IIRMES- Institute for Integrated Research in Materials, Environments and Society
in- inch
L- Liters
L/d- Liter per day
LADCPW- Los Angeles County Department of Public Works
LID- Low Impact Development
m- meter
mg/L- milligrams per liter
MGD- million gallons per day
min- minutes
MPN- Most Probable Number
ND- Non-Detect
NOAA- National Oceanic and Atmospheric Administration
NPDES- National Pollutant Discharge Elimination System
NWS- National Weather Service
PAH- Polyaromatic Hydrocarbon
PR- Percent Retention
TBF- The Bay Foundation
TMDL- Total Maximum Daily Load
TPH- Total Petroleum Hydrocarbons
TSS- Total Suspended Solids
ug/L- micrograms per liter
USEPA- United States Environmental Protection Agency

ABSTRACT

Biofiltration systems like rain gardens and bioswales are an important tool for capturing and infiltrating polluted runoff, but little data exists on their efficiencies within Mediterranean climates. A two-year study initiated in 2015 investigated water retention and pollutant loading and retention in the Ballona Creek Rain Garden (BCRG). This 300 by 3 m biofiltration system was constructed by The Bay Foundation in 2011 along Ballona Creek in Culver City, Los Angeles County, California. The purpose of the garden was to capture and infiltrate runoff from light industrial and commercial operations bordering the Creek, thus reducing pollutants entering this waterway and flowing into Santa Monica Bay 9 km downstream. During storm events, runoff enters the garden via five inlets, and when filled, flows into the creek via two outlets. The goal of this study was to sample flows and pollutant concentrations in runoff entering and leaving the garden and then integrate these to calculate mass loading estimates. Flows were measured at all inlets and outlets using 90° V-notch weirs outfitted with Hobo water level sensors to produce hydrographs. The following pollutants were measured at all flowing inlets and outlets two to three times per storm depending on its duration and intensity: fecal indicator bacteria (*E. coli* and enterococci), total suspended solids, metals (copper, zinc, and lead), and semivolatile hydrocarbons (polyaromatic hydrocarbons, diesel hydrocarbons, and motor oil hydrocarbons). The summation of load method was used to calculate the mass of contaminants entering and leaving the garden for each storm event, and their percent capture within the garden. The BCRG was very effective at infiltrating runoff and sequestering pollutants. The garden's infiltration rates ranged from 73% to 100% (with 100% for many of the smaller storms <1-in). Results for pollutant loading and retention indicated that the average percent retentions were in the 80-90% range for all pollutants, with an average of 90% for all nine pollutants sampled. This suggests rain gardens and other Low Impact Development (LID) systems can be used successfully in urban Mediterranean climates like Los Angeles to promote infiltration, capture pollutants, and prevent polluted stormwater from reaching impaired water bodies.

INTRODUCTION

Water issues are a prevalent topic all across the world today, whether the subject is access to potable water, water pollution, or management in times of drought. The threat of climate change only promises to intensify these issues and encourages people to take action.

Stormwater is important to investigate because it influences several of these water issues simultaneously, especially in Mediterranean climates where summers are dry and hot, and winters are mild and rainy (Lionello et al. 2006). Southern California along with other locations with Mediterranean climates can have no precipitation for months, allowing pollutants to accumulate on the land surface before being flushed into waterways. Historically, cities like Los Angeles took a 'quantity over quality' approach and invested more in flood control than stormwater management, which led to paved channels and other hardscapes to expedite the removal of large volumes of water out of the watershed (Roy-Poirer et al. 2010).

The introduction of Low Impact Development (LID) and Green Infrastructure (GI) has shifted thinking by encouraging solutions that mimic pre-development hydrological conditions. The goals of these LID strategies are to enhance water quality as well as reduce stormwater runoff (Davis 2005). By allowing infiltration of stormwater, it's possible to replenish groundwater reserves in areas where geology is favorable, reduce pollution in nearby water bodies through the reduction of runoff, reduce dependence on imported freshwater resources, and promote ecosystem services that enhance urban communities.

Urban Watersheds and Stormwater Pollution

Modern society has numerous incontrovertible effects on watersheds, particularly urban watersheds. A watershed is defined as an area of land where all water from precipitation (e.g. rainfall or snowfall) and all applied water (e.g. from garden hoses and car washes) drains to a common point or outlet (Perlman 2016). Urban watersheds are composed primarily of impervious surfaces that impede water infiltration. Less infiltration results in larger amounts of polluted runoff washed directly into waterways during storms, with little to no chance for treatment of any kind. This increased volume of urban stormwater can increase erosion, increase inputs of contaminants, and affect both instream and downstream biodiversity, where pollution-tolerant species dominate (Walsh et al. 2005).

Stormwater management has substantially progressed from its initial focus on flood control. The United States Environmental Protection Agency (USEPA) created the National Pollutant Discharge Elimination System (NPDES) in conjunction with the 1972 Clean Water Act (CWA) (CWA: United States Code 1972). Although the NPDES program initially only dealt with point sources of pollution, in 1990 it expanded to include nonpoint sources such as stormwater in its regulatory permitting (NPDES: Code of Federal Regulations 2003). Water bodies are placed on the 303(d) list when they do not meet water quality standards for specific pollutants. This listing triggers implementation of a Total Maximum Daily Load (TMDL) program for violating pollutants. In complying with a TMDL, permitted entities (e.g. municipalities, commercial operations) must meet certain pollutant limits in runoff or effluent discharged into a water body to enable it to meet standards. This load is then allocated to the region's permitted sources and specifies the allowable discharges in order to reverse or significantly lessen the water quality degradation (National Research Council 2009).

With the inclusion of stormwater in water quality regulations, agencies like the State Water Resources Control Board and Regional Water Quality Control Boards developed guidelines to assist permit applicants in meeting water quality objectives. With regard to water pollution, Best Management Practices (BMPs) are practices, both structural and non-structural that prevent contamination of water (U.S. EPA 1993), and can involve program development, siting principles, operational measures, technological designs or devices, or structural components (City of Los Angeles 2000). Different goals correspond with different BMPs; their selection is left to respective regions and other local agencies to select the most effective option. Stormwater BMPs specifically promote infiltration, evapotranspiration, and stormwater usage through natural systems (City of Los Angeles 2011). One way to promote these goals is by employing LID strategies.

LID systems represent an entire branch of BMPs for green infrastructure that highlight sustainable methodology and attempt to shift current hydrologic processes to more natural or pre-development versions (Zhan & Chui 2016). LID offers a wide range of practices with multiple environmental, social, and financial benefits. Rather than promoting a single solution, LID offers a toolkit that can be adapted to different locations, site sizes, costs, and implementation feasibility. LID strategies emerge with the potential to drastically improve urban waterways and mitigate the effects of urban stormwater runoff (Ambrose & Winfrey 2015). Some of these strategies are green roofs, porous pavement, and biofiltration systems.

Biofiltration systems, sometimes called bioretention systems, include structures such as bioswales and rain gardens. These systems effectively treat polluted stormwater by capturing runoff and allowing it to filter through some combination of vegetation and soil media. This action allows for sedimentation, filtration of fine particles, sorption, and uptake by vegetation (Hatt et al. 2009). Nutrient uptake and cycling occur alongside degradation of organic matter and sequestration of metals. Biofiltration systems are becoming increasingly popular for several reasons such as aesthetic enhancements, a small energy footprint, and design flexibility (Ambrose & Winfrey 2015). In addition to urban runoff decontamination, its infiltration can bolster groundwater aquifers that could be important for an area's drinking water supply.

Many of the field studies regarding performance of these systems were located on the East coast with contrasting climatic conditions. Two studies in Maryland and North Carolina found bioretention to be effective in pollutant retention as well as peak flow mitigation. The Maryland study reported retention percentages of 76, 57, and 83 for copper, lead, and zinc, respectively (Davis 2007). The North Carolina study showed a mean peak flow reduction of 99% in addition to the pollutant retention (Hunt et al. 2008).

Using biofiltration systems in cities with Mediterranean climates, like Los Angeles, is far less studied, but constitutes a great opportunity for improving water quality of receiving waters (Ambrose & Winfrey 2015). Multiple agencies from public and private sectors alike are working to construct them throughout the southern California region. Although they have gained popularity, there is very little information about how well they actually work, especially within an arid climate like that of Los Angeles.

Through this study, the author will examine the efficiency of an existing biofiltration system located in the urbanized Ballona Creek Watershed. The focus will be on estimating how pollutant loads are reduced, and the amount of water infiltrated by this system.

Ballona Creek Watershed and Study Site

The Ballona Creek Watershed is located in southern California and includes portions of the City of Los Angeles. Of the approximately 130 square miles in area it encompasses, about 87% is developed, and is the largest single watershed draining to the Santa Monica Bay (Figure 1) (Abramson 2014). This degree of urbanization and the extensive concrete-lined storm-drain system results in polluted stormwater discharges impacting water quality in Santa Monica Bay (Bay et al*.* 2003). Contaminants in the runoff can include bacteria, pathogens, surfactants, pesticides, herbicides, fertilizers, trace metals, synthetic organic chemicals, petroleum products, and sediment which often result in public beach closures (Washburn et. al 2003). Flow is measured at a rain gage positioned between Sawtelle and Sepulveda Boulevards operated by Los Angeles County Department of Public Works (LACDPW) (Gage ALERT ID 370; http://dpw.lacounty.gov/wrd/Precip/alertlist.cfm). The Los Angeles Regional Water Quality Control Board updated Ballona Creek flow statistics to reflect 24 years of flow data. From 1987 to 2012, the average daily flow ranged from 0.03- 148 cms (0.68- 3,378 MGD) with a median flow of 0.5 cms (11.0 MGD). Wet weather flow is categorized as above 1.8 cms (41.1 MGD). (Los Angeles Regional Water Quality Control Board 2013).

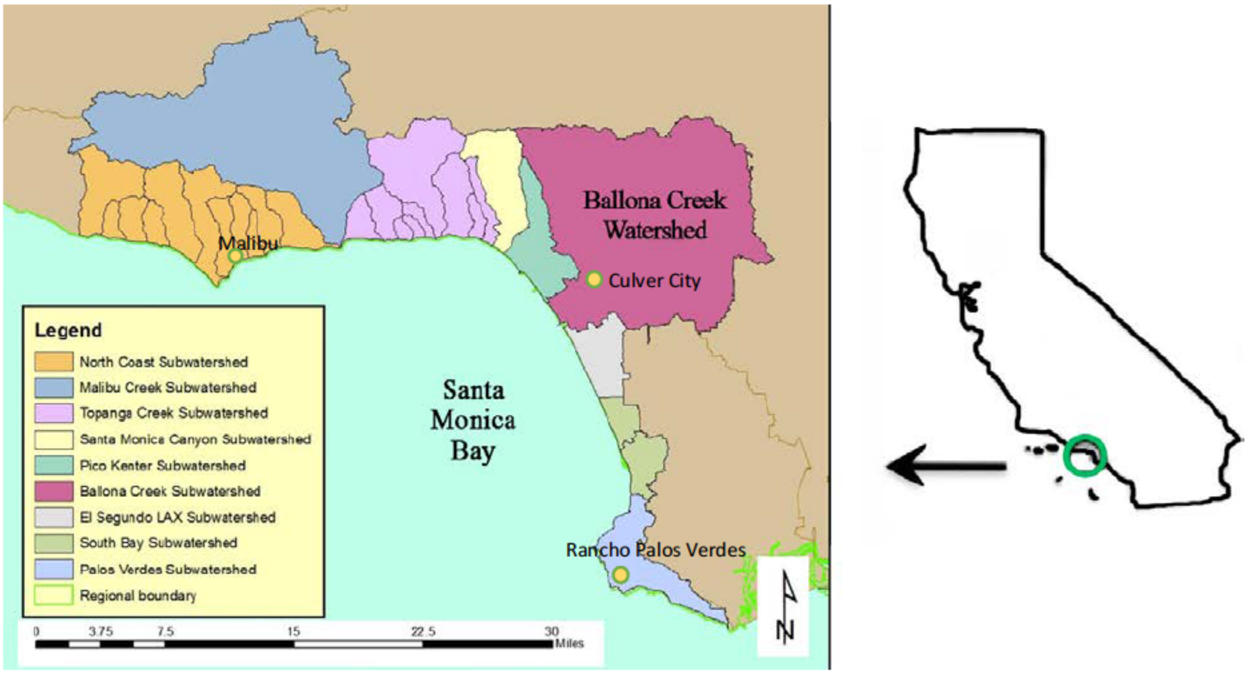


Figure 1. Location of the Ballona Creek Watershed draining into the Santa Monica Bay (after CRWQCB 2011).

Ballona Creek is listed as 'impaired' for the following pollutants: coliform fecal indicator bacteria (FIB), dissolved copper, zinc, cyanide, lead, sediment toxicity, and trash (California State Water Resources Control Board, 2017). This impairment led to the creation of Total Maximum Daily Loads (TMDLs) for trash, metals, and bacteria for this waterway.

The Ballona Creek Rain Garden

The Santa Monica Bay Restoration Foundation, also known as The Bay Foundation (TBF), is a non-profit environmental organization that supports U.S. EPA's Santa Monica Bay National Estuary Program. As part of its Bay Restoration Plan, TBF acquired funding to construct two rain gardens to intercept and infiltrate contaminated runoff adjacent Ballona Creek in Culver City, California (Figure 2). In doing so, the load of pollutants reaching Santa Monica Bay presumably is reduced from this region. There is one rain garden located on the western bank of Ballona Creek that serves a residential area, but all work for this study occurred on the eastern side that drains commercial and industrial area. This eastern site will be referred to as the Ballona Creek Rain Garden (BCRG) for purposes of this study. The BCRG was constructed in

2011 with some additional enhancements made in March 2014 to increase its retention capacity (Abramson, 2014).

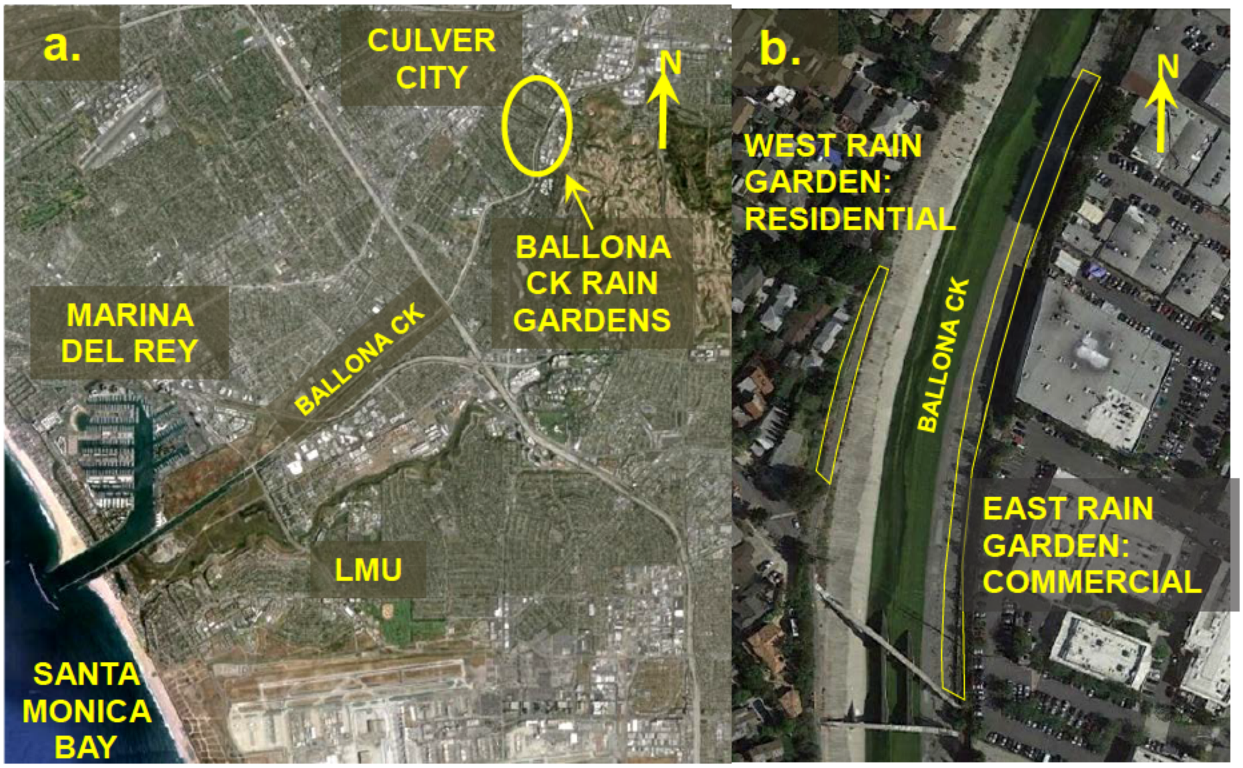


Figure 2. Location of the Ballona Creek Rain Gardens in Culver City, California: a. location of the gardens relative to Marina Del Rey and Santa Monica Bay; b. position of the gardens along the east bank of Ballona Creek where runoff is received from industrial and commercial operations.

This 300 by 3 m garden receives runoff from about 11 acres of surrounding commercial and industrial properties via five inlets (Figure 3). The basic design of the BCRG included removal of the top one foot of soil and amendment of the native soil (a sandy loam) with 50% mature, vegetative waste compost down to six feet in depth. The design also included cobble and boulders to slow stormwater flow, drought-tolerant plants providing aesthetic value as well as native habitat for wildlife, and a decomposed granite path along one edge to allow access through the site (Abramson, 2014). Runoff that enters the garden via five inlets is slowed to foster infiltration; only when the garden has reached its maximum capacity does any of the flow enter the outlet structures and discharge into the creek as shown in Figure 3. This structure was designed to capture and treat up to 0.75-in storms, with any excess flows directed into the creek.

After the original installation and the enhancements in 2014, TBF also performed monitoring work to assess performance. Total metals, hardness, total suspended solids (TSS), total petroleum hydrocarbons (TPH) from diesel and gasoline, and fecal indicator bacteria (FIB) were sampled for three storm events. There was an estimated decrease in pollutant loading across all constituents, the most notable being FIB and TSS (Abramson, 2014).

The study presented in this thesis was designed to build upon TBF's post-construction performance study and to answer questions related specifically to the retention capacity of the garden and load reductions of pollutant constituents. Obtaining additional data on the performance of this garden will also add to the growing body of information on the value of biofiltration systems within the Mediterranean climate of Los Angeles.

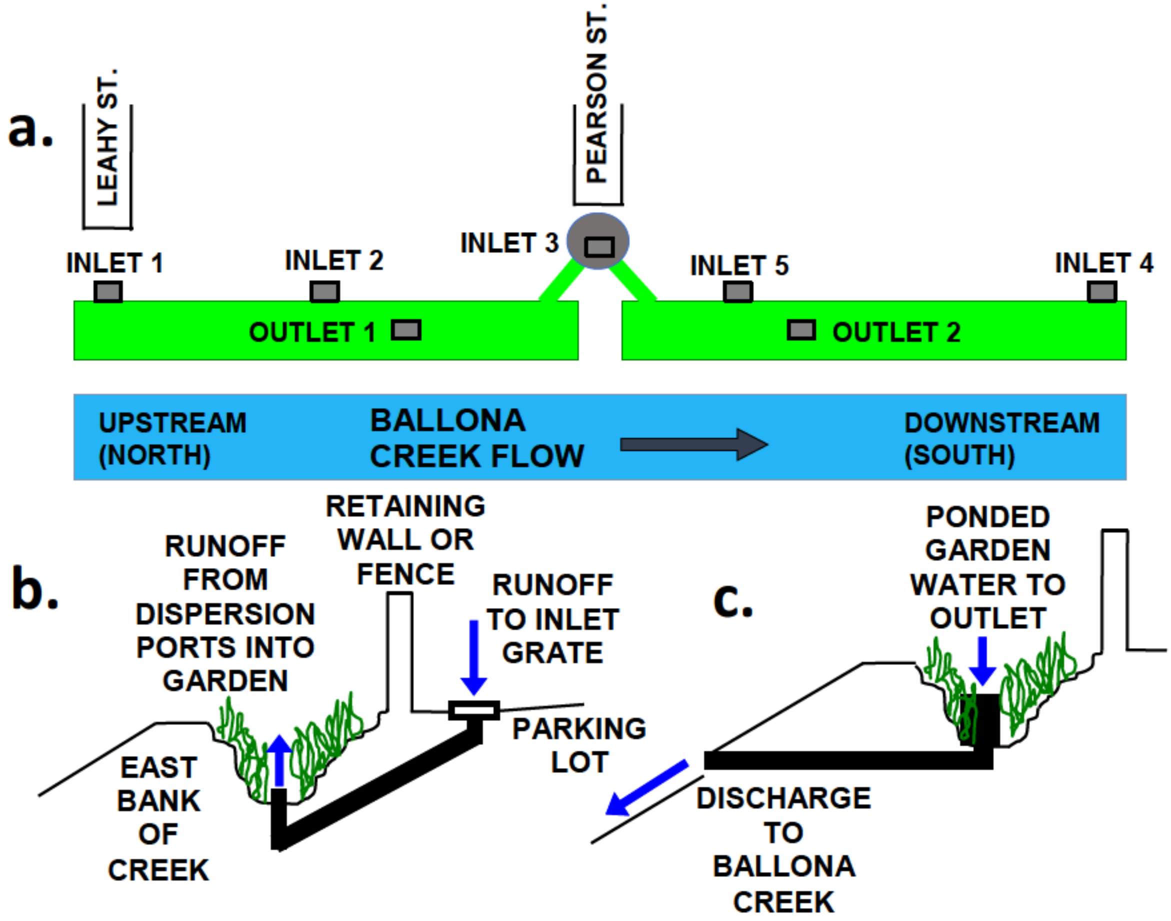


Figure 3. Garden configuration showing: a. five inlets and two outlet structures that redirect flow into Ballona Creek when at full capacity; b. cross sectional view of the general inlet design; and c. cross sectional view of the outlet design. Stormwater from surrounding parking lots is screened through grates, directed into the garden through one of five inlets, and then exits the garden through one of two outlets only when the volume of water reaches the height of the outlet structures.

This Study

The goal of this study is to determine the effectiveness of the Ballona Creek Rain Garden in infiltrating storm runoff and sequestering (and removing) associated pollutants. Specific study questions are:

- What is the water retention capacity for this rain garden?
- What is the pollutant retention efficiency for this rain garden?
- Does the size of the storm (volume, duration, intensity) affect either of the above questions and if so, to what extent?
- Are there any significant differences in pollutant concentrations between inlets (e.g. does one inlet habitually experience higher or lower pollutant concentrations when compared to other inlets?

The general approach in addressing these questions was to quantify the mass loading of pollutants entering and exiting the garden into Ballona Creek during storms along with estimates of water infiltrated into the garden. This information will provide essential evidence about the efficacy of rain gardens in Mediterranean climates and why they should continue to be promoted as a successful LID tool. The information learned from the Ballona Creek Rain Garden can then be used to help guide policy and decision-making to ensure better environmental health in urban areas.

METHODS

This study took place over two rainy seasons in 2015-16 and 2016-17. A minimum of three storms per season were targeted, with each storm having 1.9 cm (0.75 in) or more of rainfall. For each storm, the goal was to capture three sets of samples reflecting the rise, peak, and fall of runoff flows. At least two sets were obtained if the storm quickly moved through the area.

For the first season (2015-16), four storms were sampled for both hydrology and pollutant concentrations. To provide additional information regarding water infiltration, all storms forecasted to have greater than 0.25 cm (0.1 in) of rainfall were measured for flow during the

2016-17 season. Flow data for 28 storms were collected during the course of the study, four during the first season and 24 during the second season. This decision was fortuitous since the first season had less rainfall measured at the Ballona Creek gage. From November 2015 to March 2016 13.69 cm (5.39 in) of rainfall were recorded, and from November 2016 to March 2017 38.40 cm (15.12 in) were recorded (Los Angeles County Department of Public Works).

Hydrology

Weirs

To calculate runoff flows **entering and exiting the garden**, 90˚ V-notch weirs were individually designed and constructed for each of the five inlet and two outlet structures. They were designed to slow the water flow and force it to pass through each weir's V-notch. Water height passing through the notch was measured using a HOBO water level data logger (Model No. U20L-04) manufactured by Onset.

One to two days prior to a storm event, eight HOBO units were deployed to record temperature and pressure measurements at one-minute intervals for up to 15-days. Each of the inlet and outlet weirs contained a HOBO unit placed within a PVC pipe adjacent to the weir (Figures 4 and 5). One unit, placed at Inlet 3 out of reach of water, captured ambient temperature and air pressure readings.

Figure 4. V-Notch weir in position at Inlet No. 3. The inset shows the HOBO data logger that rests at the bottom of the perforated PVC pipe attached to the weir.

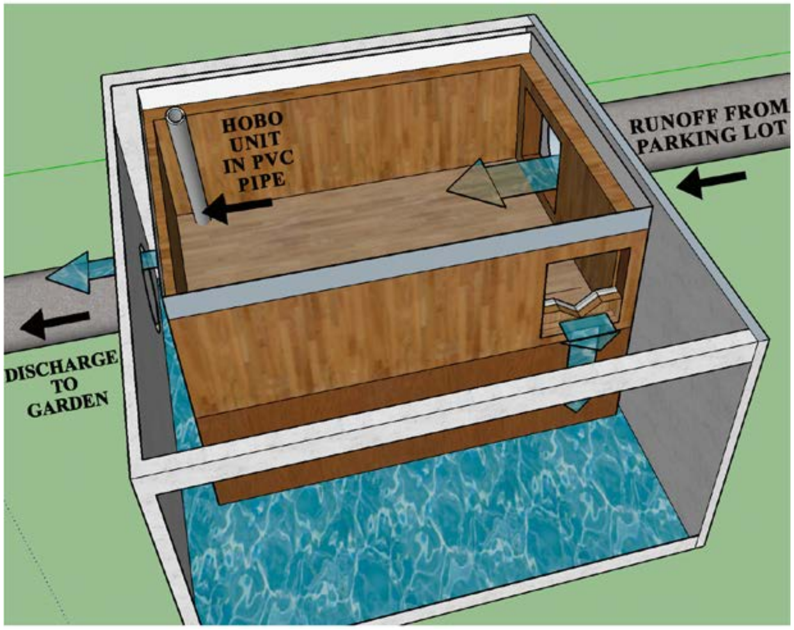


Figure 5. Schematic of the largest weir positioned at Inlet No. 4. The configuration included a large inset box within the inlet drainage system. The figure shows the v-notch as well as the PVC pipe with the HOBO unit.

After the storm passed, units were retrieved, and data were downloaded using Onset HOBOware Pro software. After adjusting water pressure by subtracting the ambient atmospheric pressure, the resulting pressure readings were converted into water heights using Equations Set 1 below (McCutcheon et al. 1993). Flows from all inlets were summed to yield a total inflow, and the same was done for outlet flows.

$$\begin{aligned}
&Water\ Pressure\ at\ Weir\ \left(\frac{lb}{in^2}\right) = Absolute\ Pressure\ \left(\frac{lb}{in^2}\right) at\ HOBO\ unit - Ambient\ Pressure\ \left(\frac{lb}{in^2}\right)\\
&Water\ Density\ (\rho)\,\frac{lb}{ft^3} = \left\{1000\,\frac{kg}{m^3}\left\{1 - \left[\frac{T + 288.94}{508929.2\ \times (T + 68.129)}\right](T - 3.986)^2\right\}\right\} \times \left[\frac{1\ lb/ft^3}{16.018\ kg/m^3}\right] \qquad (1)\\
&Water\ Height\ (ft) = \left[Weir\ Water\ Pressure\ \left(\frac{lb}{in^2}\right) * 144\ \frac{in^2}{ft^2}\right] \div Water\ Density\ (\rho)\,\frac{lb}{ft^3}
\end{aligned}$$

$Where: T = Temperature\ in\ ^{\circ}\mathrm{C}$

Based on water height (WH) relative to the weir notch, flow (gpm) was calculated using the following formulas after Grant and Dawson (1995) (Equation Set 2 and Figure 6).

$$\begin{aligned}&\text{If Water Height } (WH) > H2\text{, then Flow} = 1122 * H3^{2.5} + 3985.3 * (WH-H2)^{1.5}\\&\text{If Water Height } (WH) > H1, <H2\text{, then Flow} = 1122 * (WH-H1)^{2.5}\\&\text{If Water Height } (WH) < H1\text{, then Flow} = 0\end{aligned} \tag{2}$$

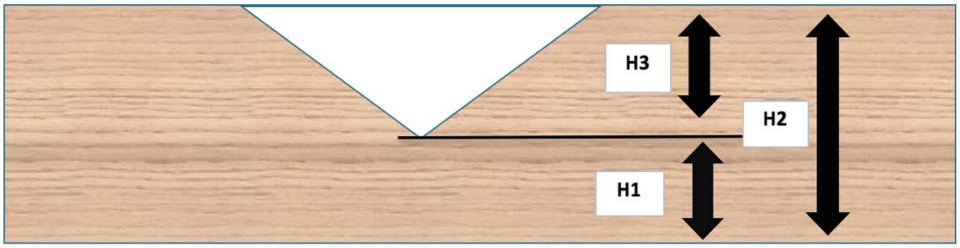


Figure 6. Water heights used to calculate flows in the V-notched weirs.

Hydrographs and Hyetographs

Using the calculations above, inflow and outflow over time were plotted to create a hydrograph for each storm showing the flow (Q) over time (t) at 1-min intervals.

Los Angeles County Public Works Water Resources Division measures rainfall intensities at a gage along Ballona Creek at Sawtelle Boulevard (Gage ID 370). This station provided rainfall intensities at 5-minute intervals for all 28 storms which were used to compile hyetographs for each storm showing rainfall intensity over the duration of the storm.

Pollutant Concentrations

Sampling Frequency/season

The pollutants sampled were: fecal indicator bacteria (FIB: *E. coli*, enterococci), total suspended solids, copper, zinc, lead, polyaromatic hydrocarbons, diesel hydrocarbons, and gas hydrocarbons. Samples were collected at each inlet and outlet by filling up each testing container with flowing water as it passed into the weir.

Fecal Indicator Bacteria

Three replicate samples for Fecal Indicator bacteria were collected in sterile 125ml polypropylene containers from each flowing inlet and outlet, placed on ice, and processed within six hours of collection time. Concentrations (Most Probable Number/100 ml) were determined using chromagenic substrate tests (APHA et al. 1998; Standard Methods Section

9223 for *E. coli* and 9230 for Enterococci). IDEXX media Colilert®-18 was used to measure densities of *E. coli* while Enterolert® was used for enterococci (IDEXX Laboratories, Inc., Westbrook, ME). Each sample was diluted to 0.01 (1 mL of sample into 99 mL of dilution water) and quantified using IDEXX Quanti-Tray® 2000 97-well trays. Lab blank controls were included with each collected batch of samples to check for sterility of the dilution water.

Total Suspended Solids

From each flowing inlet and outlet, 1 L of runoff was collected in a polyproplyene container to measure concentrations (mg/L) of total suspended solids using the gravimetric procedure described in APHA et al. (2005; Standard Methods 2540D). Within an hour of collection, up to 1 L of runoff was filtered depending on the concentration of TSS. Samples with elevated TSS resulted in less water being filtered due to clogging of the glass filters, whereas the entire 1-L sample was filtered for other samples.

Metals (Copper, Zinc, and Lead)

Metal runoff samples were collected in Corning® 50 ml self-standing centrifuge tubes. Hydrochloric acid (HCl) was added to each vial after returning to the lab to acidify samples (pH <2.0). Samples were then later processed using Inductively coupled plasma-mass spectrometry (ICP/MS) according to procedures given by U.S. EPA 1996 (EPA Method 1640).

Organics (Polyaromatic Hydrocarbons, Diesel Hydrocarbons, Gas Hydrocarbons)

The organic compounds were collected in 1.0 L amber glass jars, refrigerated, and then transported on ice to the Institute for Integrated Research in Materials, Environments and Society (IIRMES) laboratory for analyses according to EPA Method 8015 (U.S. EPA 2003).

Data Analysis

Water Infiltration

Infiltration data was calculated by comparing the garden's inflows and outflows (Gulliver et al. 2010) with the percent infiltration (% *I*) calculated as follows (Equation 3):

$$\% \, Infiltration = \left((Volume_{\,Inflow} - Volume_{\,Outflow}) \div Volume_{\,Inflow}\right) \times 100\% \qquad (3)$$

A multiple regression analysis was performed (StatPlus: AnalystSoft Inc 2017) using data from the 28 storms measured to determine if any of the three independent variables associated with storms (rainfall intensity (in/min), duration of storm event (min), and total rainfall (in) significantly affected the volume (L) of runoff infiltrated in the garden.

Pollutant Mass Loading and Retention Estimates

The summation of load method (Gulliver et al. 2010) was used to generate mass loading for each pollutant entering and exiting the garden by multiplying the discharge volume of water with the mean concentration of the pollutant during three specific "segments" of the storm hydrograph: the rise, peak, and fall. Discharge volume ($\square_{\square}$) was calculated using Equation 4 below utilizing the trapezoidal rule (Weir et al. 2010). The limits of the integral are chosen to assure that the grab sample times are the actual mid-point times for the rise and peak segments.

$$V_i = \int_{m_i}^{m_{i+1}} Q(t)dt \qquad (4)$$

WHERE:
V_i= Discharge volume for storm segment i
i = 1 *(Rise)*, 2 *(Peak)*, 3 *(Fall)*
m_i= *integral limits* = $\left\{0, \frac{t_{s1}+t_{s2}}{2}, \frac{t_{s2}+t_{s3}}{2}, t_{final}\right\}$
t_{s1}, t_{s2}, t_{s3}= *grab sample times*
$Q(t)$= *flow rate (L/min)*

During a storm event, two to three mean concentrations ($\bar{\square}_1$, $\bar{\square}_2$, $\bar{\square}_3$) for a pollutant were calculated for each segment (□) depending on the storm's duration: one for the flowing inlets, and one for the outlets. This statistic then represented the average pollutant concentration for that segment (Figure 7).

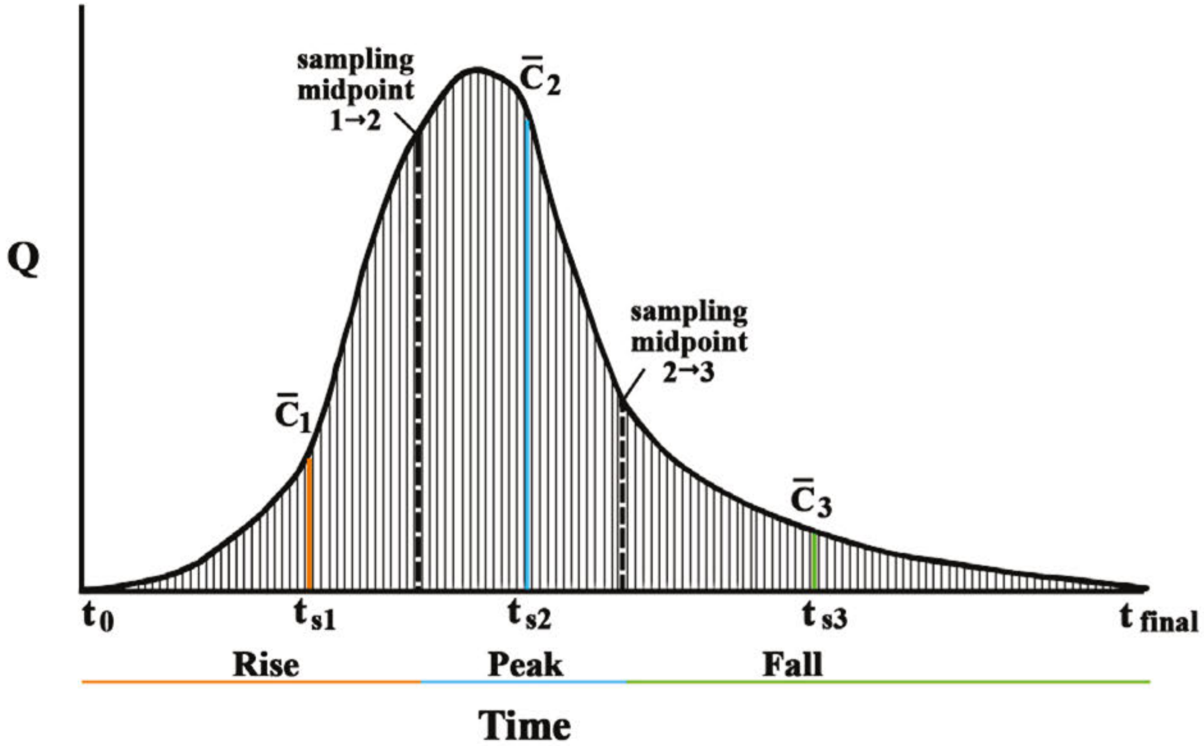


Figure 7. Example of a hydrograph showing the rise, peak, and fall segments as defined by the midpoints for the mean concentrations for each segment ($\bar{C}_1$, $\bar{C}_2$, $\bar{C}_3$). The time period for rise of the storm runs from the starting point to the midpoint between sampling time 1 and sampling time 2. The peak runs from the midpoint between sampling times 1 and 2 to the midpoint of sampling points 2 and 3. The fall runs from the midpoint of sampling times 2 and 3 to the end of the storm.

Once the discharge volume is found using the trapezoidal method, mass loads (□) were calculated using Equation 5 below combining pollutant concentrations ($\square_{\square}$) and total flows ($\square_{\square}$) for the rise, peak, and fall of the storm for all inlets and all outlets, as seen in Figure 7.

$$M = \sum_{i=1}^{3} \bar{C}_i V_i \tag{5}$$

$M = Total\ mass\ loading\ of\ pollutant$
i = 1 (Rise), 2 (Peak), 3 (Fall)
$V_i = Discharge\ volume\ for\ corresponding\ hydrograph\ segment$
$\bar{C}_i = Mean\ pollutant\ concentration\ among\ inlets\ or\ outlets$

The percent retention (□□) for each pollutant then was calculated by comparing mass loads entering and departing the garden as shown in Equation 6, below.

$$Percent\ Retention\ (PR) = \left(1 - \frac{M_O}{M_I}\right) \times 100 \tag{6}$$

WHERE:
$M_O = Total\ mass\ load\ from\ outlets$
$M_I = Total\ mass\ load\ from\ inlets$

Inlet Concentration Variation

After all the concentration data was gathered, the total suspended solids and zinc results were fed into a Kruskal Wallis online calculator (http://scistatcalc.blogspot.com/2013/11/kruskal-wallis-test-calculator.html#) to determine if specific inlets habitually experienced higher pollution levels.

RESULTS

Hydrology

The storm events were highly variable in both duration and size (Table 1). The shortest duration was just over three hours, and the longest was just under 72 hours. The total volume of infiltrated stormwater ranged from just under 80,000 L (20,996 gal) to just under 4 million L (1,034,245 gal). Three storms were targeted each season, with a total of nine storms sampled over the two-year period.

Table 1. Summary data for all storm events surveyed for hydrology over the two-year study. The date, duration, and rainfall amount are shown along with the number of sample sets taken for the storms sampled for pollutant concentrations.

Season	Storm Date	Duration (hr)	Rainfall (cm)	Rainfall (in)	Number of Sample Sets
1	5-Jan-16	24	3.48	1.37	3
1	31-Jan-16	24	0.61	0.24	2
1	5-7-Mar-16	71.98	2.82	1.11	2
1	11-12-Mar-16	23.98	1.12	0.44	2
2	20-21 Nov-16	19.5	1.60	0.63	2
2	26-Nov-16	3.25	0.51	0.2	NS
2	15-16 Dec-16	16.83	3.78	1.49	3
2	21-22 Dec-16	23.58	1.63	0.64	NS
2	30-31-Dec-16	20.42	0.61	0.24	NS

Table 1 continued

Season	Storm Date	Duration (hr)	Rainfall (cm)	Rainfall (in)	Number of Sample Sets
2	31-Dec-16	6.67	0.15	0.06	NS
2	4-5 Jan-17	14	1.07	0.42	2
2	7-Jan-17	5.67	0.18	0.07	NS
2	9-Jan-17	8.25	2.13	0.84	NS
2	10-11-Jan-17	25.42	0.61	0.24	NS
2	11-12 Jan-17	19.5	2.67	1.05	NS
2	19-Jan-17	7.83	1.93	0.76	2
2	20-Jan-17	13.5	2.54	1	NS
2	22-23 Jan-17	27.17	5.77	2.27	NS
2	3-Feb-17	14.67	0.53	0.21	NS
2	6-Feb-17	15.08	1.96	0.77	NS
2	7-Feb-17	13.25	0.91	0.36	NS
2	7-8 Feb-17	13.58	0.15	0.06	NS
2	10-11 Feb-17	18.58	0.99	0.39	NS
2	17-18 Feb-17	27.08	3.94	1.55	3
2	19-20-Feb-17	14	0.13	0.05	NS
2	21-Feb-17	5.17	0.10	0.04	NS
2	26-Feb-17	4.67	0.13	0.05	NS
2	21-22 Mar-17	19	0.30	0.12	NS

* NS indicates hydrology data only (i.e. not sampled for pollutant concentrations)

Hydrographs

A total of 28 hydrographs were created using the flow data from the HOBO units and the intensity data. Within each hydrograph there is an embedded hyetograph showing the rainfall intensity across the storm event using data from the Sawtelle rain gage. Figure 8 shows an example of a smaller storm from November 26, 2016 where roughly 0.5 cm (0.2 in) of rain fell. Along with many of the smaller storms, 100% of the water was retained in this storm, as evidenced by the orange line representing zero recorded outflow across the duration of the storm.

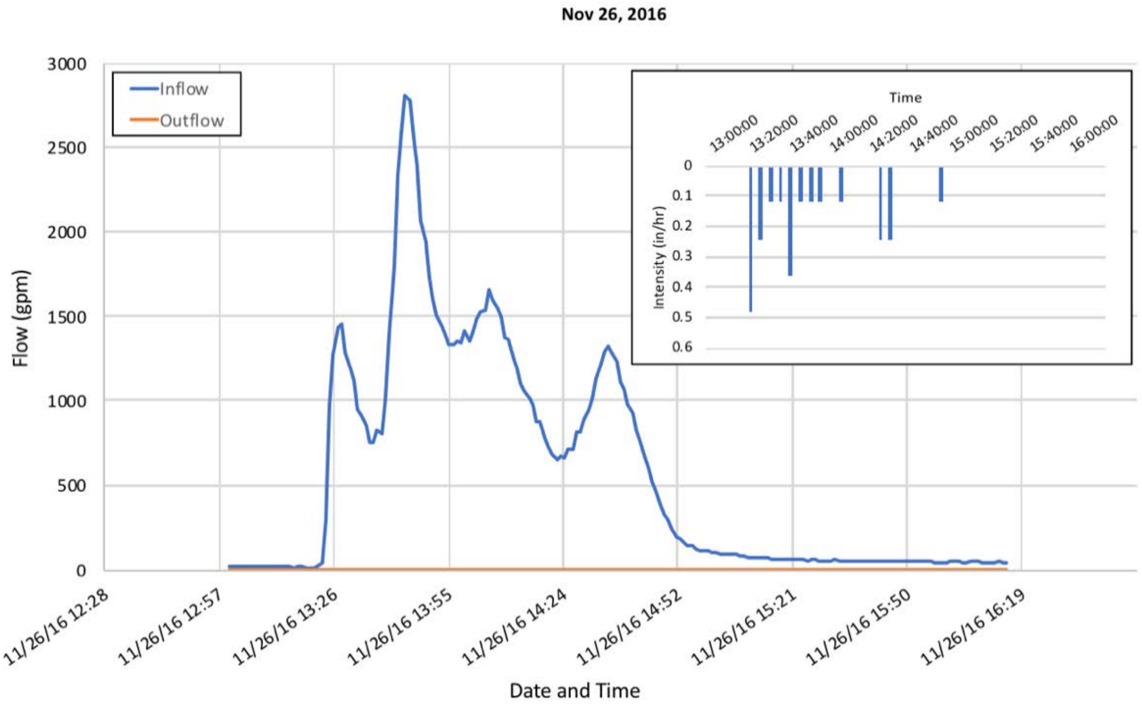


Figure 8. November 26, 2016 storm hydrograph and embedded hyetograph. The blue line shows the combined inflow from all inlets and the orange line shows the combined outflow.

Figure 9 shows an example of a large storm that occurred on January 22-23, 2017 where a total rainfall of 5.77 cm (2.27 in) was recorded. This figure shows the correspondence between the hydrograph and the hyetograph where the similarities between peaks in rainfall intensity and garden flow reflected real-time conditions. This storm retained approximately 75% of the combined inflow. All other hydrographs are displayed in Appendix 1.

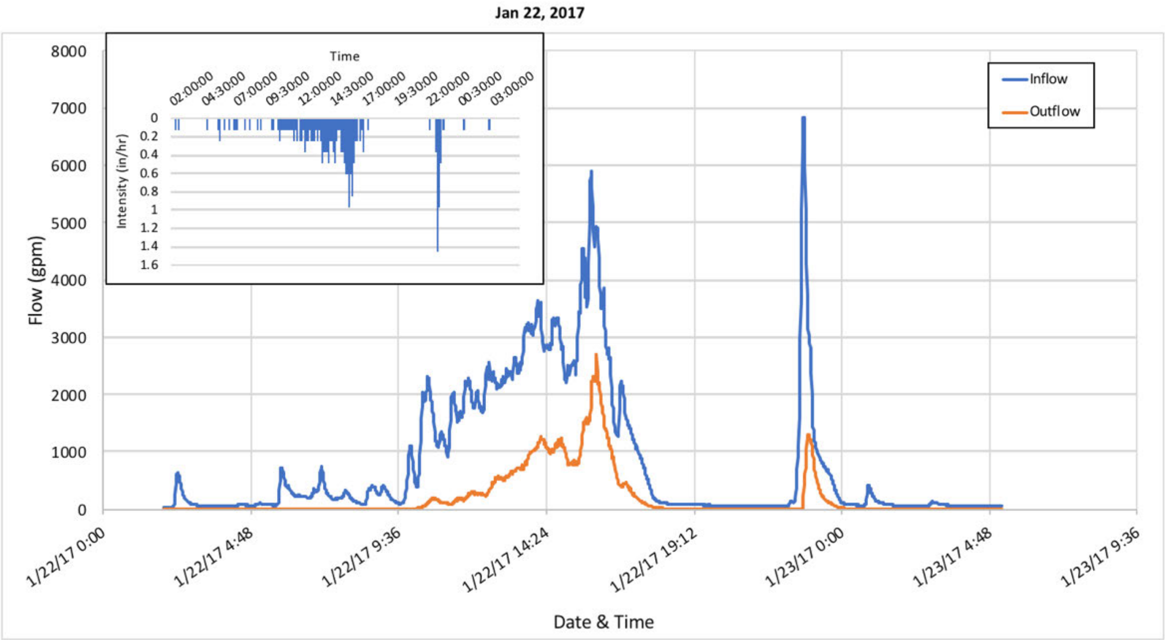


Figure 9. The hydrograph and embedded hyetograph from the January 22-23, 2017 storm.

Infiltration

The garden's infiltration rates ranged from 73% to 100%. During the largest storm in 2017 when 5.77 cm (2.27 in) of rain fell, nearly 4 million L (1 million gal) were infiltrated (Table 1, Figure 10). Even in such a large storm, the garden still infiltrated 75% of the total flow. Ten of the 28 total storms recorded had 100% infiltration within the garden. These smaller storms are seen on the left side of Figure 10, indicating the least amount of volume infiltrated but the highest infiltration percentage. The trend lines show high correlation, with $R^2 = 0.77$ for percent volume as the blue line, and $R^2 = 0.93$ for total volume infiltrated as the orange line. This trend is supported by the corresponding multiple regression analysis for the garden's infiltration capacity where total rainfall significantly predicted infiltration ($p < 0.05$) but rainfall intensity and storm duration were not significant ($p > 0.05$) (Table 2).

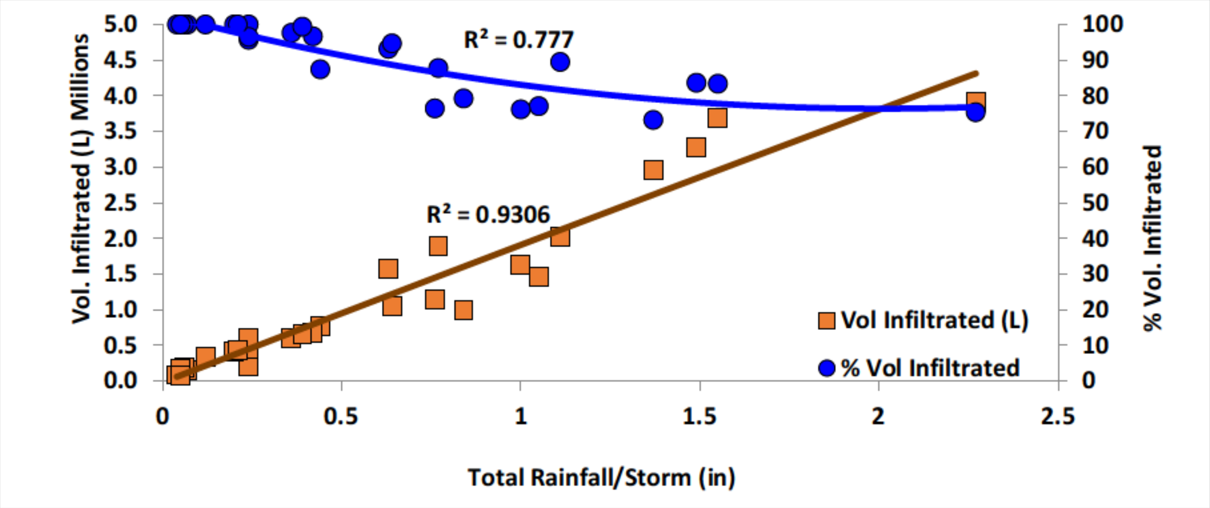


Figure 10. Relationship between total infiltration and percent infiltration per storm.

Table 2. The multiple regression analysis using the StatPlus software showing rainfall intensity (in/min), duration of storm event (min), and total rainfall (in) and their effect on the total volume of water infiltrated in the garden.

	Coefficient	Standard Error	LCL	UCL	t Stat	p-value	H_0 (5%)
Intensity (in/min)	809,847.80	1,126,861.92	-1,515,880.90	3,135,576.49	0.72	0.48	Accept
Duration (min)	39.82	85.76	-137.18	216.81	0.46	0.65	Accept
Total Rainfall (in)	1,856,122.54	129,792.16	1,588,244.69	2,124,000.39	14.30	<0.001	Reject

Pollutant Concentrations

Pollutant concentrations were variable across individual storm events as well as time periods within the storms. Among the nine sampled storms, the average concentration by storm event was frequently higher in the inlets than the outlets for all pollutants (Table 3). Eight out of 18 average concentrations by storm event for fecal indicator bacteria were greater in the outlet than then inlet (Table 3). The organics as a group had five out of 24 occurrences of higher average outlet concentrations compared to average inlet concentrations by storm. The metals and total suspended solids each had a single higher outlet concentration (one out of 27 for metals and one out of nine for total suspended solids).

Table 3. Mean concentrations of pollutants for each storm sampled with the total number of samples taken throughout the storm (n), the standard error of the mean (SE), and the range of the values for all inlets and outlets. This table does not reference time period within storms; each value is reflective of all data throughout the entire storm ("--" indicates the inlet or outlet was not flowing and "nd" indicates no sample was collected).

E Coli								
		Inlet MPN/100mL				**Outlet MPN/100mL**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	39	3042	705	100-20140	12	581	81	200-1210
1/31/16	21	2280	641	100-9320	3	3510	273	3130-4040
3/5/16	21	7257	1873	200-324550	12	5117	678	2530-9590
3/11/16	24	4647	1590	100-27550	6	237	44	100-410
11/20/16	24	2425	380	100-5650	3	16877	177	16700-17230
12/15/16	42	7492	2261	100-48840	6	4952	186	4260-5450
1/5/17	24	638	107	100-1600	3	240	70	100-310
1/19/17	30	654	139	100-2880	9	511	109	100-1180
2/17/17	39	2138	402	100-8620	6	5762	1579	2010-10860
Enterococci								
		Inlet MPN/100mL				**Outlet MPN/100mL**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	39	9284	1487	1200-51720	12	7528	2173	2260-12740
1/31/16	24	12998	2171	1680-34480	3	7390	1274	5560-9840
3/5/16	21	7012	1286	410-19350	12	6721	1005	2330-15150
3/11/16	24	5276	1136	1350-26130	6	6885	1052	4480-10220
11/20/16	24	7376	1212	410-20640	3	32143	5888	23820-43520
12/15/16	42	7377	2507	200-81640	6	6862	1765	2500-12100
1/5/17	24	2883	864	100-15650	3	2967	177	2720-3310
1/19/17	30	1906	511	100-11780	9	3858	522	1950-6760
2/17/17	39	6583	1151	200-30760	6	8008	682	5460-9880
Total Suspended Solids								
		Inlet mg/L				**Outlet mg/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	12.2	3.1	0.8-37.2	4	24.4	12.3	0-54
1/31/16	8	1.6	0.6	0.2-3.2	1	0.8	--	--
3/5/16	7	0.8	0.5	0-3	4	0.6	0.5	0-2
3/11/16	8	7.1	2.7	0.1-19.6	2	7	6.9	0.1-13.8

Table 3 continued

11/20/16	8	9.3	4.1	1.7-37.9	1	1.5	--	--
12/15/16	14	23.8	6.4	0.1-74.4	2	0.5	0.3	0.2-0.8
1/5/17	8	17.7	5.9	1.2-49.3	1	2.2	--	--
1/19/17	10	7.6	1.7	1.9-19.1	3	2.2	1	1.2-4.3
2/17/17	13	26.7	13.6	1.7-181.5	2	2.4	0.2	2.2-2.6
Copper (Cu-65)								
		Inlet ug/L				**Outlet ug/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	3.7	0.5	1.4-6.5	4	2.5	0.5	1.3-3.6
1/31/16	8	2.6	0.3	1.7-3.8	1	1.7	--	--
3/5/16	7	3.1	0.5	2.0-5.65	4	1.2	0.1	1.1-1.4
3/11/16	8	19.6	4	7.5-44.3	2	16	5.7	10.3-21.7
11/20/16	8	60.2	5.9	35.7-91.2	1	55.8	--	--
12/15/16	14	68.2	9.6	33.6-144	2	27.9	4.1	23.8-31.9
1/5/17	8	38.3	5.4	22.4-63.8	1	18.3	--	--
1/19/17	10	12	7.2	2.1-76.7	3	5.1	0.7	4.1-6.5
2/17/17	13	13.6	3.5	2.7-41.9	2	5	1.9	3.1-7.0
Zinc (Zn-66)								
		Inlet ug/L				**Outlet ug/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	24.3	3.7	9.5-50.8	4	8.8	1.5	5.9-12.9
1/31/16	8	23.7	3.4	8.9-37.4	1	8.9	--	--
3/5/16	7	45.8	7.8	14.6-82.6	4	21.1	2.4	15.4-27.2
3/11/16	8	249.9	56.7	105.8-508.6	2	158.9	10.9	148-170
11/20/16	8	472.3	48	290.3-621.1	1	444.1	--	--
12/15/16	14	459.3	38.1	247.1-709.1	2	196.7	2.5	194.1-199.3
1/5/17	8	493.7	50.4	283.6-649.3	1	320.3	--	--
1/19/17	10	144.7	20.1	61.7-272.2	3	115.8	6.4	106.1-127.9
2/17/17	13	190.4	22.6	110.9-373.8	2	163.3	31.6	131.7-194.9
Lead (Pb-208)								
		Inlet ug/L				**Outlet ug/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	0.5	0.1	0-1.5	4	0.2	0.1	0-0.5

Table 3 continued

1/31/16	8	0.03	0.01	0-0.09	1	0	--	--
3/5/16	7	0.05	0	0-0.3	4	0.06	0	0-0
3/11/16	8	4.4	1.4	0.1-10.4	2	2.1	1.7	0.4-3.9
11/20/16	8	18.2	6.1	7.6-58.7	1	12.4	--	--
12/15/16	14	18.4	2.4	7.1-32.9	2	11.7	5.8	5.9-17.5
1/5/17	8	9.3	2.5	2.7-20.2	1	5.9	--	--
1/19/17	10	1	0.2	0.4-1.8	3	0.7	0.1	0.5-0.9
2/17/17	13	1.7	0.5	0.4-6.6	2	1.2	0.6	0.6-1.9
Polyaromatic Hydrocarbons								
		Inlet ug/L				**Outlet ug/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	14.9	2.7	3.3-35.4	4	13.3	5.9	1.7-25.3
1/31/16	6	8.3	2.1	1.1-14	1	18.6	--	--
3/5/16	7	2.7	0.9	0.58-6.1	4	7.3	2.1	3.2-11.4
3/11/16		nd	nd	nd	nd	nd	nd	nd
11/20/16	7	16.2	4.9	4.3-41.4	1	5.7	--	--
12/15/16	14	48.8	8.7	5.3-114.9	2	10.4	5.2	5.1-15.6
1/5/17	8	9.1	1.7	1.7-15.3	1	1.6	--	--
1/19/17	10	4.4	0.9	0.4-10.1	3	2.5	1.1	0.8-4.4
2/17/17	13	21.5	9.9	0.9-117.2	2	3	0.8	2.3-3.8
Diesel Hydrocarbons								
		Inlet ug/L				**Outlet ug/L**		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	0.11	0.02	.04-.22	4	0.08	0.01	0.05-0.11
1/31/16	6	847.1	750.8	75.5-4601	1	110.7	--	--
3/5/16	7	116.2	0	35.8-249.2	4	58.8	6	40.9-66.0
3/11/16		nd	nd	nd	nd	nd	nd	nd
11/20/16	7	83.2	5.7	69.9-113.7	1	98.7	--	--
12/15/16	14	80.4	14.2	26.8-221.1	2	51.2	26.1	25.1-77.2
1/5/17	8	87.6	10.2	44.8-130	1	37.7	--	--
1/19/17	10	43.5	3.8	21.9-61.2	3	46.8	9.3	35.7-65.4
2/17/17	13	205.2	57.5	23.3-498.6	2	104.1	82.2	21.9-186.3

Table 3 continued

Motor Oil Hydrocarbons								
		Inlet ug/L				Outlet ug/L		
Storm	**n**	**Mean**	**SE**	**range**	**n**	**Mean**	**SE**	**range**
1/5/16	12	0.01	0	.004-0.02	4	0.005	0	0.002-0.008
1/31/16	6	32.8	18.6	3.6-122.3	1	2.7	--	--
3/5/16	7	115.7	0	16.3-377.5	4	170.9	71.5	53.9-362.2
3/11/16		nd	nd	nd	nd	nd	nd	nd
11/20/16	7	380	107.3	68-805.3	1	81.5	--	--
12/15/16	14	318.8	62.6	89.7-941.6	2	100.1	42.2	57.9-142.3
1/5/17	8	248.3	60.1	62.4-544.3	1	44.4	--	--
1/19/17	10	90	12.5	14.1-170.9	3	62.6	9.5	45.1-77.8
2/17/17	13	329	121.7	50-1529.3	2	82.1	35.2	46.9-117.2

Both inlet and outlet concentrations for Enterococci samples tended to have higher concentrations than their *E. coli* counterparts. The bacteria counts also showed extreme variation, as seen in the range column in Table 3. On March 5, 2016, the lowest *E. coli* inlet concentration was 200 MPN/100mL, but the peak reached 324,550 MPN/100mL; whereas, the lowest outlet concentration for *E. coli* during the same storm was 2,530 MPN/100mL and the peak was 9,590 MPN/100mL.

Metals all tended to have greater mean concentrations among the inlet samples relative to the outlets. Zinc had the highest concentrations overall with mean values ranging from 23.7 ug/L to 493.7 ug/L followed by copper ranging from 2.6 to 68.2 ug/L. Lead displayed the lowest mean concentrations ranging from 0.03 ug/L to 18.4 ug/L.

Like metals, mean concentrations of the organic pollutants tended to be greater in samples from the inlets relative to those sampled from the outlets. Concentrations for both diesel and motor oil hydrocarbons had a very wide range over all storm events. Diesel mean concentrations ranged from 0.1 ug/L to 847 ug/L and motor oil mean concentrations ranged from 0.01 ug/L to 380 ug/L, both displaying wide variation. The polyaromatic hydrocarbons had much smaller range of mean concentrations (2.7 ug/L to 48.8 ug/L), which may indicate a higher level of stability within the environment (Table 3).

A Kruskal-Wallis analysis of variance was completed using mean values of TSS and zinc to test if specific inlets experienced significantly higher pollution levels regularly. These two pollutants were selected given their relatively high concentrations throughout the study. On a per storm basis, the tests showed no significant differences among inlets ($p > 0.05$) for either pollutant, most likely due to the variability displayed over each storm.

Mass Loading

Mean pollutant concentrations were calculated for the rise, peak, and/or falling periods of each storm (Table 4, Figure 7) using sampling results that were integrated with flow data to estimate the mass of pollutants entering and exiting the garden. Table 4 shows the concentrations used for calculating the mass load of pollutants on a per storm basis. In contrast to the concentrations, mass loading into the garden was always greater from the five inlets relative to the mass of pollutants leaving the garden via the two outlets, resulting in overall pollutant retention for every storm (Table 5).

Table 4. Mean pollutant concentration used in mass loading calculations for every storm sampled. The C1, C2, and C3 values for inlets and outlets were then combined with flow data as specified in Equation 5 (Methods) to calculate mass loads. See Figure 7 for details on how concentrations were determined ("--" = inlet or outlet not flowing, nd = sample not collected).

E. coli						
	Inlet Mass Loading Calculation Inputs MPN/L			**Outlet Mass Loading Calculation Inputs MPN/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	24417	17558	55775	4467	5450	7863
1/31/16	30708	12266	--	35100	--	--
3/5/16	86867	53500	--	43983	58350	--
3/11/16	29867	63075	--	1667	3067	--
11/20/16	22417	26075	--	--	168767	--
12/15/16	78520	47633	104517	--	49600	49433
1/5/17	7575	5175	--	2400	--	--
1/19/17	4093	8987	--	2733	6300	--

Table 4 continued

2/17/17	19558	36320	4533	--	57617	--
Enterococci						
	Inlet Mass Loading Calculation Inputs MPN/L			**Outlet Mass Loading Calculation Inputs MPN/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	67458	70917	137617	102967	86233	25700
1/31/16	105366	154583	--	73900	--	--
3/5/16	68075	72844	--	56967	77450	--
3/11/16	67042	38475	--	90667	47033	--
11/20/16	76583	70933	--	--	321433	--
12/15/16	40553	32400	167017	--	107167	30067
1/5/17	44783	12867	--	29667	--	--
1/19/17	12427	25687	--	33933	40900	--
2/17/17	141017	36140	27758	--	80083	--
Total Suspended Solids						
	Inlet Mass Loading Calculation Inputs mg/L			**Outlet Mass Loading Calculation Inputs mg/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	8.7	16.5	11.5	8.8	44.3	0
1/31/16	0.9	2.3	--	0.8	--	--
3/5/16	0.1	1.7	--	1	0.2	--
3/11/16	13.6	0.6	--	13.8	0.1	--
11/20/16	14.4	4.1	--	1.5	--	--
12/15/16	41.5	12.3	15.9	--	0.8	0.2
1/5/17	16.8	18.6	--	2.2	--	--
1/19/17	10.1	5.1	--	4.3	1.2	--
2/17/17	70.7	8.4	5.5	--	2.4	--
Copper (Cu-65)						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	2.4	4.4	4.2	3.3	2.7	1.3
1/31/16	2.7	2.6	--	1.7	--	--
3/5/16	2.5	3.8	--	1.2	1.3	--
3/11/16	24.3	15	--	21.7	10.3	--
11/20/16	65	55.3	--	55.8	--	--

Table 4 continued

12/15/16	94.5	43.2	66.7	--	23.8	31.9
1/5/17	35.8	40.7	--	18.3	--	--
1/19/17	5	18.9	--	6.5	4.4	--
2/17/17	30.8	4.8	7.4	--	5	--
Zinc (Zn-66)						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	17.2	29.2	26.7	9.1	10.1	5.9
1/31/16	22.4	25.1	--	8.9	--	--
3/5/16	47.6	43.4	--	21.3	20.9	--
3/11/16	300.1	199.6	--	148	169.9	--
11/20/16	490.6	454	--	444.1	--	--
12/15/16	468	380.5	547.1	--	194.2	199.3
1/5/17	478.6	508.8	--	320.3	--	--
1/19/17	162.6	126.9	--	113.4	117	--
2/17/17	291.7	131.9	162.2	--	163.3	--
Lead (Pb-208)						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	0.3	0.8	0.4	0.13	0.3	0
1/31/16	0.01	0.06	--	0	--	--
3/5/16	0.07	0.03	--	0.04	0.1	--
3/11/16	5.5	3.2	--	3.9	0.4	--
11/20/16	25	11.5	--	12.4	--	--
12/15/16	24.9	12.8	17.1	--	5.9	17.5
1/5/17	8.7	10	--	5.9	--	--
1/19/17	0.9	1	--	0.9	0.6	--
2/17/17	3.7	0.7	0.9	--	1.2	--
Polyaromatic Hydrocarbons						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	11.6	14.3	19	25.3	13.1	1.7
1/31/16	4.1	12.5	--	18.6	--	--

Table 4 continued

3/5/16	2.9	2.4	--	6.8	7.8	--
3/11/16						
11/20/16	26.4	8.6	--	--	5.7	--
12/15/16	77.5	29.4	37	--	15.6	5.1
1/5/17	8.4	9.8	--	1.6	--	--
1/19/17	4.4	4.5	--	4.4	1.5	--
2/17/17	60.2	6.1	2.2	--	3	--
Diesel Hydrocarbons						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	0.106	0.107	0.11	0.1	0.1	0.05
1/31/16	1611.5	82.7	--	110.7	--	--
3/5/16	97.5	141.2	--	64.1	53.5	--
3/11/16						
11/20/16	88.1	79.6	--	--	98.7	--
12/15/16	134.1	53.7	46.4	--	77.2	25.1
1/5/17	85.2	90	--	37.7	--	--
1/19/17	52.4	34.6	--	65.4	37.6	--
2/17/17	307	146.7	176.5	--	104.1	--
Motor Oil Hydrocarbons						
	Inlet Mass Loading Calculation Inputs ug/L			**Outlet Mass Loading Calculation Inputs ug/L**		
Storm	**C1 Rise**	**C2 Peak**	**C3 Fall**	**C1 Rise**	**C2 Peak**	**C3 Fall**
1/5/16	0.008	0.01	0.01	0.005	0.006	0.002
1/31/16	50.3	15.3	--	2.7	--	--
3/5/16	142.1	80.5	--	125.8	215.9	--
3/11/16						
11/20/16	555.9	248.1	--	--	81.5	--
12/15/16	432.2	251.8	260.8	--	142.3	57.9
1/5/17	291	205.7	--	44.4	--	--
1/19/17	105.5	74.5	--	77.8	55	--
2/17/17	789	120.3	129.8	--	82.1	--

Using the concentrations from Table 4, masses of pollutants were calculated for rise, peak, and/or fall segments for each inlet and outlet per storm and then summed to get a total mass. Figures 11 through 19 display mass loading data and retention for each analyte. The overall average retention across the nine storms with all nine analytes was 90.1% (Table 5); the means and standard errors are grand means of the data shown in Figures 11 to 19. For FIB, Enterococci had higher masses for both inlets (154.3 ± 45.7 MPN X 10^9) and outlets (20.8 ± 5.9 MPN X 10^9) compared to *E. coli* (113.3 ± 50.4 MPN X 10^9 and 10.8 ± 4.7 MPN X 10^9), but the average retention within the garden was slightly higher for *E. coli* (87.2% ± 5.2) relative to Enterococci (83.3 ± 4.8%) (Figures 11 and 12). Enterococci had the lowest average % retention within the garden for all nine pollutants. Total suspended solids displayed considerable variability in percent retention, ranging from 47.1 – 99.7% (Figure 13). The average mass of Zinc entering the garden surpassed the other metals by a substantial margin, with averages of 474.8 ± 195.5g versus 52.0 ± 26.1g and 12.6 ± 7.2g for copper and lead, respectively. Despite the difference in inlet and outlet masses, the average retention rates for all metals were very similar, ranging from 92.2 ± 1.8% - 92.9 ± 1.3% (Table 5, Figures 14 to 16). The organics mass trends were similar to their concentration trends, with PAHs again much lower than both diesel and motor oil mass inputs (Figures 17 to 19, Table 5). Motor oil hydrocarbons displayed high input masses at an average of 432.5 ± 172.6 g, but they also experienced the highest retention within the garden at 94.1 ± 2.0 %. Data per storm used to generate means in Table 5 are given in Appendix 2.

Table 5. The average mass of each pollutant measured at the inlets and outlets, the retention within the garden, and the percent retention. The number of storms (n) used in calculating the mean and standard error (SE) are shown for each.

		Inlets		**Outlets**		**Retention**		**% Retention**	
Pollutant	**n**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
E. coli (MPN X 10^9)	9	113.3	50.4	10.8	4.7	102.5	48.7	87.2	5.2
Enterococci (MPN X 10^9)	9	154.3	45.7	20.8	5.9	133.5	42.7	83.3	4.8
Total Suspended Solids (kg)	9	27.2	11.6	2.8	1.8	24.9	11.6	88.1	5.8
Copper (g)	9	52.0	26.1	3.7	2.0	48.3	24.1	92.9	1.3
Zinc (g)	9	474.8	195.5	38.5	15.1	436.3	181.8	92.2	1.8
Lead (g)	9	12.6	7.2	1.3	0.9	11.3	6.4	92.5	1.6
Total PAHs (g)	8	39.2	19.5	1.9	0.8	37.3	18.9	89.9	3.5
Diesel hydrocarbons (g)	8	221.0	92.8	15.9	7.4	205.1	86.4	90.4	2.7
Motor oil hydrocarbons (g)	8	432.5	172.6	19.2	7.6	413.3	165.9	94.1	2.0

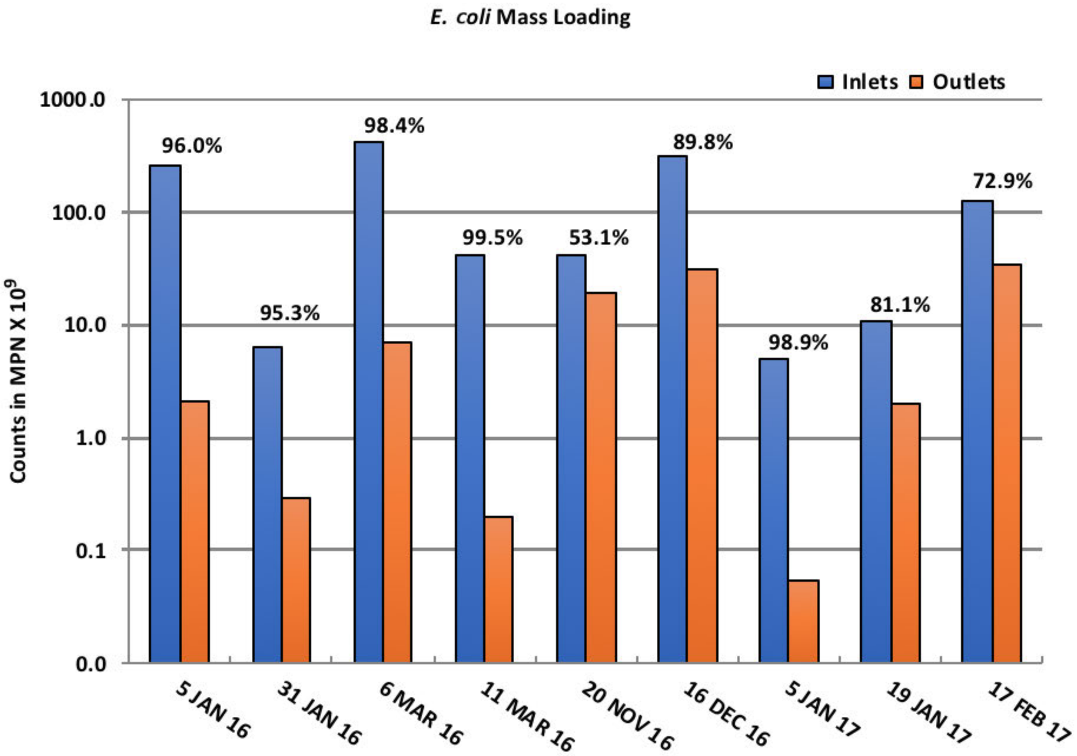


Figure 11. The mass (log scale) of E. coli measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

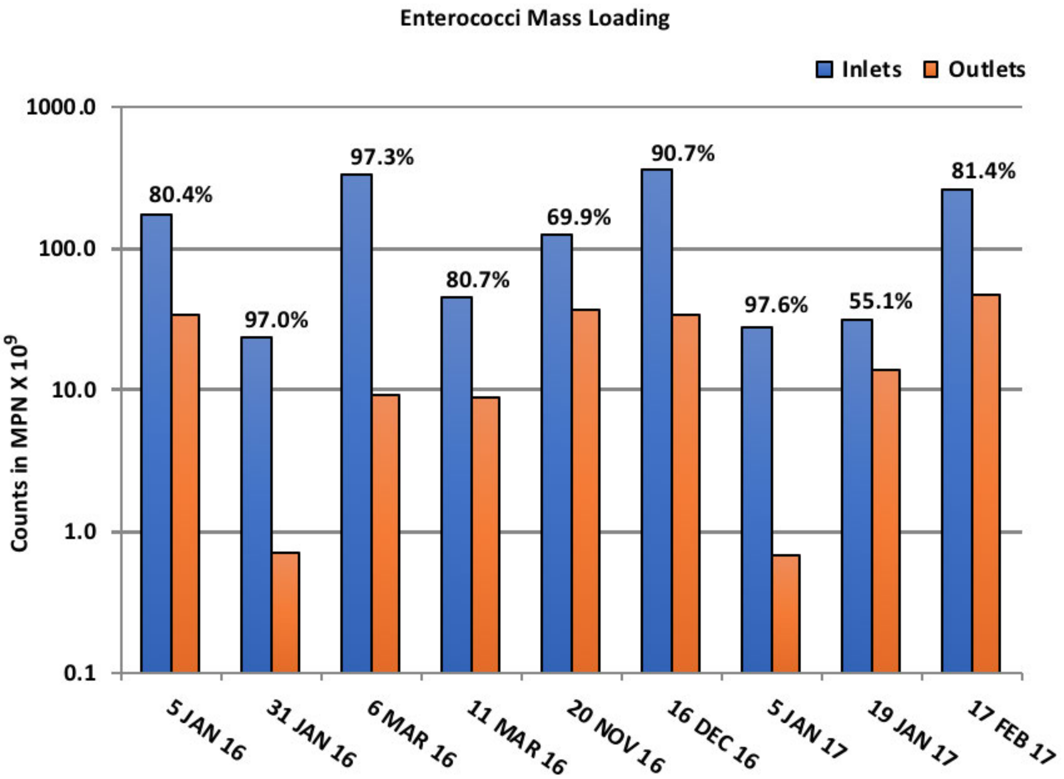


Figure 12. The mass (log scale) of Enterococci measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

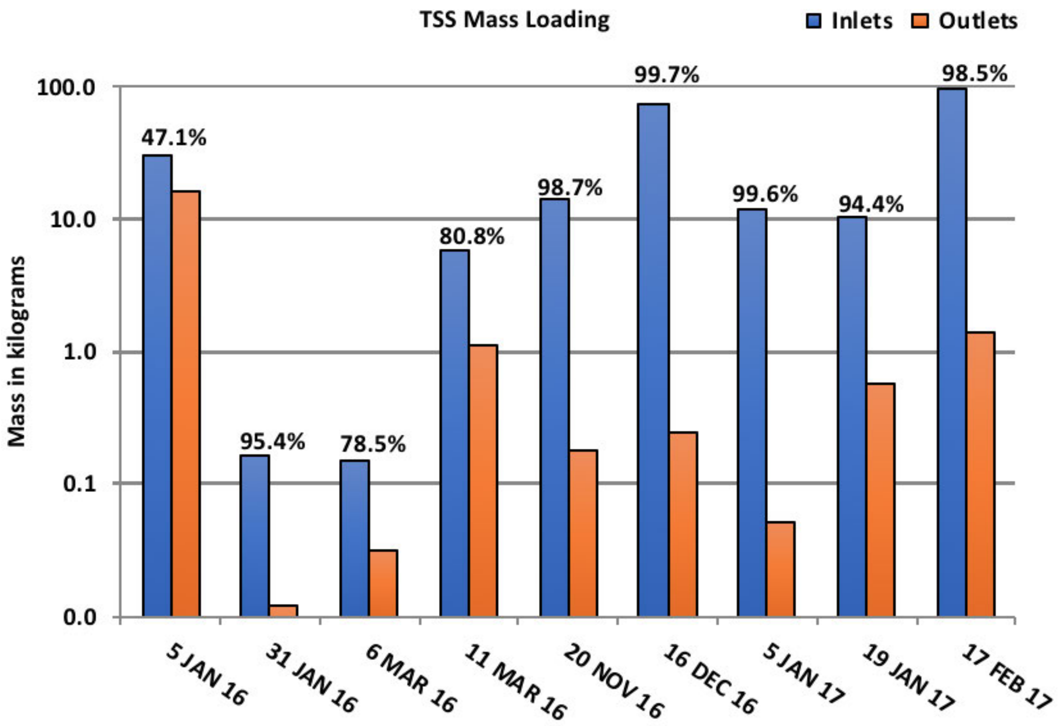


Figure 13. The mass in kilograms (shown in a log scale) of total suspended solids measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

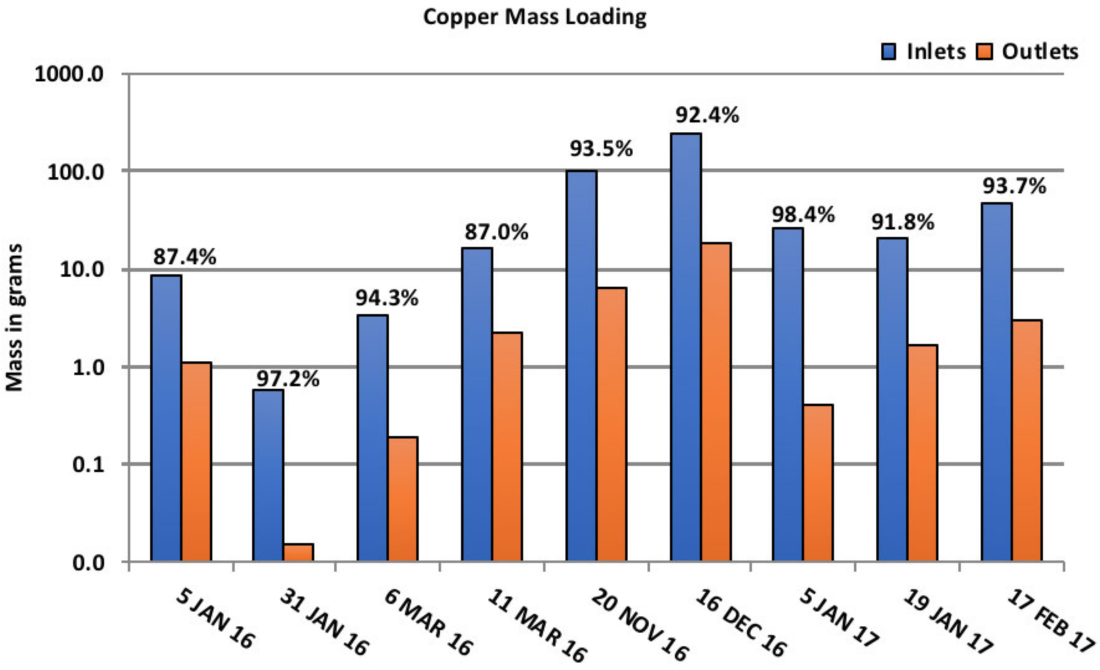


Figure 14. The grams of mass (log scale) of Copper measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

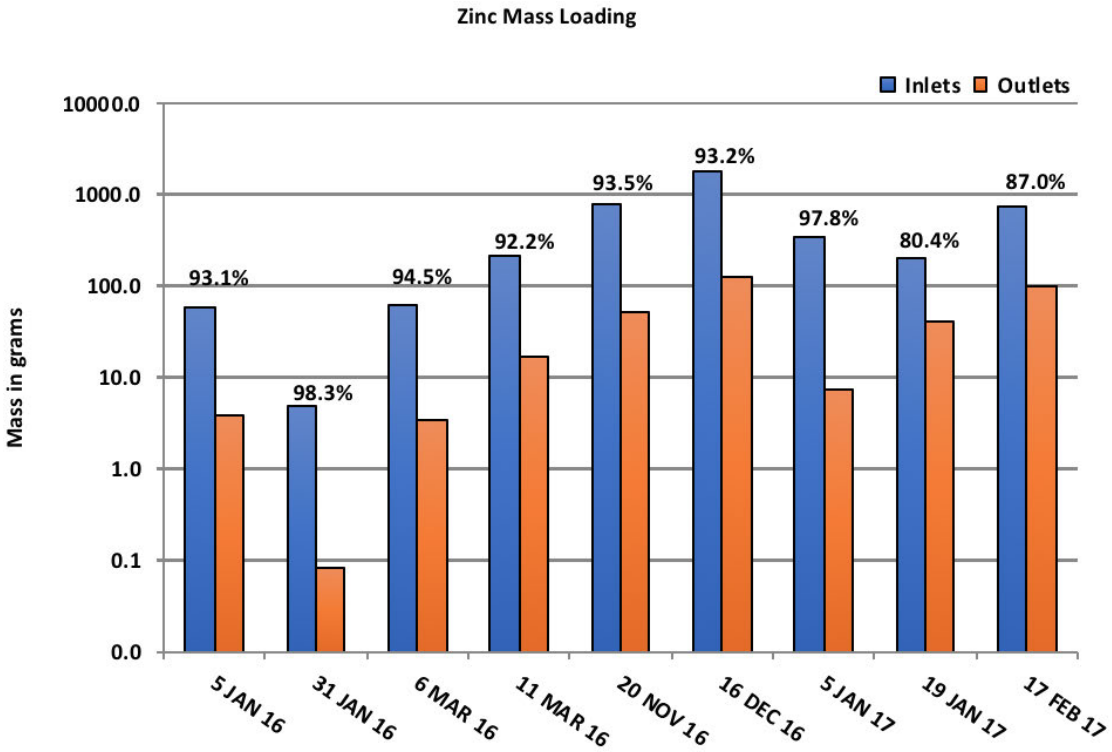


Figure 15. The mass (log scale) of Zinc measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

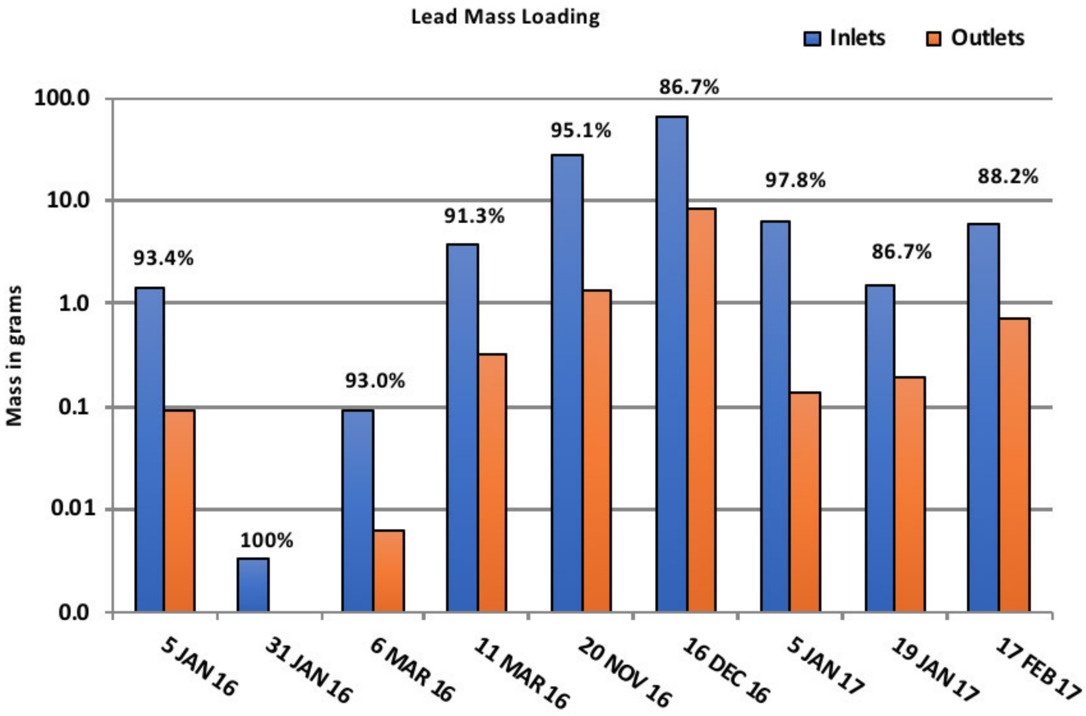


Figure 16. The mass (log scale) of Lead measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm. The lead measurements taken at outlets for the January 31, 2016 storm were 0 ug/L, so the outlet mass is absent for this figure.

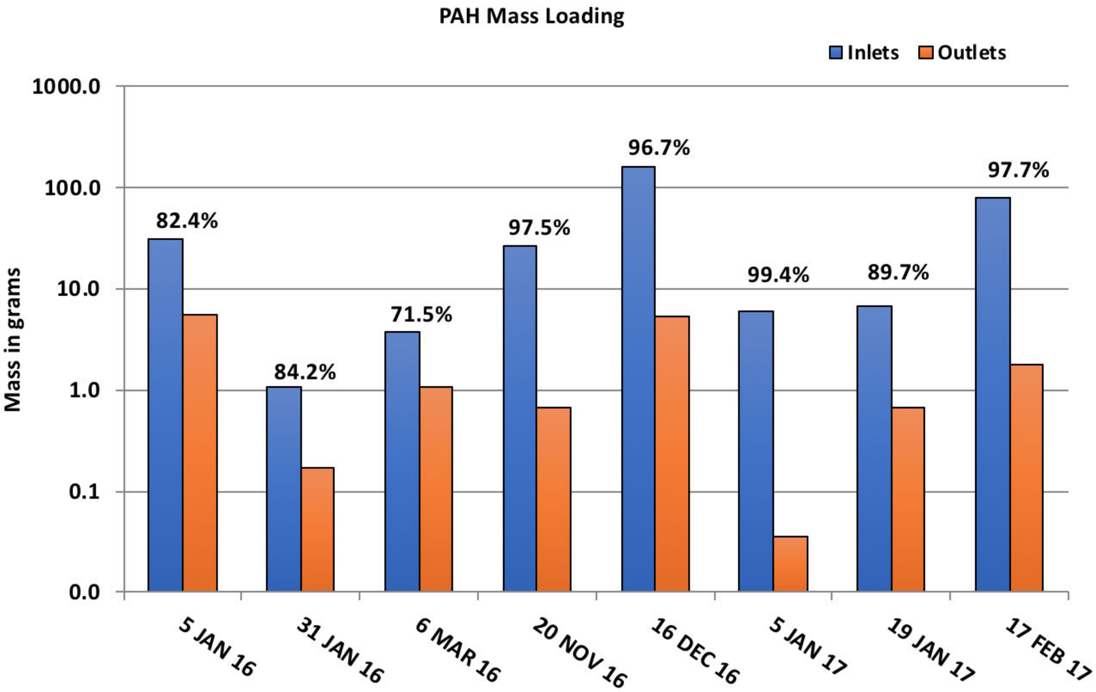


Figure 17. The mass (log scale) of polyaromatic hydrocarbons measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

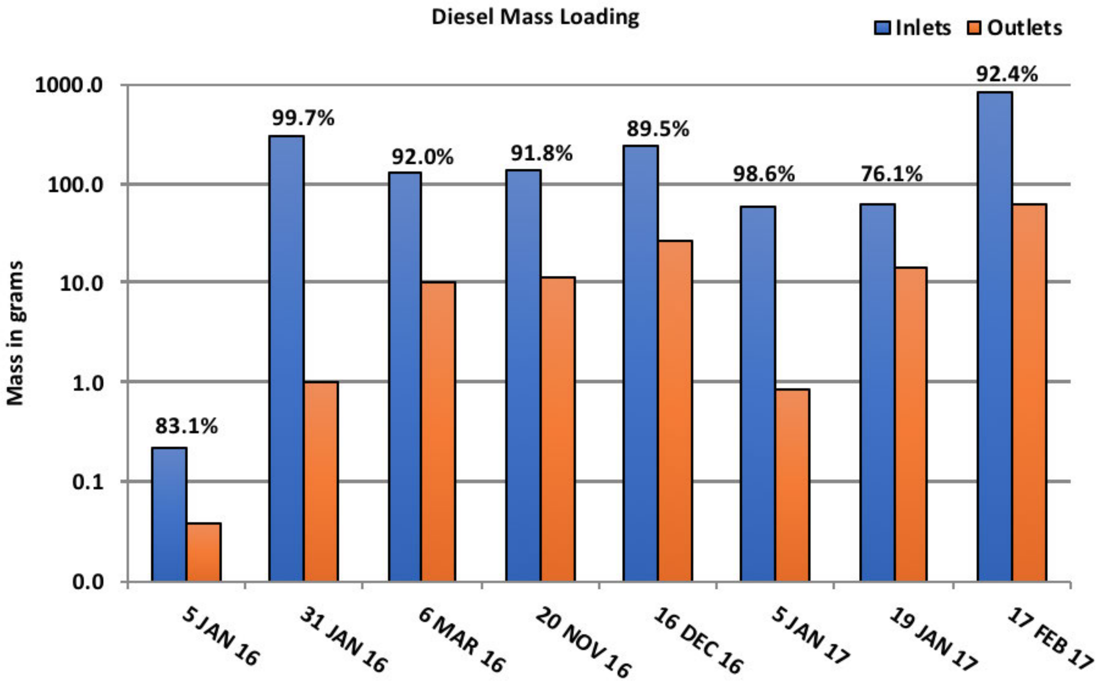


Figure 18. The mass (log scale) of diesel hydrocarbons measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

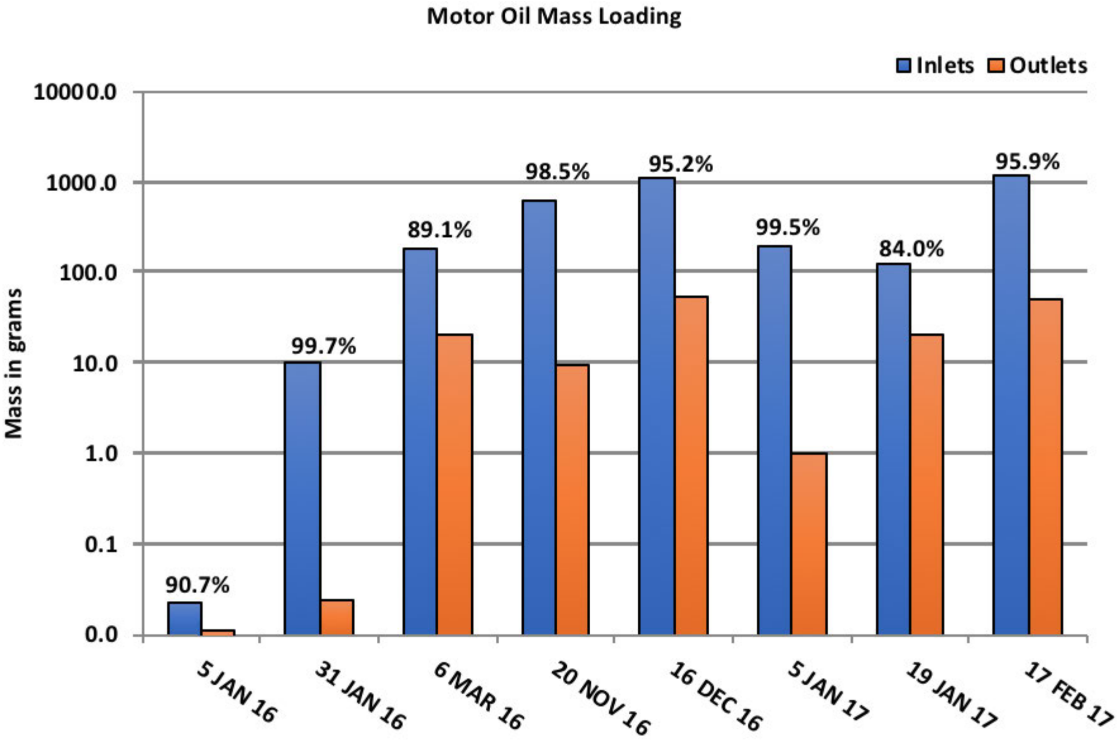


Figure 19. The mass (log scale) of motor oil hydrocarbons measured at the inlets (shown in blue) and outlets (shown in orange) along with the percent retention for each storm.

DISCUSSION AND CONCLUSIONS

System Performance

The Ballona Creek Rain Garden continues to perform well six years after its original construction. The data from this study show that these systems are capable of retaining large amounts of urban stormwater as well as associated pollutants and can also effectively capture and retain dry-weather runoff. The capture of dry-weather flow was observed on multiple occasions at the BCRG. Runoff from landscape irrigation and car washes frequently made its way to the garden (primarily the southern end) and formed a small pond area before infiltration occurred. It was assumed that all dry-weather runoff was quickly infiltrated within the garden, although it was not included in the infiltration volume calculations. Discounting this dry-weather flow, the BCRG conservatively retained 31.6 million L of urban stormwater over a two-year period, with an average of 1.13 million ± 0.2 million L per storm.

The pollutant retention capacity of this garden compares favorably with other biofiltration studies, offering further proof of their efficiency in southern California and other arid climates. A field-scale study of two bioretention systems in southeast Australia found averages of 80-90% retention for suspended solids and heavy metals (Hatt et al. 2009). A study of a North Carolina biofiltration system reported average reductions of 69% for fecal coliform counts and 71% for *E. coli* counts, corroborating results from this study (Hunt et al. 2008). Although environmental data for metals and bacteria are highly variable by nature, the Ballona Creek Rain Garden achieved comparable pollutant mass retention levels with average percentages for FIB retention above 80%, organics above 89%, TSS at 88%, and metals greater than 90% (Table 5). The similarities between mass loading results from this study and published results from other systems, taken with the well-documented methodology for mass loading calculations, indicate high validity for the study as a whole.

Within Mediterranean climates like Los Angeles, biofiltration systems can be especially effective in meeting TMDL requirements. As mentioned previously, Ballona Creek has TMDLs for both bacteria and metals. In order to comply with water quality requirements within the TMDL for bacteria in Ballona Creek, several projects were considered and drafted within an environmental impact report. The Final Environmental Impact Report for the Ballona Creek Bacteria TMDL Project lists three project proposals (Catalyst Environmental Solutions Corporation 2018). One of these proposed projects uses a pump station to transport 3.6 million L/day (0.96 MGD) of dry weather runoff to Hyperion Water Reclamation Plant for treatment. On February 17 and 18, 2017, the Ballona Creek Rain Garden captured 0.97 million gal of stormwater. Although this was not dry-weather flow, this was the impact from a single project. If more of these biofiltration systems were constructed along the Creek, the collective impact from multiple biofiltration projects dispersed along the creek could be significant.

Assumptions

It is important to note some study assumptions and analyses constraints. One key assumption was related to inflow and outflow; outflow is assumed to equal inflow minus infiltration, discounting any effects evaporation may have. The representativeness of grab samples with the timing of the sampling sets is another key assumption. The use of grab samples is assumed to represent average pollutant concentrations at rise, peak, and fall segments within storms, and the timing of the sampling runs corresponded with these segments. Timing of sampling runs for storm events was planned using real-time radar observations from the National Weather Services' Los Angeles-Oxnard Forecast Office (https://www.weather.gov/lox/) to capture the first *steady* rainfall, the peak of the storm, and the falling point before rainfall ceased. With regard to variation between inlet concentrations, the Kruskal Wallace tests were not performed for every analyte; total suspended solids and zinc were chosen for their relatively high concentrations and were assumed to represent the patterns of the other analytes. Since the variability between storms was more significant than the variability between inlets for both TSS and zinc, the other analytes are likely to present similar patterns of significance as the differences in their values were similar.

Despite these assumptions, the study most likely *underestimated* infiltration data. Portions of the runoff at Inlet 3 was observed on several occasions to bypass the v-notch weir, and no data were collected from Inlet 5 during the first season. The volume of water that bypassed the v-notch weir was not included in the flow calculations, but still received by the garden, leading to underestimation of infiltration results. This indicates the amount of water infiltration for BCRG is actually *greater* than 31.6 million L over the two-year period, and the average per storm infiltration is over 1.13 million ± 0.2 million L.

Management

Although the performance of the garden showed high success rates, it's possible for management issues like maintenance to hinder the efficiency of similar systems. System longevity is an important component in planning and construction of rain gardens. Issues like lack of funding for upkeep and maintenance can actually shorten their lifespan. The design goals (i.e. metal retention or peak flow attenuation) must be carefully planned and are met when regularly inspected and maintained (Hunt et al. 2012). The Ballona Creek Rain Garden undergoes regular maintenance coordinated by The Bay Foundation with work days using volunteers to remove invasive plants and care for native ones. In addition to maintenance and upkeep, these systems bring up the important issue of pollutant fate and ownership. In restoring more natural drainage to urban areas, pollutants are captured rather than discharged to water bodies. This capture, although beneficial to nearby and downstream communities, has the potential to create 'ownership' of pollutants (Davis 2005). 'Ownership' creates additional questions that need to be addressed. Is there a responsibility to periodically test soil and/or plants for levels of heavy metals? Is the original constructor of the system always responsible for maintenance or does it pass to sequential landowners? Is there a finite lifespan for biofiltration systems, and what happens when it reached? If heavy metals accumulate in the soil or plants, is there a point when soil and/or plants need to be removed and replaced to avoid long-term liability? Because these systems provide benefits to populations downstream, should the cost of constructing and/or maintaining them be shared with other areas? All of these questions, while important to investigate, do not detract from rain gardens' efficiencies in pollutant retention and water infiltration.

Further Research

Despite the increase in information gained from this study about biofiltration in Mediterranean climates, more research is still needed. Specific topics like pollutant fate, system lifespan, and potential ecosystem services provided would be of great benefit in understanding these LID systems and strengthening the need for them. Much of the current research suggests die-off of bacteria occurs within a few days of biofiltration capture (Zhang et al. 2001), but this consequence depends heavily on microbial conditions within the system, composition of the runoff, and exposure to UV light. Contaminant and nutrient uptake levels can vary with surrounding land uses as well as climatic conditions. The organic pollutants like PAHs are usually captured near the surface in mulch or soil media due to the hydrophobicity of the compounds (Hunt et al. 2012). The metals were also found to primarily gather in the upper layers of soil media (Li & Davis 2008). This could mean periodically replacing this upper layer would elongate the lifespan of the system. Results from another study onsite at the Ballona Creek Rain Garden found zinc sequestration in upper soil layers, but had difficulty finding other metals above non-detect (ND) levels. Although the metals' concentrations in BCRG fell below regulatory limits, it is difficult to say anything conclusively about their location in the soil media (Yousavich 2018). More work is needed to determine the role of plants in metal sequestration as well as soil media. Presently, a research program in the BCRG has been implemented assessing variability between soil and several components of plants, individuals of the same species, as well as incorporating leaf litter as a component for pollutant sequestration (Britt, unpublished data).

Another important area of study is to better characterize ecosystem services provided by these LID systems. These services are defined as “the benefits human populations derive, directly or indirectly, from ecosystem functions” (Costanza et al. 1997), and offer urban green spaces that have the potential to benefit human health as well as promote biodiversity (Bolund and Hunhammar 1999). They can help combat heat islands that are frequently associated with urban areas, mitigate flooding, and recharge aquifers. Long-term studies should also be done to determine the effect of pollutant accumulation on continued retention capacity and additional work on their fate through soil geochemical processes. The longevity of biofiltration systems needs to be studied further to ascertain their potential impact on stormwater management.

Although more research should be done to truly measure longevity, pollutant fate, and ecosystem services provided by biofiltration systems, this two-year study sheds further light on biofiltration system usage within Mediterranean climates like southern California. The combined average pollutant retention levels ranging from 83% to 94% across all sampled analytes (Table 5) combined with the 73-100% stormwater infiltration range (Figure 10), and the understanding that these values may be underrepresenting the full range of retention, shows that these biofiltration systems can truly have a positive impact stormwater management in urban areas.

REFERENCES

Abbott, R.C., K.K. Johnston, M. Grubbs, and I.D. Medel. 2016. Rain Gardens: Water-Wise Investments in our Future. Final Report Prepared by The Bay Foundation for the Metropolitan Water District of Southern California.

Abramson, Mark. 2014. Ballona Creek Low Impact Development Rain Gardens Project. The Bay Foundation Final Project Certification Report. Grant Agreement No. 09-847-550.

Ambrose, Richard F. and Brandon K. Winfrey. 2015. Comparison of Stormwater Biofiltration systems in Southeast Australia and southern California. WIREs Water, 2: 131-146.

AnalystSoft Inc, StatPlus Mac. 2017. Version v6.

American Public Health Association; American Water Works Association; Water Environment Federation. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd ed.; Washington, DC, USA.

Ballona Creek Watershed Management Planning Group. 2015. Enhanced Watershed Management Program for the Ballona Creek Watershed. Los Angeles, CA.

Bay, S., B. H. Jones, K. Schiff, and L. Washburn. 2003. Water quality impacts of stormwater discharges to Santa Monica Bay. Marine Environmental Research 56:205–223.

Britt, G. 2018. Unpublished data.

Bolund, Per and Sven Hunhammar. 1999. Ecosystem services in urban areas. Ecological Economics, 29 (1999): 291-301.

California Regional Water Quality Control Board – Los Angeles Region. 2013. Reconsideration of Certain Technical Matters of the Ballona Creek Estuary Toxics TMDL and Ballona Creek Metals TMDL. Los Angeles, CA.

California Regional Water Quality Control Board- Los Angeles Region and U.S. Environmental Protection Agency Region 9. 2005. Total Maximum Daily Load for Metals in Ballona Creek. Los Angeles, CA.

Catalyst Environmental Solutions Corporation. 2018. Final Environmental Impact Report, Ballona Creek Bacteria Total Maximum Daily Load Project. SCH 2017021047.

City of Los Angeles. 2007. Ballona Creek Metals TMDL and Ballona Creek Estuary Toxic Pollutants TMDL Coordinated Monitoring Plan. Los Angeles, CA.

City of Los Angeles 2011. Development Best Management Practices Handbook. Low Impact Development Manual.

Clean Water Act. 1972. 33 United States Code. § 1201 et seq.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387 (15), 253–260.

Davis, A. 2005. Green Engineering Principles Promote Low-impact Development. Environmental Science & Technology, 39(16), pp.338A-344A.

Davis, A. P. 2007. Field Performance of Bioretention: Water Quality. Environmental Engineering Science, 24(8), 1048-1064. doi:10.1089/ees.2006.0190.

Dietz, M.E. & Clausen, J.C. 2006. A Field Evaluation of Rain Garden Flow and Pollutant Treatment. Environ. Sci. Technol. 40, 1335–1340.

Erickson A.J., Weiss P.T., & Gulliver J.S. 2013. Impacts and composition of urban stormwater

Optimizing Stormwater Treatment Practices, Springer, pp. 11-22.

Grant, D.M. & Dawson, B.D. 1995. Isco Open Channel Flow Measurement Handbook. Lincoln, NE: Isco Environmental Division.

Hatt B.E., Fletcher T.D., & Deletic A. 2009. Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale J. Hydrol., 365, pp. 310-321.

Hunt W.F., Smith J.T., Jadlocki S.J., Hathaway J.M., & Eubanks P.R. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. J. Environ. Eng., 134 pp. 403-408.

Hunt W.F.; Davis, A.P.; Traver, R.G. 2012. Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design. J. Environ. Eng. 138, 698–707.

IDEXX Laboratories, Inc., Westbrook, ME.

Liu J., Sample D.J., Bell C., Guan Y. 2014. Review and research needs of bioretention used for the treatment of urban stormwater. Water, 6, pp. 1069-1099.

Low Impact Development Center. 2007. LID Techniques. Bioretention. Beltsville, MD.

Lionello, P., Bhend, J., Luterbacher, J., Buzzi, A., Della-Marta, P. M., & Krichak, S. O. 2006. Cyclones in the Mediterranean region: Climatology and effects on the environment. Developments in Earth and Environmental Sciences, 4, 325–372.

Los Angeles County Department of Public Works. 2009. Stormwater best management practice design and maintenance manual for publicly maintained storm drain systems.

Los Angeles County Public Works Water Resources Division. Rain Gage ID 370 data.

McCutcheon, S.C., Martin, J.L, & Barnwell, T.O. Jr. “Water Density as Function of Temperature and Concentration.” Handbook of Hydrology. D. R. Maidment, McGraw-Hill, 1993.

National Pollutant Discharge Elimination System. 40 Code of Federal Regulations. 2003. Chapter I. Subchapter D. Water Programs. EPA Administered Permit Programs. § 122.

National Research Council. 2008. Urban Stormwater Management in the United States. Committee on Reducing Stormwater Discharge Contributions to Water Pollution. The National Academies Press. Washington D.C.

Onset. HOBO water level data logger (Model No. U20L-04).

Perlman, Howard. 2016. What is a Watershed. The United States Geological Survey Water Science School.

Roy-Poirier, A., Champagne, P. and Filion, Y. 2010. Review of Bioretention System Research and Design: Past, Present, and Future. Journal of Environmental Engineering, 136(9), pp.878-889.

State Water Resources Control Board. 2017. Final California 2014 and 2016 Integrated Report (303(d) List/305(b) Report).

United States Environmental Protection Agency. 1993. Guidance Manual for Developing Best Management Practices (BMP). Office of Water, EPA 833-B-93-004.

United States Environmental Protection Agency. 1996. Method 1640: Determination of Trace Elements in Ambient Waters by On-Line Chelation Preconcentration and ICPM. EPA 821/R-96-007 EPA 821/R-96-007.

United States Environmental Protection Agency. 2003. “Method 8015C (SW-846): Nonhalogenated Organics Using GC/FID,” Revision 4. Washington, DC.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005b. The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3):706–723.

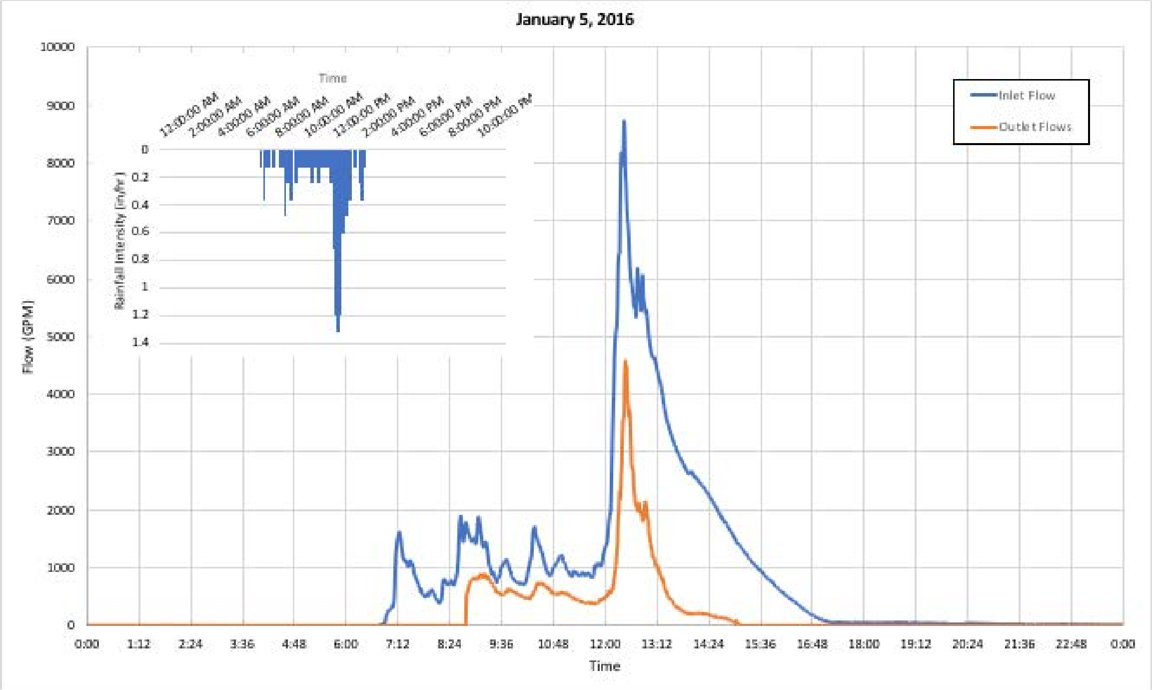
Washburn L, McClure KA, Jones BH, Bay SM. 2003. Spatial scales and evolution of stormwater plumes in Santa Monica Bay. Mar. Environ. Res.56, 101–125.

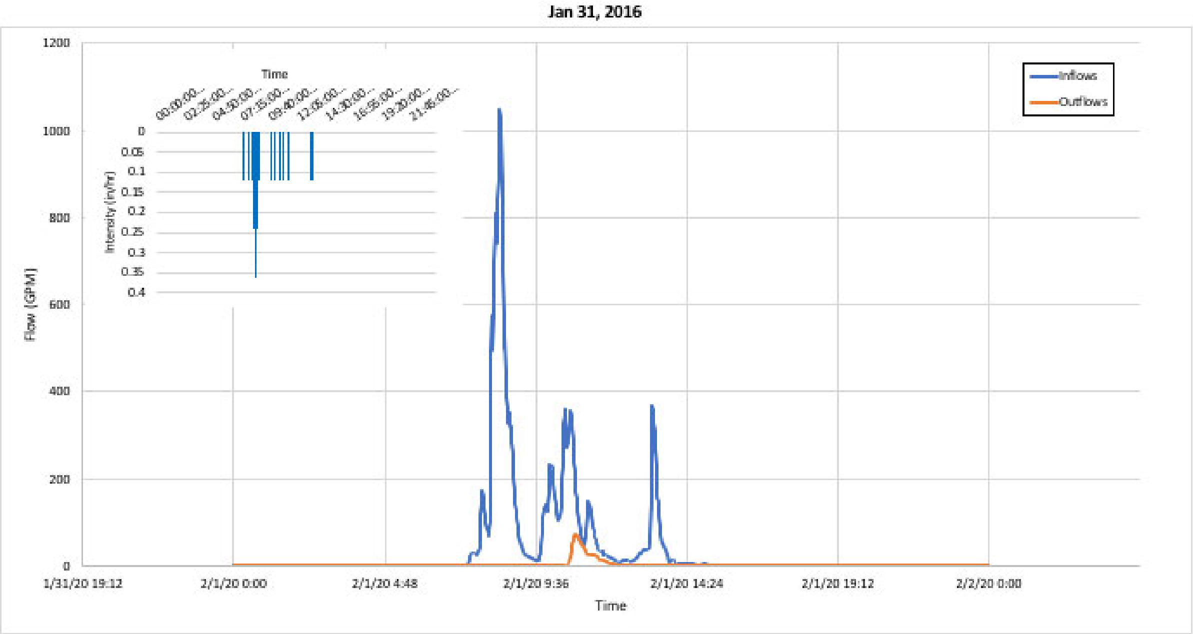
Weir, M., Hass, J. & Thomas, G. (2010). Thomas' calculus, Twelfth Edition. Harlow: Addison-Wesley.

Yousavich, D. 2018. Heavy Metal Sequestration in Bioretention Soil in a Rain Garden in Culver City, California.

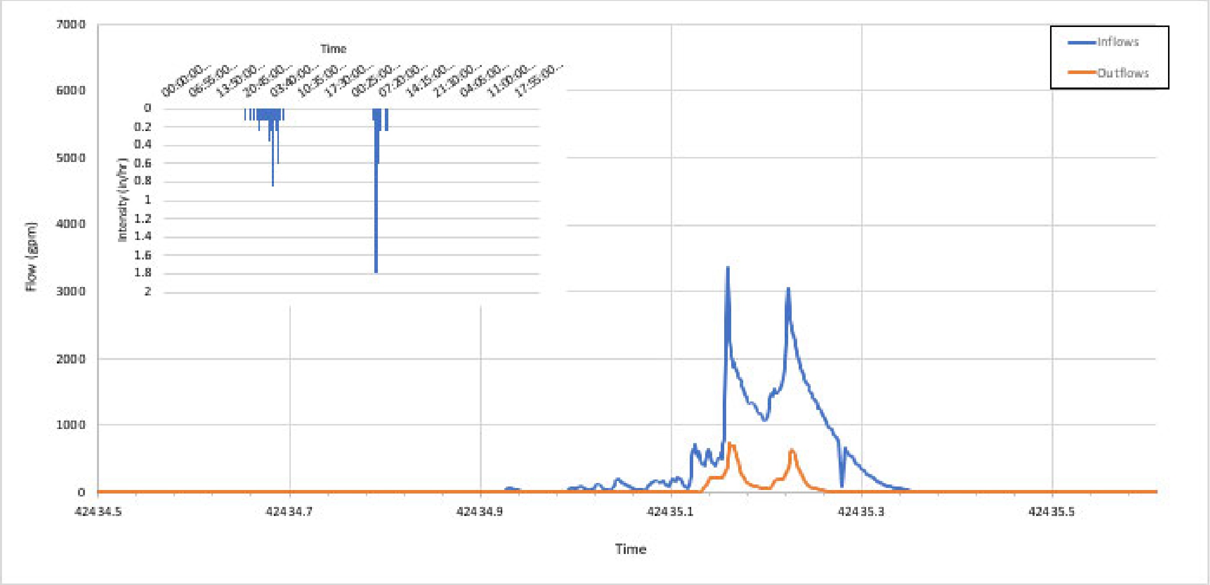
Zhang, L. Seagren, E.A., Davis, A.P., & Karns, J.S. 2010. The capture and destruction of Escherichia coli from simulated urban runoff using conventional bioretention media and iron oxide-coated sand. Water Environ Res. Aug; 82 (8):701-14.

APPENDIX 1: HYETOGRAPHS

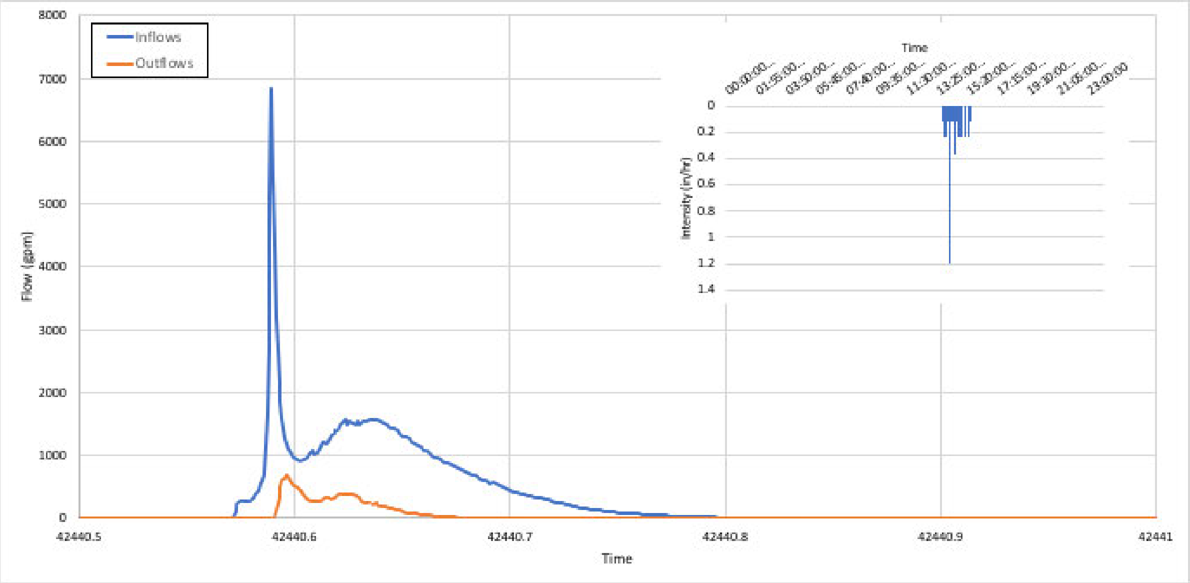




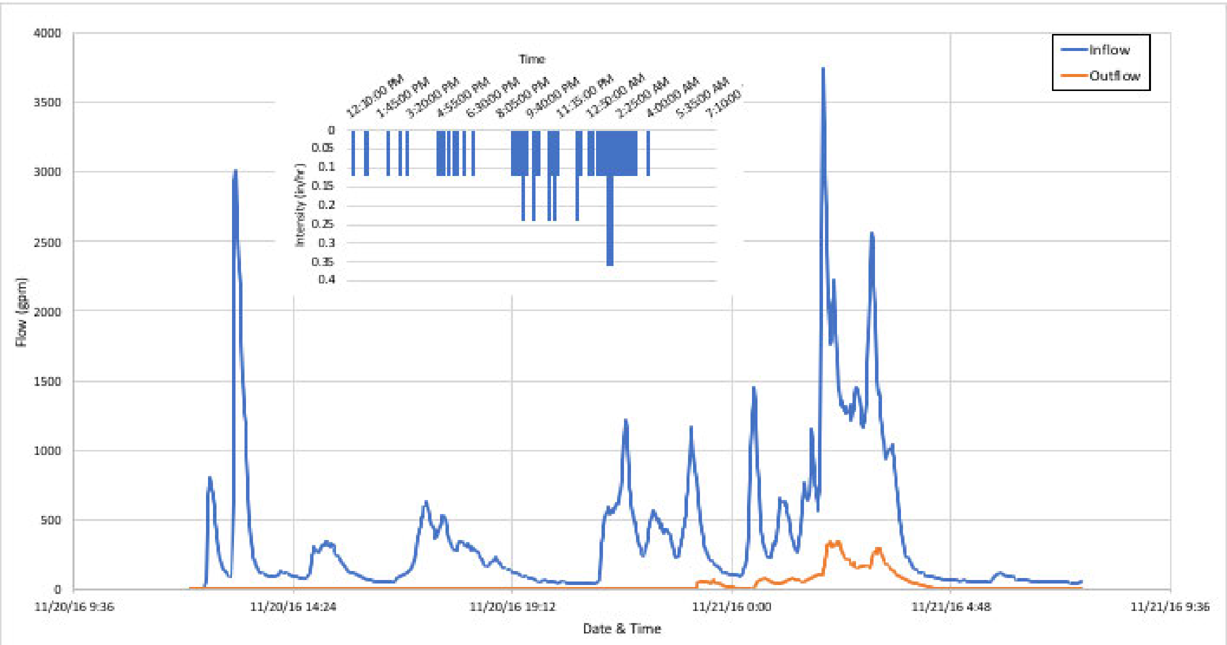
Mar 5-8, 2016



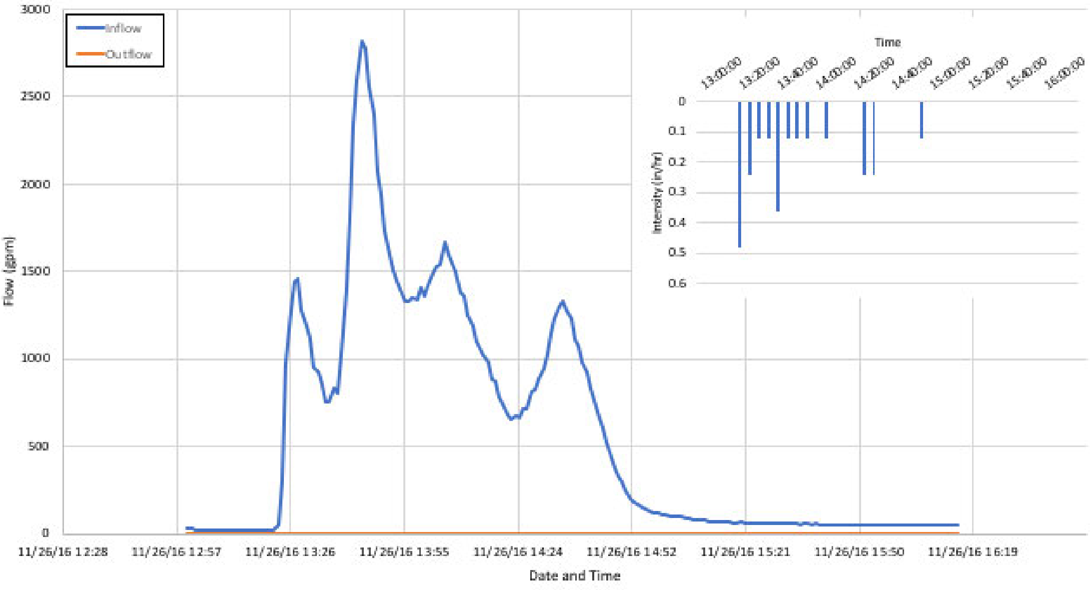
Mar 11, 2016



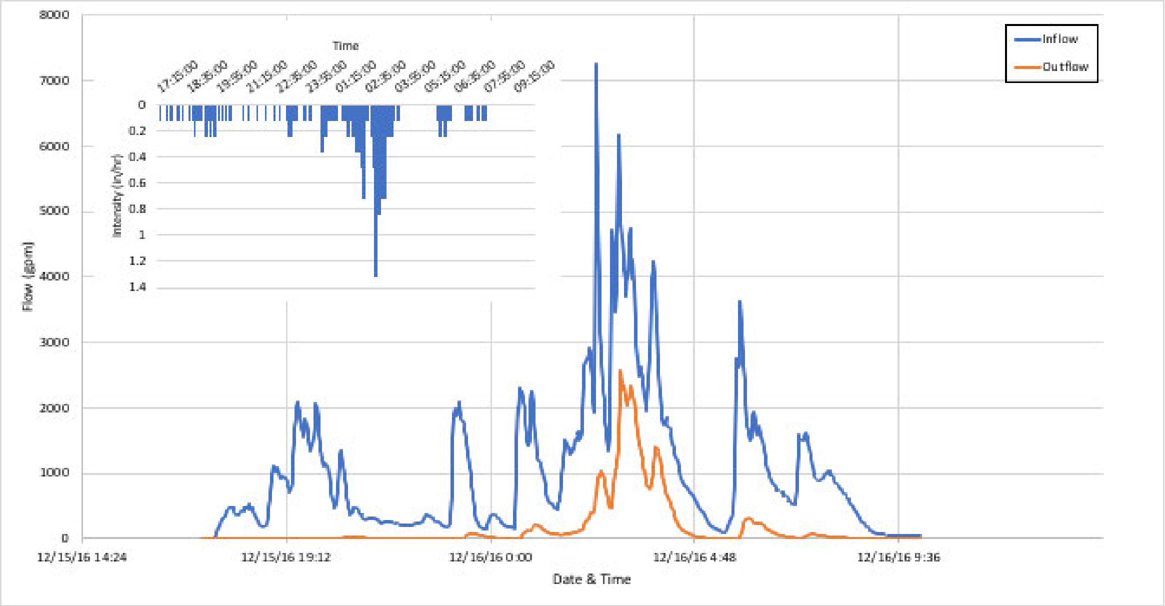
Nov 20, 2016



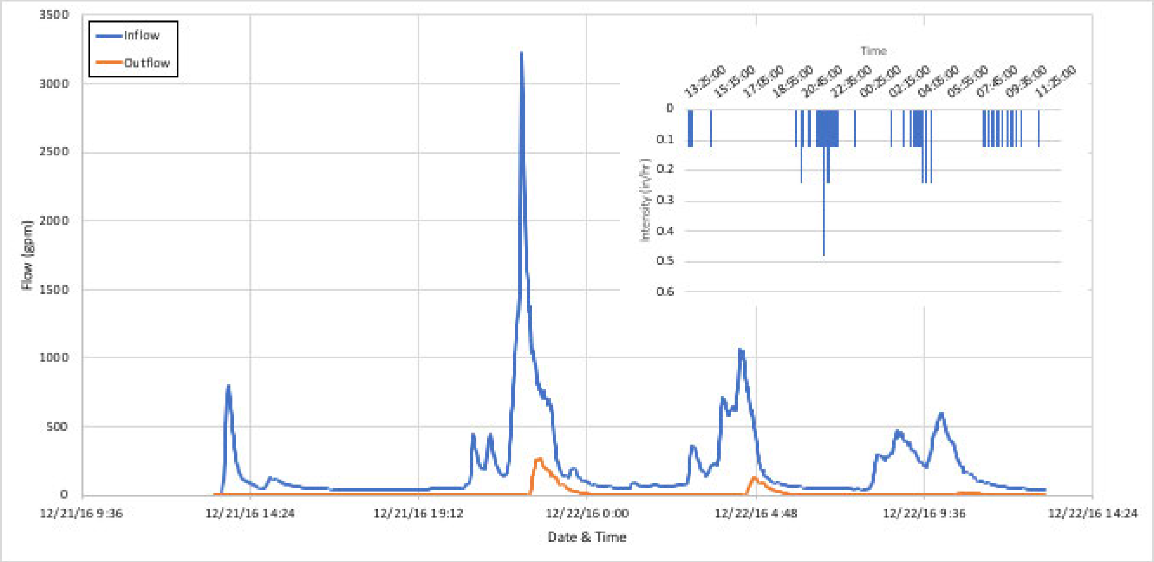
Nov 26, 2016



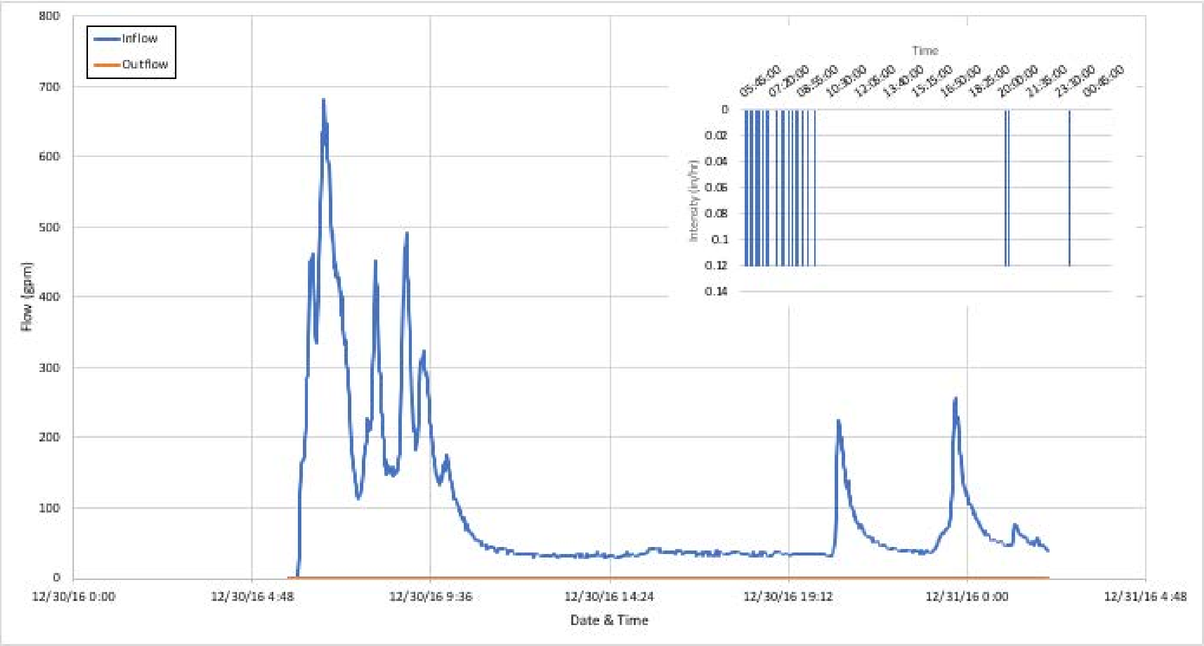
Dec 15, 2016



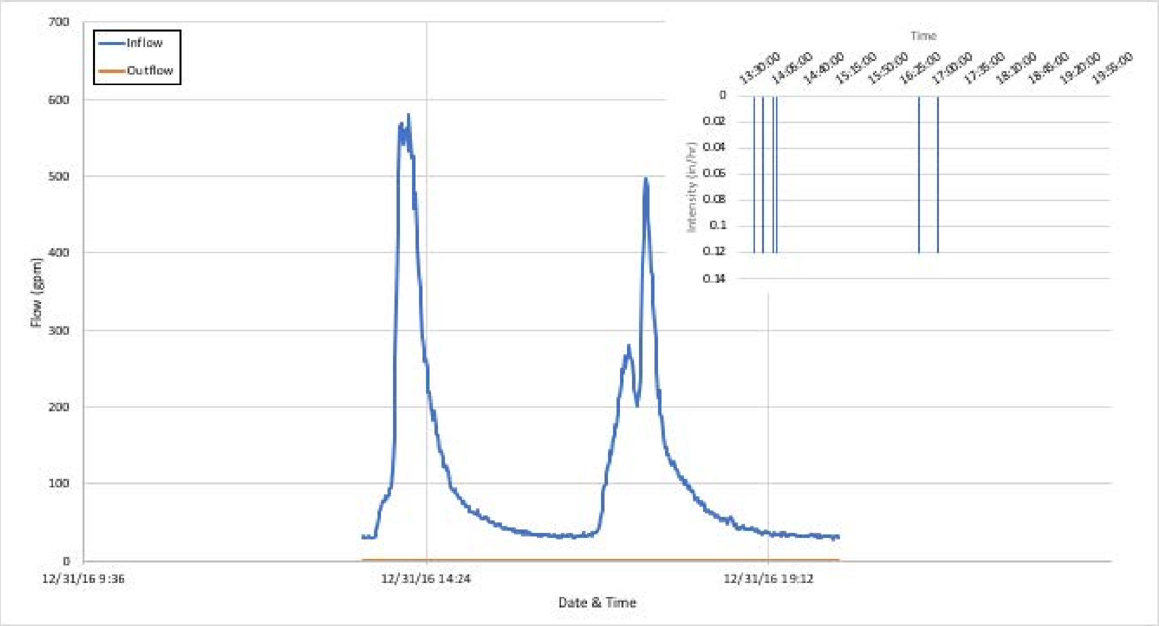
Dec 21, 2016



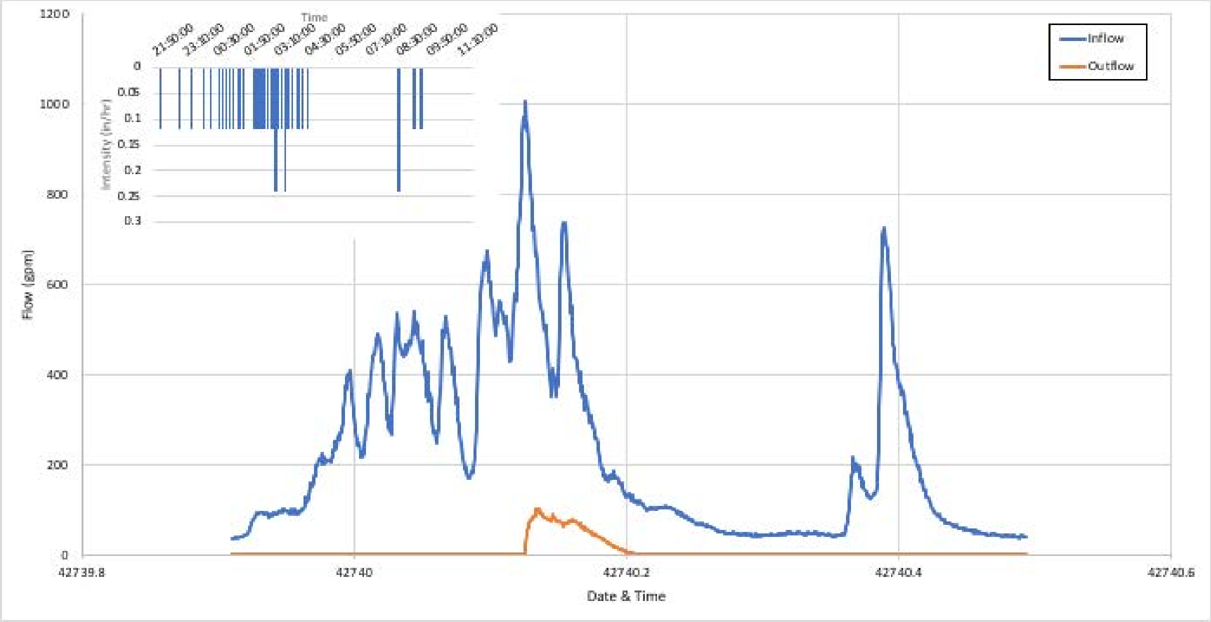
Dec 30, 2016



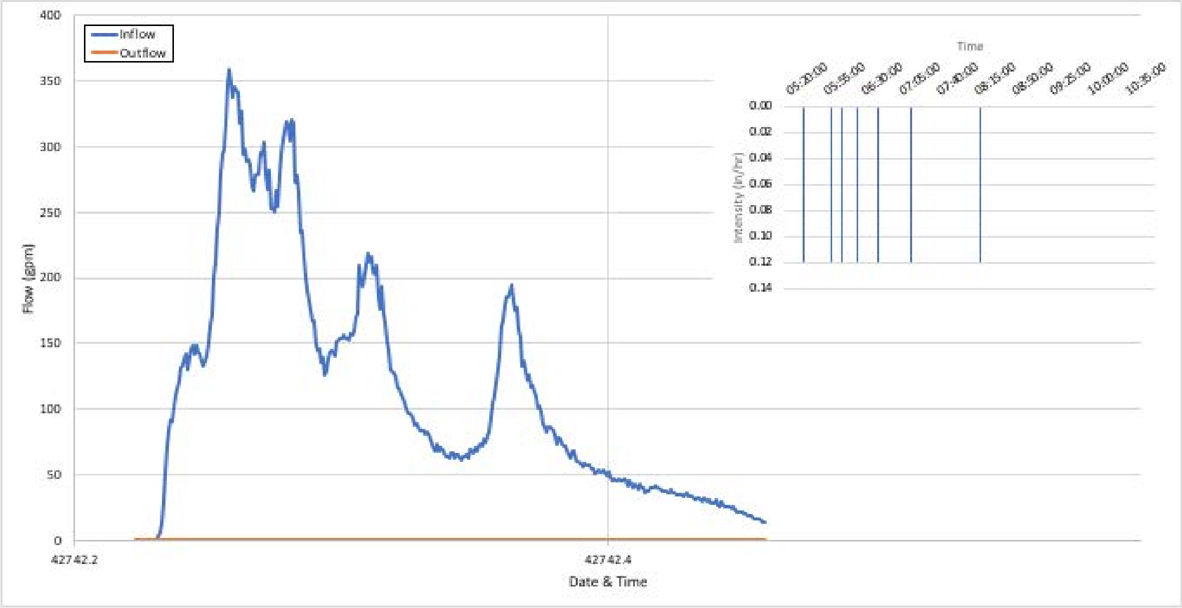
Dec 31, 2016



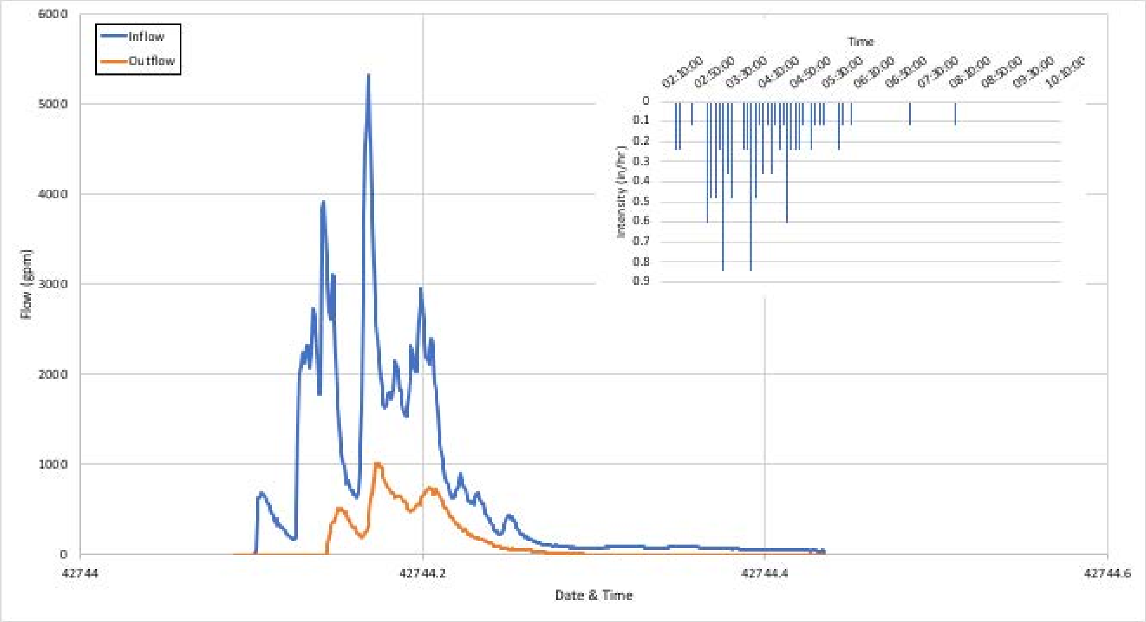
Jan 4-5, 2017



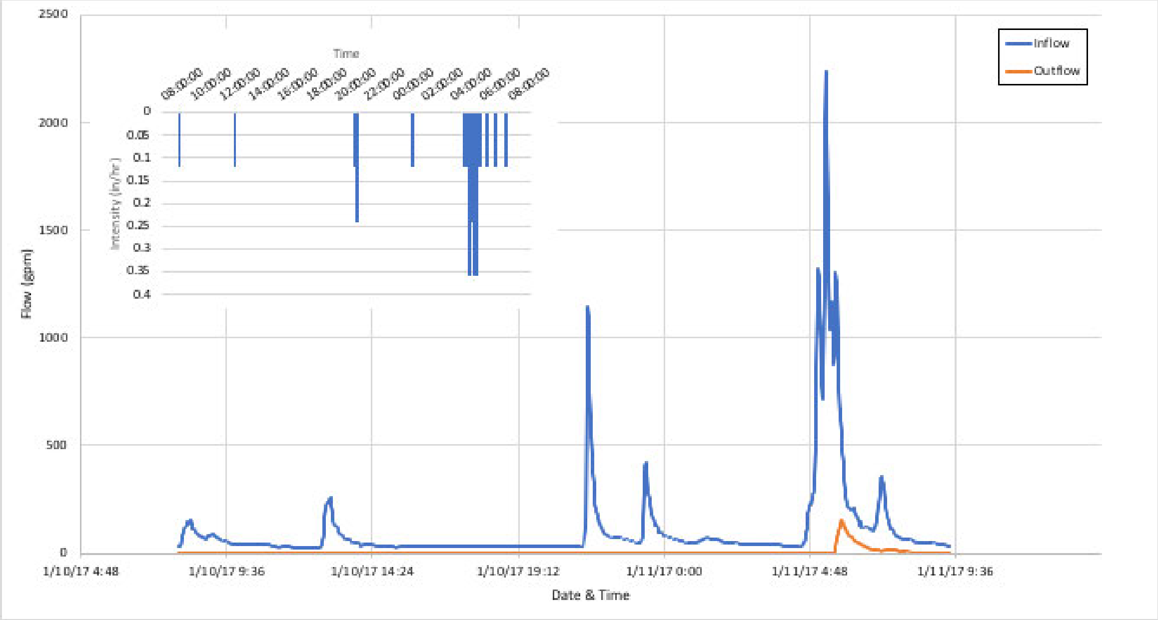
Jan 7, 2017

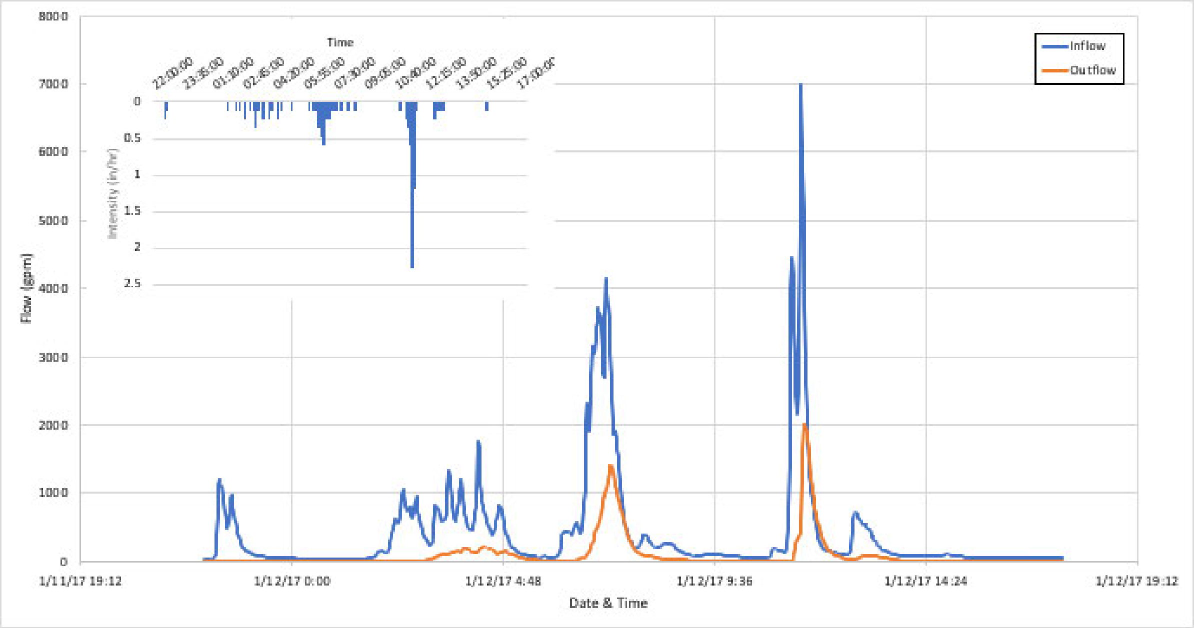


Jan 9, 2017

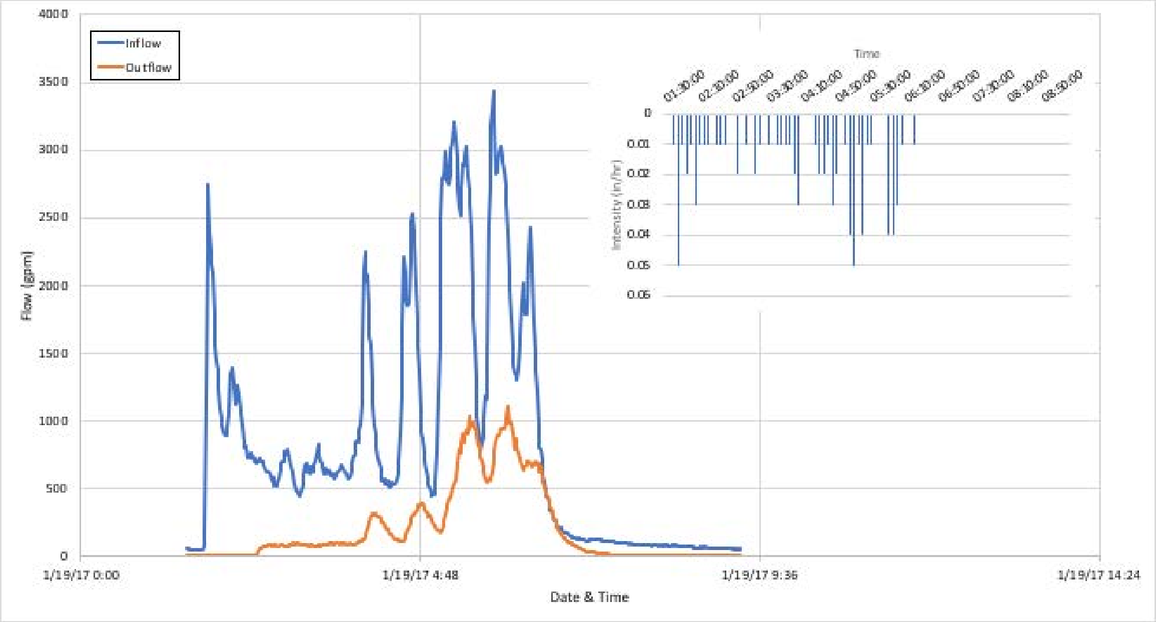


Jan 10, 2017



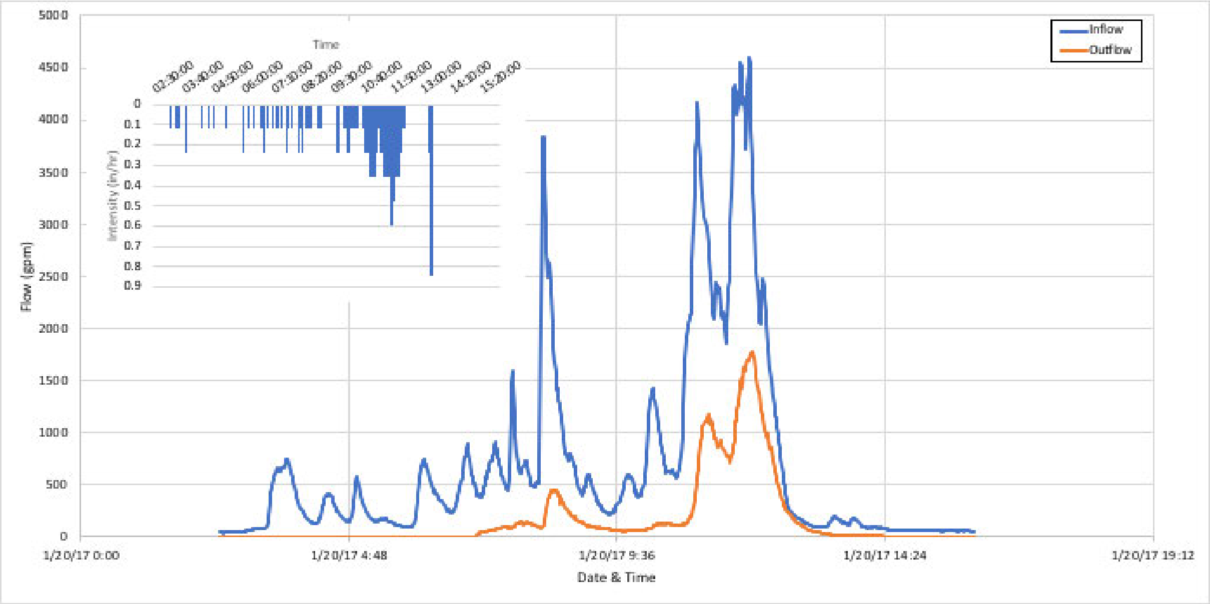


Jan 11-12, 2017

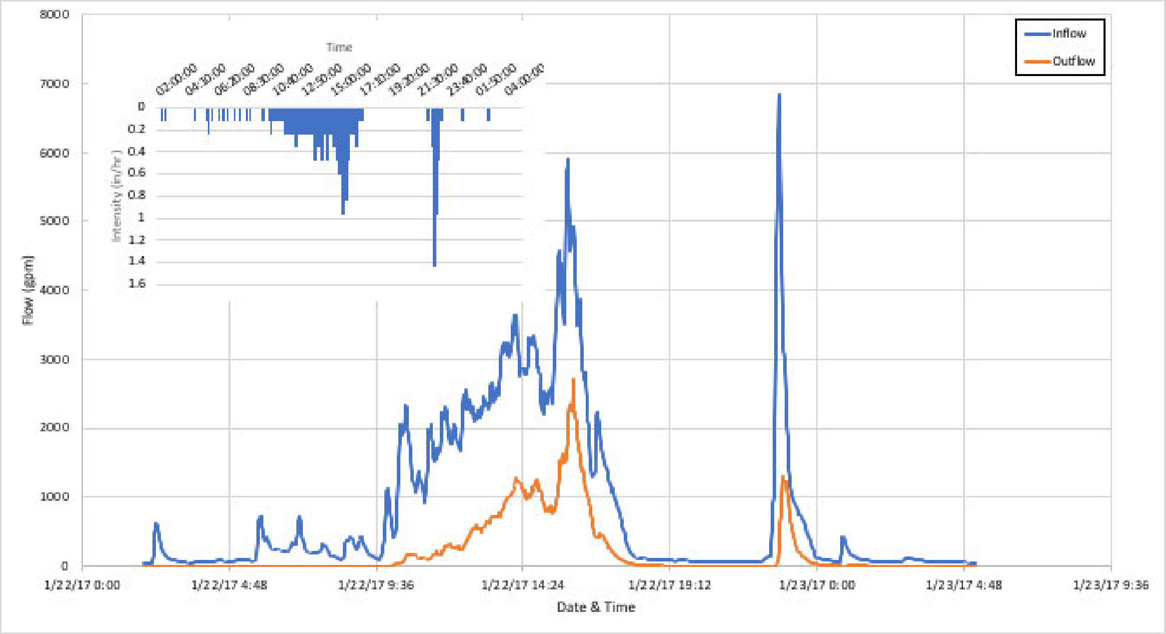


Jan 19, 2017

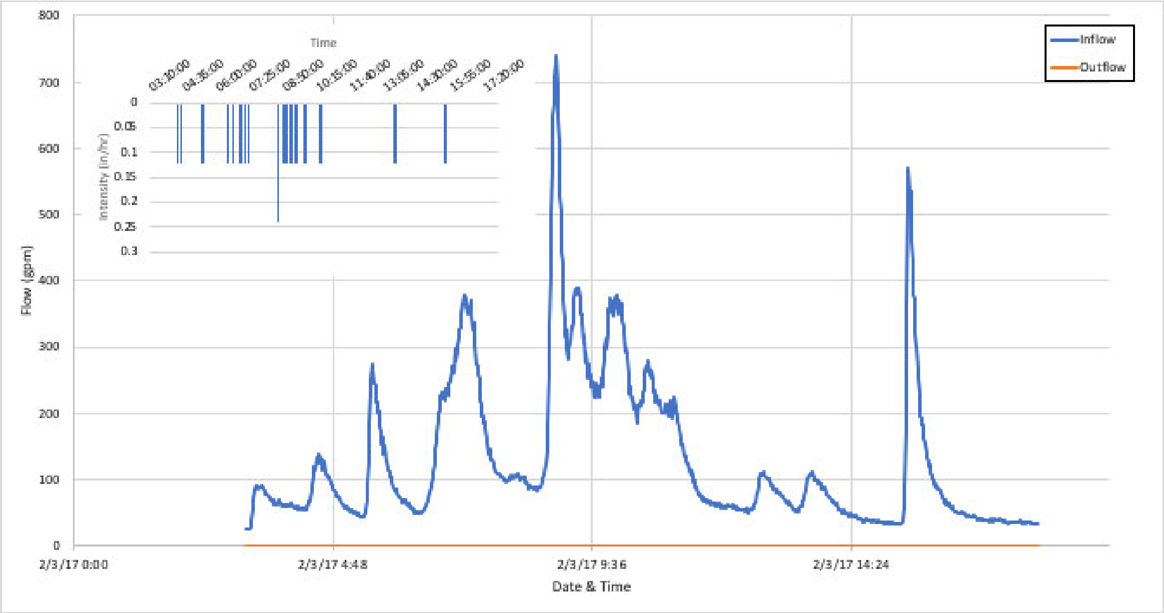
Jan 20, 2017



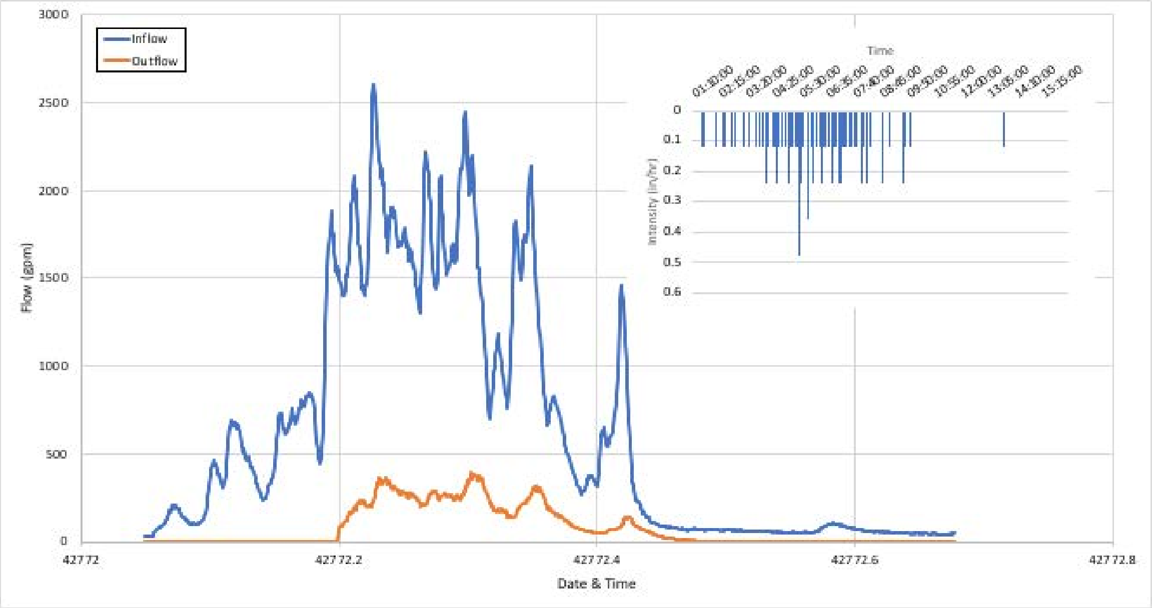
Jan 22, 2017



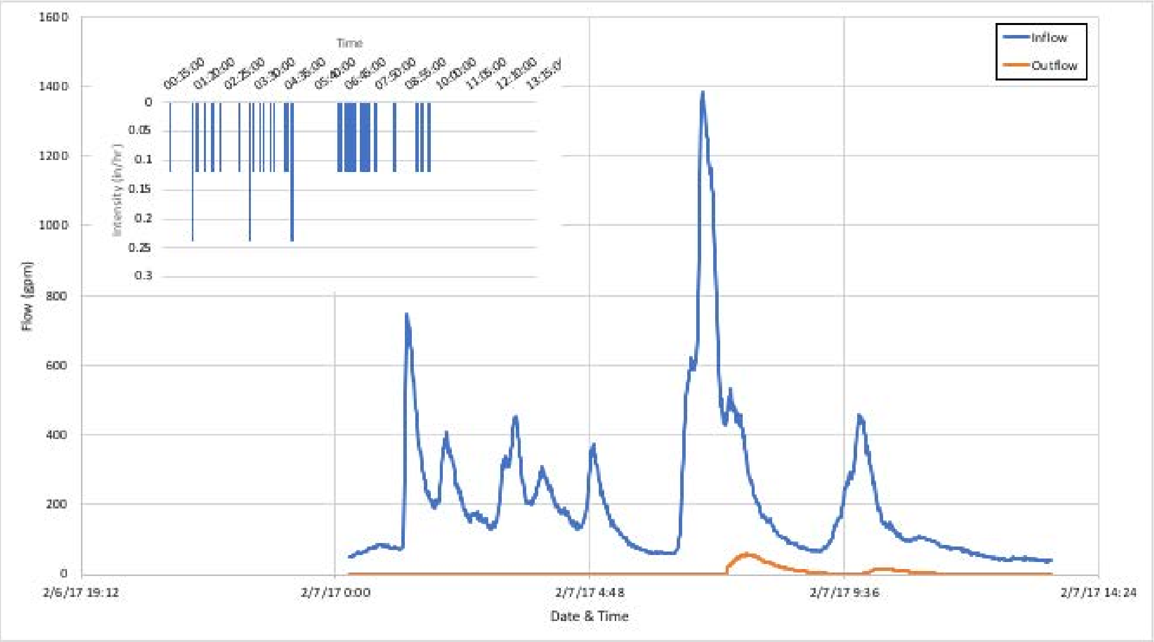
Feb 3, 2017



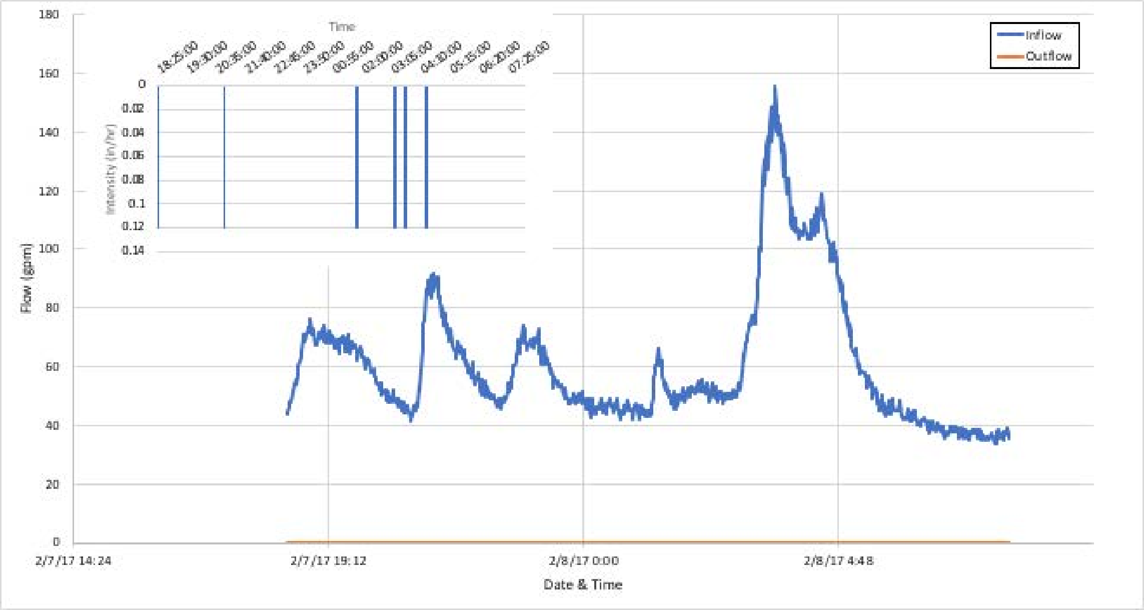
Feb 6, 2017



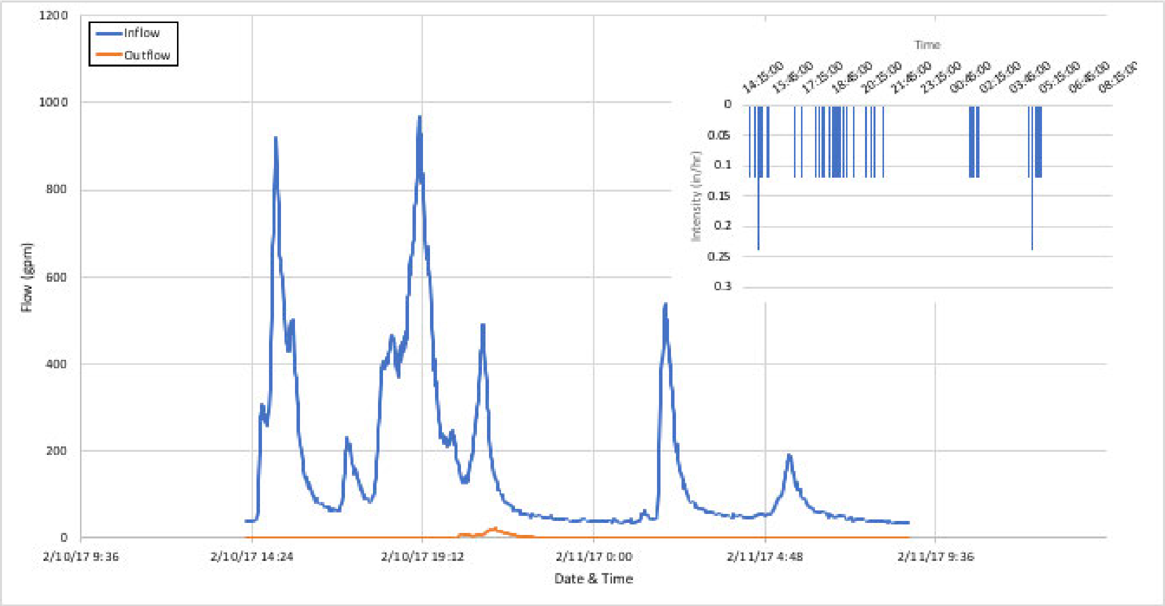
Feb 7, 2017



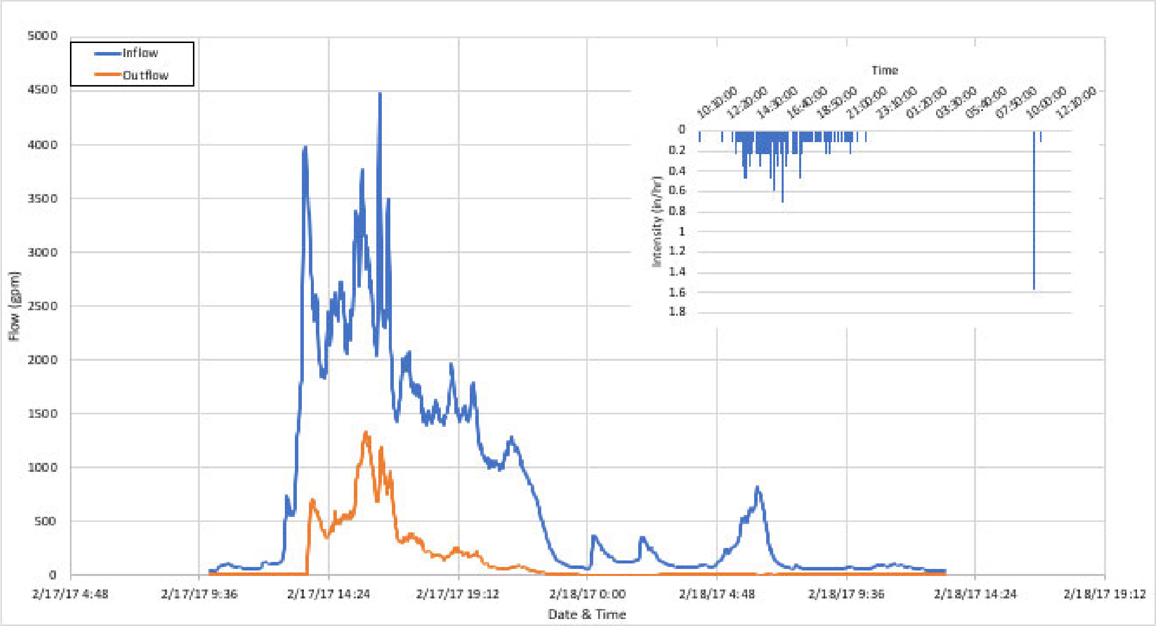
Feb 7-8, 2017



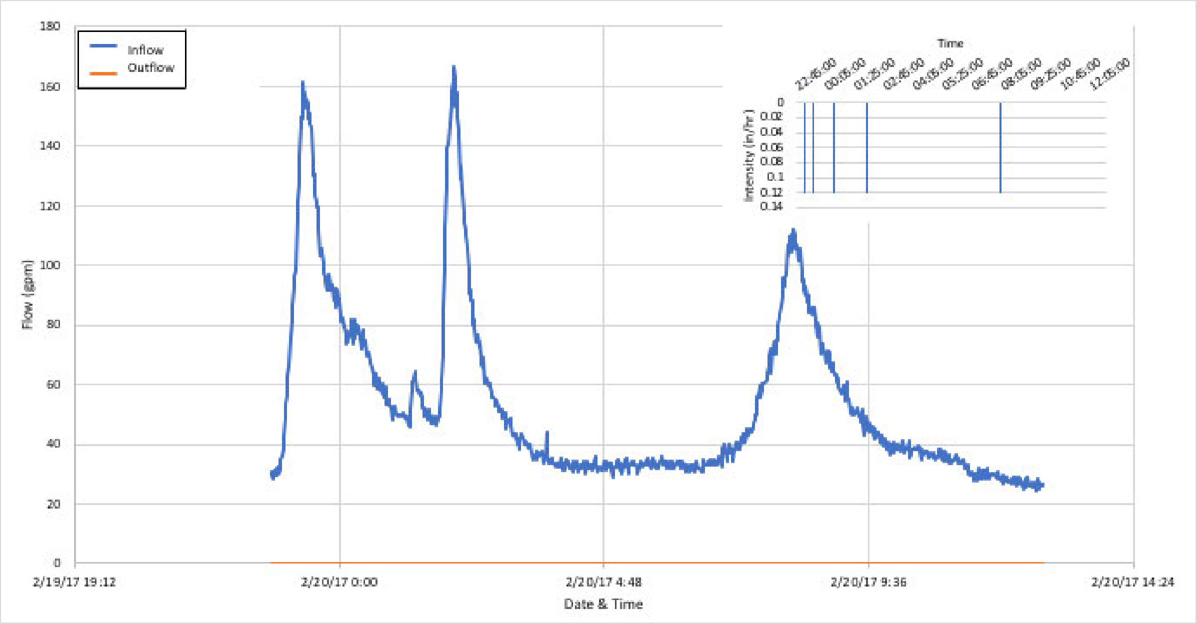
Feb 10-11, 2017



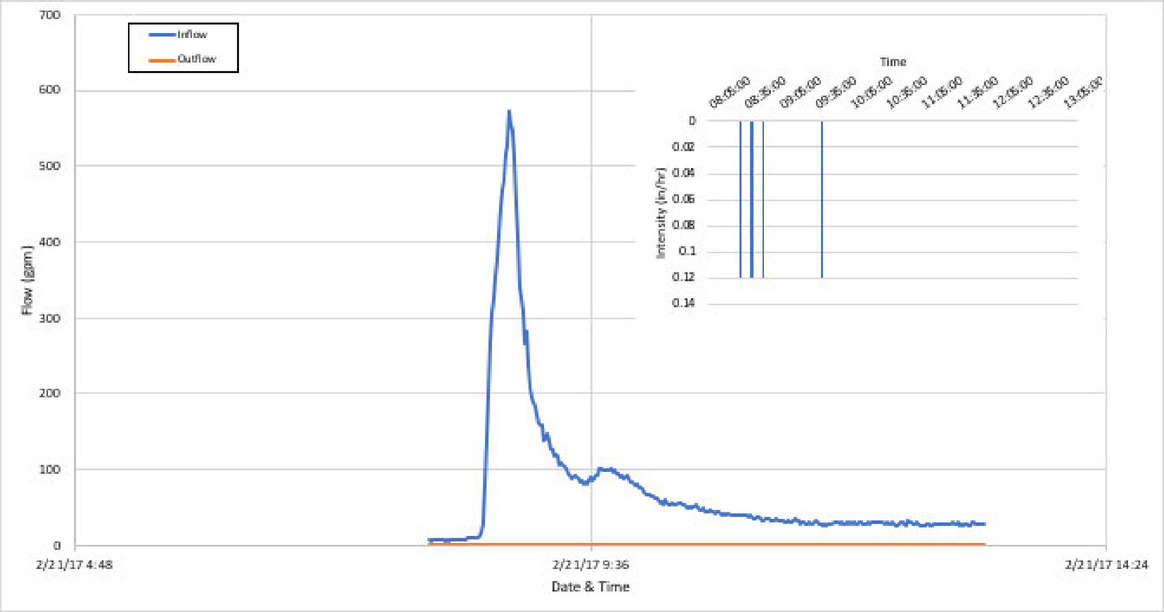
Feb 17, 2017



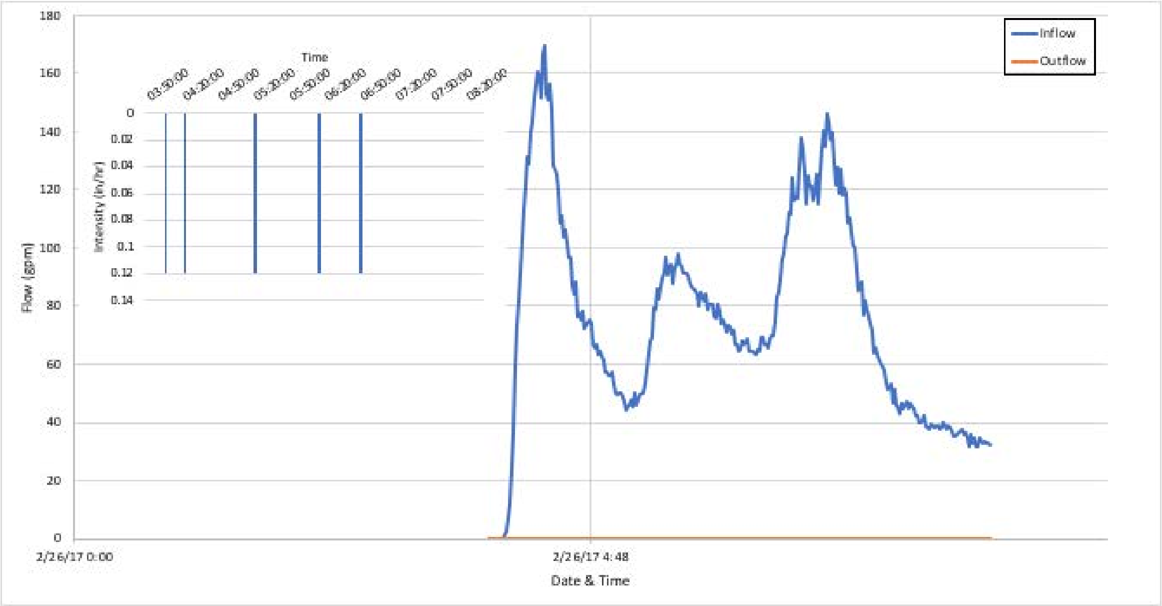
Feb 19-20, 2017



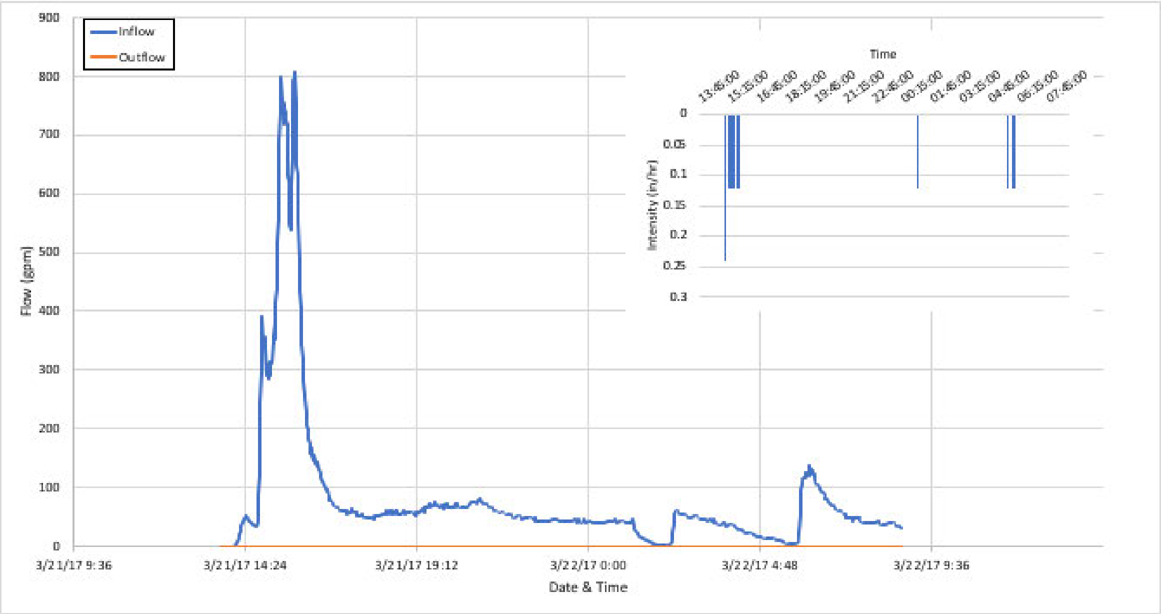
Feb 21, 2017



Feb 26, 2017



Feb 21-22, 2017



APPENDIX 2: MASS LOADING DATA

(used in Table 5 calculations)

Total Pollutant Mass					
E. coli	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=MPN X 10^9	Jan 5 2016	54.0	2.1355	51.9	96.0
	Jan 31 2016	6.4	0.3	6.1	95.3
	Mar 6 2016	426.4	7.0	419.4	98.4
	Mar 11 2016	41.5	0.2	41.3	99.5
	Nov 20 2016	41.80	19.60	22.2	53.1
	Dec 15 2016	306.0	31.1	274.8	89.8
	Jan 5 2017	5.06	0.06	5.01	98.9
	Jan 19 2017	10.8	2.0	8.8	81.2
	Feb 17 2017	127.8	34.7	93.2	72.9
Average		**113.3**	**10.8**	**102.5**	**87.2**
ST DEV		**151.2**	**14.0**	**146.0**	**15.7**
ST Error		**50.4**	**4.7**	**48.7**	**5.2**
Enterococci	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=MPN X 10^9	Jan 5 2016	175.4	34.4	141.0	80.4
	Jan 31 2016	23.7	0.7	23.0	97.0
	Mar 6 2016	334.5	9.1	325.4	97.3
	Mar 11 2016	45.5	8.8	36.8	80.7
	Nov 20 2016	124.1	37.3	86.80	69.9
	Dec 15 2016	367.5	34.3	333.2	90.7
	Jan 5 2017	27.9	0.7	27.2	97.6
	Jan 19 2017	31.2	14.0	17.2	55.1
	Feb 17 2017	259.0	48.2	210.8	81.4
Average		**154.3**	**20.8**	**133.5**	**83.3**
ST DEV		**137.1**	**17.8**	**128.1**	**14.3**
ST Error		**45.7**	**5.9**	**42.7**	**4.8**
Total Suspended Solids	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=kg	Jan 5 2016	30.8	16.3	14.5	47.1
	Jan 31 2016	0.16	0.007	0.2	95.4
	Mar 6 2016	0.15	0.032	0.1	78.5
	Mar 11 2016	5.9	1.1	4.8	80.8
	Nov 20 2016	13.9	0.2	13.8	98.7
	Dec 15 2016	73.7	0.2	73.5	99.7

	Jan 5 2017	12.0	0.1	12.0	99.6
	Jan 19 2017	10.3	0.6	9.7	94.4
	Feb 17 2017	97.2	1.4	95.8	98.5
Average		**27.1**	**2.2**	**24.9**	**88.1**
ST DEV		**34.8**	**5.3**	**34.7**	**17.4**
ST Error		**11.6**	**1.8**	**11.6**	**5.8**
Copper	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=g	Jan 5 2016	8.7	1.1	7.6	87.4
	Jan 31 2016	0.6	0.02	0.6	97.2
	Mar 6 2016	3.3	0.2	3.1	94.3
	Mar 11 2016	16.9	2.2	14.7	87.0
	Nov 20 2016	100.4	6.5	94.0	93.5
	Dec 15 2016	243.8	18.5	225.3	92.4
	Jan 5 2017	25.8	0.4	25.4	98.4
	Jan 19 2017	20.7	1.7	19.0	91.8
	Feb 17 2017	48.1	3.0	45.1	93.7
Average		**52.0**	**3.7**	**48.3**	**92.9**
ST DEV		**78.2**	**5.9**	**72.4**	**3.8**
ST Error		**26.1**	**2.0**	**24.1**	**1.3**
Zinc	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=g	Jan 5 2016	57.5	3.9	53.5	93.1
	Jan 31 2016	4.8	0.1	4.8	98.3
	Mar 6 2016	62.0	3.4	58.7	94.5
	Mar 11 2016	215.2	16.7	198.5	92.2
	Nov 20 2016	794.7	51.6	743.1	93.5
	Dec 15 2016	1834.4	124.4	1710.0	93.2
	Jan 5 2017	340.9	7.4	333.5	97.8
	Jan 19 2017	209.0	41.0	168.0	80.4
	Feb 17 2017	754.9	98.2	656.7	87.0
Average		**474.8**	**38.5**	**436.3**	**92.2**
ST DEV		**586.4**	**45.4**	**545.4**	**5.5**
ST Error		**195.5**	**15.1**	**181.8**	**1.8**
Lead	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass =g	Jan 5 2016	1.4	0.1	1.3	93.4
	Jan 31 2016	0.003	0.0	0.003	100.0
	Mar 6 2016	0.1	0.01	0.1	93.0
	Mar 11 2016	3.8	0.3	3.4	91.3
	Nov 20 2016	28.6	1.4	27.2	95.1
	Dec 15 2016	65.6	8.7	56.9	86.7

	Jan 5 2017	6.3	0.1	6.1	97.8
	Jan 19 2017	1.5	0.2	1.3	86.7
	Feb 17 2017	6.2	0.7	5.4	88.2
Average		**12.6**	**1.3**	**11.3**	**92.5**
ST DEV		**21.7**	**2.8**	**19.1**	**4.7**
ST Error		**7.2**	**0.9**	**6.4**	**1.6**
Polyaromatic Hydrocarbons	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=g	Jan 5 2016	31.2	5.5	25.7	82.4
	Jan 31 2016	1.1	0.2	0.9	84.2
	Mar 6 2016	3.8	1.1	2.7	71.5
	Mar 11 2016	--	--	--	--
	Nov 20 2016	26.6	0.7	25.9	97.5
	Dec 15 2016	160.0	5.3	154.7	96.7
	Jan 5 2017	6.07	0.04	6.03	99.4
	Jan 19 2017	6.6	0.7	6.0	89.7
	Feb 17 2017	78.4	1.8	76.6	97.7
Average		**39.2**	**1.9**	**37.3**	**89.9**
ST DEV		**55.1**	**2.2**	**53.5**	**9.9**
ST Error		**19.5**	**0.8**	**18.9**	**3.5**
Diesel Hydrocarbons	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=g	Jan 5 2016	0.2	0.0	0.2	83.1
	Jan 31 2016	306.5	1.0	305.5	99.7
	Mar 6 2016	127.8	10.2	117.5	92.0
	Mar 11 2016	--	--	--	--
	Nov 20 2016	140.7	11.5	129.2	91.8
	Dec 15 2016	250.2	26.2	224.0	89.5
	Jan 5 2017	60.6	0.9	59.7	98.6
	Jan 19 2017	61.4	14.7	46.7	76.1
	Feb 17 2017	820.6	62.6	757.95	92.4
Average		**221.0**	**15.9**	**205.1**	**90.4**
ST DEV		**262.6**	**20.8**	**244.3**	**7.7**
ST Error		**92.8**	**7.4**	**86.4**	**2.7**
Motor Oil Hydrocarbons	**Storm Date**	**Inlets**	**Outlets**	**Retained**	**% Retention**
Mass=g	Jan 5 2016	0.02	0.002	0.02	90.7
	Jan 31 2016	9.9	0.02	9.9	99.7
	Mar 6 2016	184.9	20.1	164.8	89.1
	Mar 11 2016	--	--	--	--
	Nov 20 2016	627.5	9.5	618.0	98.5

	Dec 15 2016	1117.9	53.3	1064.6	95.2
	Jan 5 2017	195.2	1.0	194.2	99.5
	Jan 19 2017	128.1	20.5	107.5	84.0
	Feb 17 2017	1196.8	49.3	1147.4	95.9
Average		**432.5**	**19.2**	**413.3**	**94.1**
ST DEV		**488.1**	**21.5**	**469.3**	**5.6**
ST Error		**172.6**	**7.6**	**165.9**	**2.0**