FINAL REPORT

HYBRID LOW IMPACT DEVELOPMENT/ BEST MANAGEMENT PRACTICE FOR DOD INDUSTRIAL SITE STORM WATER RUNOFF

Environmental Restoration Project
ER-201634

April 15 2020

Naval Facilities Engineering and Expeditionary Warfare Center (EXWC)

Mr. Gary Anguiano, P.E., EXWC
Mr. Mark Foreman, EXWC
Mr. James Pilkington, EXWC

This Page Intentionally Blank

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
4/15/2020

2. REPORT TYPE
ESTCP Final Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Hybrid Low Impact Development/Best Management Practices for DoD Industrial Site Storm Water Runoff

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
ER-201634

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Gary Anguiano, P.E.
Mark Foreman
James Pilkington

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Facilities Engineering and Expeditionary Warfare Center (EXWC)

8. PERFORMING ORGANIZATION REPORT NUMBER
ER-201634

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program
4800 Mark Center Drive, Suite 16F16
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
ER-201634

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Department of Defense (DoD) is under increasing pressure from regulators and local communities to protect water bodies by reducing the total magnitude and concentration of industrial site pollutants being discharged within storm water runoff into harbors, bays, lakes, and streams. The objective of this project is to demonstrate a small footprint storm water technology for industrial areas that merges structural Best Management Practice (BMP) and Low Impact Development (LID) principles to decrease the concentration of pollutants such as suspended solids, dissolved and particulate metals, and oil and grease to the National Pollution Discharge Elimination System (NPDES) permit requirements. The hybrid technology can be applied to new construction of industrial facilities, or retrofit existing industrial sites that are faced with meeting increasingly stringent NPDES discharge limits.

15. SUBJECT TERMS
Hybrid Low Impact Development, Best Management Practices, DoD, Industrial Site, Storm Water Runoff

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			James Pilkington
UNCLASS	UNCLASS	UNCLASS	UNCLASS	225	19b. TELEPHONE NUMBER *(Include area code)* 805-982-1335

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

This Page Intentionally Blank

ABSTRACT

The Department of Defense (DoD) is under increasing pressure from regulators and local communities to protect water bodies by reducing the total magnitude and concentration of industrial site pollutants being discharged within storm water runoff into harbors, bays, lakes, and streams. The objective of this project is to demonstrate a small footprint storm water technology for industrial areas that merges structural Best Management Practice (BMP) and Low Impact Development (LID) principles to decrease the concentration of pollutants such as suspended solids, dissolved and particulate metals, and oil and grease to the National Pollution Discharge Elimination System (NPDES) permit requirements. The hybrid technology can be applied to new construction of industrial facilities, or retrofit existing industrial sites that are faced with meeting increasingly stringent NPDES discharge limits.

The storm water technology is a full-scale 100 gallons per minute (gpm) hybrid LID/BMP system designed to decrease contaminant concentrations within runoff to ultra-low NPDES permit effluent limits. The system's innovative feature is the merging of a sustainable LID with a structural BMP along with a 1,100 gallon water storage system. The LID's engineered soil and plant matrix mimics the contaminant removal mechanism of a natural swale within a small footprint and exceeds traditional swale percolation rates, while the structural BMP media bed polishes the LID effluent. The accompanying storage tank holds a portion of the effluent to irrigate LID plants during dry periods, or it can be used for other site-specific applications. The multi-stage passive treatment allows the system to operate without an operator for multiple rain events and seasons. The small footprint and rapid processing times of this technology are desirable at industrial sites where usable space is at a premium.

System monitoring occurred from February 2018 through May 2019 at the installation location at the Metals Finishing Complex at Naval Base Point Loma (NBPL). The system capital cost was $157,010 for the one-acre site. All effluent event mean concentration (EMC) values for copper were below the NBPL permit limit of 33.2 µg/L. For total copper, only one out of fourteen effluent results met the ultra-low NPDES permit limit of 2.9 µg/L for areas such as Hawaii. The seasonal effluent EMC was 5.2 µg/L and seasonal efficiency ratio (ER) was 97%. For dissolved copper, which is thought to be the more toxic fraction, the seasonal effluent EMC was 2.8 µg/L and the average seasonal ER was 97%. All effluent EMC values for total zinc were well below the NBPL permit limit of 260 µg/L. The average seasonal ER for both total and dissolved zinc was 98%. All effluent EMC values for total suspended solids (TSS) were well below the NBPL permit limit of 100 mg/L and the ultra-low benchmark of 50 mg/L. The average seasonal ER was 95%.

The hybrid system achieved high metals and suspended solids removal consistently over two rain seasons. The average removal percentage for total and dissolved copper was 97%, total and dissolved zinc was 98%, and TSS was 95%. Over the project life, the system received minimal maintenance and only two contractor maintenance cycles were performed to replace the top three inches of mulch on the LID biofilter. Multiple research and development projects continue to use the site as a test bed. The system is still in place at NBPL and actively treating storm water runoff.

This Page Intentionally Blank

TABLE OF CONTENTS

Page

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

Page

ACRONYMS AND ABBREVIATIONS

ASTM	American Society of Testing & Materials
BAT	Best Available Technology Economically Achievable
BCT	Best Conventional Pollutant Control Technology
BMP	Best Management Practice
BSM	Biofiltration Soil Media
CFR	Code of Federal Regulations
CFS	Cubic Feet per Second
COI	Constituents of Interest
COTS	Commercial Off-the-Shelf
CRWQCB	California Regional Water Quality Control Board
CWA	Clean Water Act
DLA	Defense Logistics Agency
DoD	Department of Defense
EMC	Event Mean Concentration
EPA	United States Environmental Protection Agency
ER	Efficiency Ratio
ERA	Exceedance Response Actions
ESTCP	Environmental Security Technology Certification Program
ET	Evapotranspiration
FRC MFC	Fleet Readiness Center Metal Finishing Complex
FS-50	Activated Alumina FS-50
gpm	gallons per minute
HPDE	High Density Polyethylene
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
IGP	Industrial General Permit
IHRA	Industrial High Risk Area
ILRA	Industrial Low Risk Area
INEA	Industrial No Exposure Area
iNFADS	internet Navy Facilities Asset Data Store
LC	Lethal Concentration
LID	Low Impact Development
LLC	Limited Liability Corporation

MS4s	Small Municipal Separate Storm Sewer System
mg/L	Milligrams per Liter
NAL	Numeric Action Limit
NASSCO	National Steel and Shipbuilding Company
NAVSTA	Naval Station San Diego
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NBC	Naval Base Coronado
NBPL	Naval Base Point Loma
NESDI	Navy Environmental Sustainability Development to Integration
NOAA	National Oceanographic and Atmospheric Administration
NOV	Notice of Violation
NPDES	National Pollution Discharge Elimination System
NRRC	Naval Regional Recycling Center San Diego
OSHA	Occupational Safety and Health Administration
O&G	Oil and Grease
O&M	Operations and Maintenance
PAH	Poly Aromatic Hydrocarbons
PCB	Poly Chlorinated Biphenyls
PPB	Parts Per Billion
PPM	Parts Per Million
POC	Point of Contact
QA	Quality Assurance
QC	Quality Control
ROS	Regression of Order Statistics
SIC	Standard Industrial Code
SMI	Storm Water Management Incorporated
SWPPP	Storm Water Pollution Prevention Plan
TAPE	Testing Assessment Protocol-Ecology
TBD	To Be Determined
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
µg/L	Micrograms per Liter
WSO	Weather Service Office

ACKNOWLEDGMENTS

The authors thank the Environmental Security Technology Certification Program (ESTCP) for the funding that enabled us to undertake this project. Appreciation for technical assistance is extended to Dr. Herbert Nelson and Dr. Anne M. Andrews, ESTCP directors (Present and former) and Dr. Andrea Leeson, Environmental Restoration (ER) Program Manager, Tim Thompson, and ER committee members and to the Noblis staff including Cara Patton, Marcrina Xavier, and Tammy Ryan for their administrative assistance.

We would like to thank the following individuals and their respective commands for their support during the effort that has led to the completion of this project and the production of this report. Thanks to Gene Fabian of the U.S. Army Aberdeen Test Center for his role as the Technology Transfer specialist and Quality Assurance Officer. Thanks to Mr. Rob Chichester of Naval Region Southwest for his guidance and coordination with local regulatory agencies.

Thanks to Mr. Mark Foreman (retired) of the Naval Facilities Engineering and Expeditionary Warfare Center for his role in design, selection, fabrication and construction.

EXECUTIVE SUMMARY

This technology demonstration addresses elevated concentrations of environmental pollutants commonly found within Department of Defense (DoD) industrial site storm water runoff. The project focus is decreasing toxic metal concentrations (primarily copper and zinc) within storm water runoff emanating from high risk industrial areas. The DoD is under increasing pressure from regulators and local communities to reduce the amount of storm water pollutants discharging into oceans, harbors, bays, lakes, and streams. This technology demonstration provides the DoD with an additional method to decrease the concentration of toxic contaminants within storm water runoff, thereby avoiding Notices of Violation (NOVs) from regulating agencies and improving public perception of DoD environmental stewardship.

The hybrid Low Impact Development/Best Management Practice (LID/BMP) system is an innovative, low maintenance, and gravity driven technology that combines LID with a structural BMP to remove metals, suspended solids, and low concentrations of petroleum hydrocarbons from storm water runoff. The high flow LID media and plant matrix reduce the concentration of typical pollutants found in storm water by mimicking the contaminant removal mechanism of a natural swale. It occupies a smaller footprint than a natural swale by exceeding traditional swale percolation rates. The structural BMP further polishes the LID effluent with adsorbent media to remove problematic ionic contaminants like copper and zinc down to ultra-low levels.

The project objective was to demonstrate and validate a full scale, modular 100 gallon per minute (gpm) Hybrid LID/BMP System that decreases metal concentrations within storm water runoff from high risk industrial areas to ultra-low NPDES permit limitations. The demonstration was conducted at the Fleet Readiness Center Metal Finishing Complex (FRC MFC) located on Naval Base Point Loma (NBPL) in San Diego, California. Table 1-1 has the site-specific system performance objectives of the demonstration plan derived from the California Regional Water Quality Control Board (CRWQCB), San Diego Region Water Discharge Requirements for the United States Department of the Navy, Naval Base Point Loma Complex of San Diego County, NPDES Permit No. CA0109363.

Table 1-1. Demonstration Plan Performance Objectives

Performance Objective		Data Requirements	Success Criteria	Results
Quantitative				
Reduce Pollutants In Effluent	Whole Effluent Acute Toxicity Limitation	Hybrid LID/BMP effluent sampling data according to "Methods for Estimating the Acute Toxicity of Effluent and Receiving Waters to Freshwater and Marine Organisms", EPA Method 821-R-02-012	80% survival in 100% effluent from Hybrid LID/BMP outlet	Met
	Reduce total copper in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total copper to less than 33.2 µg/L[1]	Met
			(or 2.9 µg/L ultra-low secondary success criteria)	Not Met
	Reduce total zinc in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total zinc to less than 260 µg/L[1]	Met
			(or 95 µg/L ultra-low secondary success criteria)	Met
	Reduce oils and grease in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 1664, Revision A (TAPE TPH-dx Method EPA 8015 B)	Reduce Hybrid LID/BMP effluent concentration of oil and grease grab samples to less than 15 mg/L	Met
	Reduce TSS in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 2540.B	Reduce Hybrid LID/BMP effluent concentration of TSS to less than 100 mg/L[1]	Met
	Limit export of other storm water pollutants	Storm water influent, LID biofilter effluent, and dual-media filter BMP effluent sampling data. Lab analysis according to various EPA methods.	Limit other potentially regulated storm pollutants that could be exported by treatment components (orthophosphate and total phosphorus)	Met
Limit Capital Cost		Watershed Acreage and actual Capital Cost	Less than $100,000 per acre of drainage	Not Met
Vegetation Health		Observational data and photos during field demonstration	Plants maintain health and do not dieback during dry summer months	Met
Qualitative				

Performance Objective		Data Requirements	Success Criteria	Results
Reduce Preventative Maintenance	Ease of use	Field photographs, field technician feedback, and maintenance log input	Minimal annual maintenance requirement (inspection, sweeping and particulate cleanup)	Met
[1] TMDL mass load reduction criteria is included within the NBPL NPDES permit via compliance with NAL and acute toxicity requirements.				

The Hybrid LID/BMP System is comprised of three main components, a pretreatment gabion wall, LID biofilter, and a dual media BMP. These three components treat the storm water runoff as it passes through the system. There are two overflow bypasses, one for the LID biofilter, and one for the BMP media filter. The multi-stage passive system works together to polish the storm water to meet NPDES permit levels.

The pretreatment filter gabion wall is intended to extend the life and improve the performance of the LID biofilter by acting as a roughing filter to remove gross solids, trash, and debris from storm water runoff. The twelve inch tall by six inch wide gabion is constructed of ¾ inch to 2 inch rail ballast (AREMA size No. 4A) enclosed within a ultra-violet resistant, plastic coated wire mesh wrapped within U.S. Fabrics 1540 woven geo-fabric. The gabion is oriented so that it extends across the upstream sides of the LID biofilter to intercept runoff. As the gabion wall fills in with gross solids over time, it creates a small pond upstream of the LID for solids to settle. Operations and maintenance (O&M) activities for the gabion include "as needed" sweeping of the asphalt settling area immediately upstream of the LID, sweeping of the upstream face of the woven geo-fabric, and disposal of the swept sediments.

The LID biofilter is the next stage of the Hybrid LID/BMP System, and features a proprietary high performance modular biofiltration product called FocalPoint purchased from California Filtration Specialists. The FocalPoint biofilter is designed to remove copper, zinc, total suspended solids (TSS), oils and grease (O&G), and other pollutants of concern. The LID footprint for the demonstration is approximately 10 feet by 20 feet and has a design flow rate of approximately 1 gpm/ft^2 when clean, which equates to a 200 gpm maximum flow rate. However, the design flow rate is expected to diminish over the life cycle of the technology as the biofiltration soil media (BSM) filters TSS and other particulates. The LID biofilter was intentionally oversized to minimize the required preventative maintenance frequency and reduce the BSM replacement frequency. Typical southern Californian native vegetation (Cleveland Sage, Purple Sage) with very low water demands are planted in the BSM. The native plants have appropriate root thickness, density, and length to prevent clogging and short-circuiting of the BSM. The LID biofilter removes typical storm water pollutants at a high hydraulic conductivity of 100 inches per hour. Sand and gravel in the BSM remove particulate pollutants and provide structure for vegetation and some water retention. A small amount of peat in the BSM removes dissolved and organically complexed copper, zinc, and other hydrophobic organics. The peat content also improves the nutrients and water holding capacity of the BSM for healthy plant growth.

The storage tank, irrigation controller, and drip irrigation system are designed to provide sufficient water to meet LID biofilter vegetation needs during dry summer months. The

FocalPoint modular underdrain performs as the storage tank and has an impermeable liner to prevent infiltration of water into underlying soils. The storage tank dimensions are approximately 10 feet wide by 20 feet long by 9 inches deep with a total storage volume of approximately 1,100 gallons. A submersible pump located at the bottom of the inspection port within the storage tank supplies water via drip irrigation piping located on the surface of the LID biofilter. The drip irrigation ensures distribution of water across the very porous BSM (underneath the mulch layer). A Rain Bird ESP-SMT smart modular controller provides an adjustable irrigation schedule with a soil moisture sensor override to prevent overwatering during summer months.

The dual-media filter BMP functions as a polishing stage downstream of the LID biofilter to further reduce copper and zinc concentrations below applicable benchmarks. The BMP consists of a two-chamber concrete vault with external dimensions of 16’ long by 8’ 3” wide and 5’ 9” deep. The first chamber holds the adsorption media: (12 feet long and 7 feet 2 ¼ inch wide) filled with 6 inches of 8x30 mesh bone char on top of 9 inches of 28x48 mesh iron coated activate alumina (FS-50). The second chamber is a second clear well chamber (2 foot 7 ½ inch long by 7 feet 2 ¼ inch wide) for hydraulic controls and monitoring infrastructure.

Storm water exiting the LID biofilter flows directly into a 4 inch PVC distribution header, which is slightly sloped in the direction of flow and extends the length of the filter media bed. The distribution header sits atop of the media bed on top of the geofabric layer with a 2 inch layer of ¾ inch gravel for support and scour prevention. The majority of the remaining pollutants that enter the BMP media bed are in the dissolved fraction or associated with very fine TSS. The bone char and FS-50 layers reduce the concentration of the dissolved contaminants. A ¾ inch washed river stone layer is included below the FS-50 to assist with drainage and prevent media from bleeding into the underdrain.

The dual-media filter BMP is designed for a flow rate of 100 gpm. Flow through the dual-media filter BMP is moderated by a level control weir located within the clear well that maintains an 8 minute contact time between the adsorbent media and storm water runoff. This level control weir can easily be modified to obtain a shorter or longer contact time. Discharge from the weir overflows into the clear well and then continues into the outlet pipe leading to discharge outfall. Any remaining water within the adsorbent media bed and clear well drains through a weep hole over a 72-hour period. Figure 1-1 and Figure 1-2 provide a plan and cross section view of the entire system.

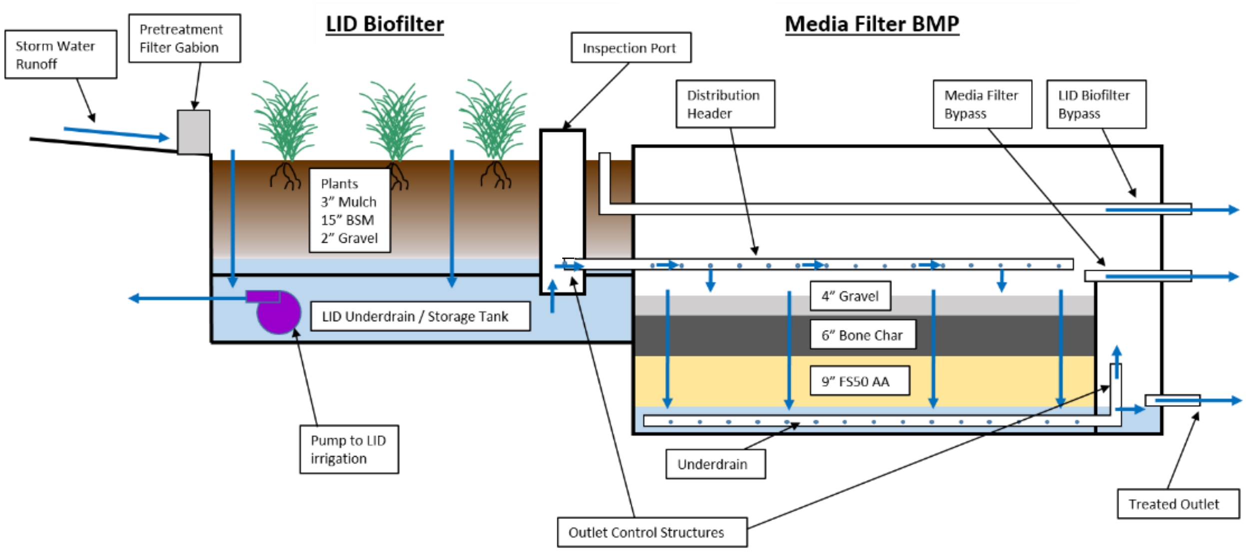


Figure 1-1. Conceptual Cross Section Diagram for Hybrid LID/BMP System

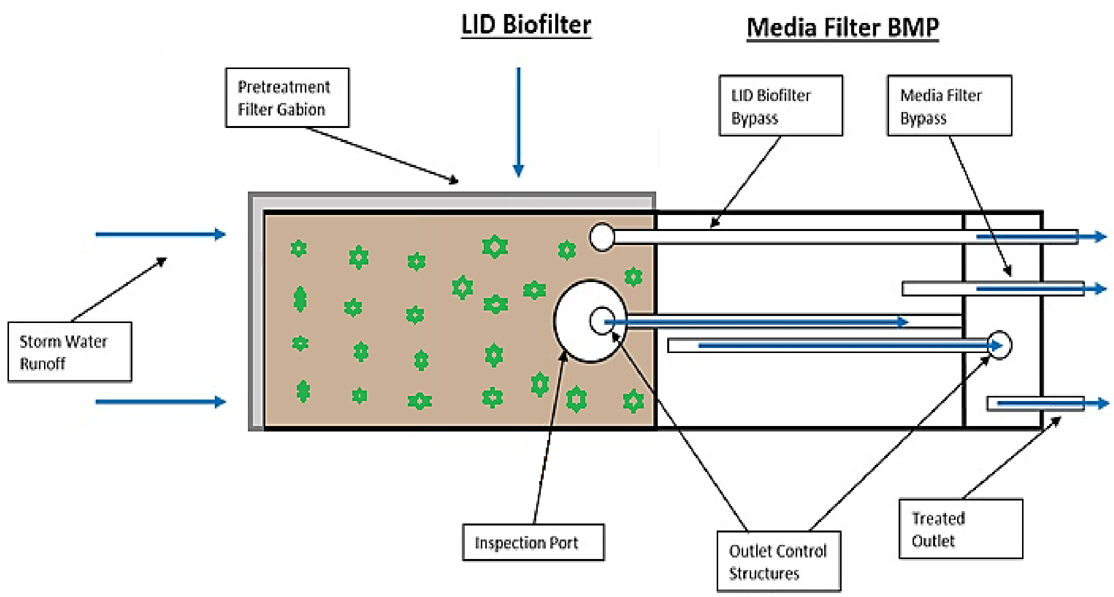


Figure 1-2. Conceptual Plan View Diagram for Hybrid LID / BMP System

The ability of the technology to remove and/or limit the export of pollutants was evaluated on the basis of pollutant concentrations in composite storm water samples collected at the influent and effluent of the Hybrid LID/BMP System. Additional samples were collected at the inlet and outlet of each component of the LID biofilter stage to better understand the pollutant removal process (and efficiency) for TSS and targeted metals. Effluent concentrations in the LID biofilter and media filter samples were compared to influent concentrations to assess removal or export of pollutants by each system component. Composite water quality samples were collected from 14 qualifying storms during the demonstration period. The Naval Facilities Engineering Command (NAVFAC) Environmental Laboratory located at Naval Base Coronado in San Diego collected the storm water samples, and sample analysis was conducted by an accredited laboratory, ALS Environmental Services Laboratory located in Kelso, Washington. ALS Environmental Services Laboratory was able to meet the lower metals detection limits required for this demonstration project. The data for copper, zinc, and TSS are presented below in the following tables.

Table 1-2. System Copper Reduction Data

Rain Event Date	Total Copper Influent/Effluent EMC (µg/L)	Dissolved Copper Influent/Effluent EMC (µg/L)	Total Copper Efficiency Ratio (%)	Dissolved Copper Efficiency Ratio (%)
11/29/18	308/5.79	98.5/1.82	98	98
12/5/18	112.0/5.71	49.3/1.87	95	96
1/5/19	39.3/3.2	31.8/0.95	92	97
1/12/19	84.9/5.97	78.8/6.14	93	92
1/14/19	66.5/4.23	64.5/3.9	94	94
1/31/19	118.0/6.32	75.5/2.07	95	97
2/13/19	82.3/5.02	53.8/2.31	94	96
2/20/19	176/1.49	88.3/0.80	99	99
3/2/19	218/5.29	35.8/2.87	98	92
3/11/19	67.8/4.05	50.4/1.83	94	96
3/20-21/19	217/6.01	63.7/2.9	97	95
4/29/19	379/5.64	298/3.08	99	99
5/10/19	134/4.61	102/2.37	97	98
5/19/19	137/9.32	116/5.59	93	95
Seasonal Efficiency Ratio	153/5.2	86.2/2.8	97	97

Table 1-3. System Zinc Reduction Data

Rain Event Date	Total Zinc Influent/Effluent EMC (µg/L)	Dissolved Zinc Influent/Effluent EMC (µg/L)*	Total Zinc Efficiency Ratio (%)	Dissolved Zinc Efficiency Ratio (%)
11/29/18	769/8.5	433/4.8	99	99
12/5/18	320.0/10.0	223.0/6.1	97	97
1/5/19	156/4.5	140.0/2.5	97	98
1/12/19	246.0/5.3	242.0/9.2	98	96
1/14/19	204.0/13.2	203.0/14.7	94	93
1/31/19	473.0/7.1	404.0/4.2	99	99
2/13/19	241.0/6.2	207.0/5.0	97	98

2/20/19	702/2.5	625/1.9	99	99
3/2/19	424/3.2	94.5/4.4	99	95
3/11/19	240/4.3	204/2.1	98	99
3/20-21/19	379/4.2	291/2.2	99	99
4/29/19	599/7.5	539/5.9	99	99
5/10/19	217/6.1	181/4.7	97	97
5/19/19	265/9.2	239/7.2	97	97
Seasonal Efficiency Ratio	374/6.6	288/5.4	98	98

Table 1-4. System Total Suspended Solids Reduction Data

Rain Event Date	TSS Influent EMC (mg/L)	TSS Effluent EMC (mg/L)	TSS Efficiency Ratio (%)
11/29/18	280	6.4	98
12/5/18	82.6	5.2	94
1/5/19	7.4	2.4	68
1/12/19	25	2.5	90
1/14/19	26.5	2.2	92
1/31/19	30.7	4.2	86
2/13/19	15.3	3.5	77
2/20/19	58	1.2	98
3/2/19	16.8	1^{U}	94
3/11/19	4	1.2	70
3/20-21/19	99.6	2.7	97
4/29/19	33.6	2.2	94
5/10/19	16.5	1^{U}	94
5/19/19	9.0	1.2	87
Seasonal Efficiency Ratio	50.4	2.6	95

^{U} The analyte was analyzed for, but was not detected at or above the MRL. Substituted MRL value for calculation.

All effluent event mean concentration (EMC) values for copper were below the NBPL permit limit of 33.2 µg/L. For total copper, one out of fourteen effluent results met the ultra-low NPDES permit limit of 2.9 µg/L, for areas such as Hawaii. The seasonal effluent EMC was 5.2 µg/L and seasonal efficiency ratio (ER) was 97%. For dissolved copper, which is thought to be the more toxic fraction, the seasonal effluent EMC was 2.8 µg/L and the average seasonal ER was 97%. All effluent EMC values for total zinc were well below the NBPL permit limit of 260 µg/L. The average seasonal ER for both total and dissolved zinc was 98%. All effluent EMC values for total suspended solids (TSS) were well below the NBPL permit limit of 100 mg/L and the ultra-low benchmark of 50 mg/L. The average seasonal ER was 95%.

The project goal was to limit system capital costs to $100,000 per acre of drainage. The system capital cost was $157,010 for the one-acre site. The cost exceedance is due to the construction complexity of the site, San Diego's high regional construction cost, and the built-in uncertainties with installing a prototype system on a government installation. When assessing the system's ability to meet the most stringent permit requirements, its small footprint, minimal maintenance requirements, and the total lifecycle cost still makes the system a feasible option. Sites that do not have as many physical restraints as the NBPL site (limited accessibility – i.e., buildings, fences, and underground utilities) are expected to be more affordable. Furthermore, there is some economy of scale with larger watershed areas that reduce overall capital cost.

Site layout is a key factor for system implementation. To achieve gravity flow for the entire process, the site must have a 4.5 foot drop in elevation from the asphalt area to the invert of the outfall or discharge point. The BMP media vault is a modular unit, so with larger drainage areas, multiple vaults must be installed in parallel to handle the larger flowrates expected. The LID component is customizable and not based on a set unit size.

This project demonstrated the Hybrid LID/BMP System's ability to achieve high metals and suspended solids removal consistently over two rain seasons. The average removal percentage for total and dissolved copper was 97%, total and dissolved zinc was 98%, and TSS was 95%. Over the project life, the system received minimal maintenance and only two contractor maintenance cycles were performed to replace the top three inches of mulch on the LID biofilter. Multiple research and development projects continue to use the site as a test bed. The system is still in place at NBPL and actively treating storm water runoff.

1.0 INTRODUCTION

1.1 BACKGROUND

This technology demonstration addresses elevated concentrations of environmental pollutants commonly found within Department of Defense (DoD) industrial site storm water runoff. The project focus is decreasing toxic metal concentrations (primarily copper and zinc) within storm water runoff emanating from high risk industrial areas. The DoD is under increasing pressure from regulators and local communities to reduce the amount of storm water pollutants discharging into oceans, harbors, bays, lakes, and streams. This technology demonstration provides the DoD with an additional method to decrease the concentration of toxic contaminants within runoff water, thereby avoiding Notices of Violation (NOVs) from regulating agencies and improving public perception of DoD environmental stewardship.

The hybrid Low Impact Development/Best Management Practice (LID/BMP) system is an innovative, low maintenance, and gravity driven technology that combines LID with a structural BMP to remove metals, suspended solids, and low concentrations of petroleum hydrocarbons from storm water runoff. The high flow LID media and plant matrix reduce the concentration of typical pollutants found in storm water by mimicking the contaminant removal mechanism of a natural swale. It occupies a smaller footprint than a natural swale by exceeding traditional swale percolation rates. The structural BMP further polishes the LID effluent with adsorbent media to remove problematic ionic contaminants like copper and zinc down to ultra-low levels. Project studies suggest that the hybrid system will provide more effective pollutant removal at a lower capital and operating cost than most commercially available structural storm water BMPs now on the market.

DoD installations must comply with National Pollution Discharge Elimination System (NPDES) storm water permit requirements. Compliance is usually achieved by completing a multi-phase process consisting of source reduction, and implementation of both non-structural (i.e., street sweeping) and structural BMPs aimed at reducing the amount of pollutants that enter the storm water runoff.

Non-structural BMPs are usually simple changes in management practices that reduce the potential contamination of storm water runoff. Examples of non-structural BMPs include regularly sweeping work areas, training employees to properly dispose of wastes, cleaning catch basins, and storing materials under covered areas. Implementation of non-structural BMPs alone may not be adequate to comply with NPDES permit discharge requirements. An additional phase to implement structural BMPs may be required if all applicable non-structural BMPs are in place and contaminants in the site storm water runoff still exceed the permitted effluent limits. Structural BMPs are technologies designed to reduce runoff volume and target specific contaminants to reduce pollutant concentrations.

Storm water runoff from DoD high risk industrial areas can be roughly characterized as having elevated metals content, moderate suspended solids and organic (hydrocarbon) content, and low nutrient and bacteria content. The elevated metal concentrations in storm water runoff from DoD high risk industrial areas can be attributed to outdoor metal working processes such as cutting and grinding, storage of metal objects outdoors, and use of metal bearing materials such as corrosion inhibiting and anti-fouling paints. Organic material is often attributed to small leaks in vehicles (i.e., motor oil, hydraulic fluid, and antifreeze). Sediment is usually fine particles of soil deposited on the watershed by wind or erosion. Dust created by industrial processes (such as media blasting) is another source of fine particles, as well as wearing of brake pads and tires from material handling equipment.

For the Navy, the problem of contaminated storm water runoff is especially severe in San Diego. As the *San Diego Daily Transcript* reported on April 2, 2000, "The main chemicals of concern in San Diego Bay are copper, mercury, zinc, total chlordane, total PCBs, and PAHs (poly-aromatic hydrocarbons). Contaminated sediments pose a substantial threat to aquatic life, wildlife, fisheries, and human health. Fish and bottom-dwelling creatures suffer disease, death, reproductive failure, or impaired growth upon exposure to pollutants in the sediment. Trace metals (i.e., copper, mercury, zinc) in the sediments are harmful particularly because they persist in the marine environment and bio-accumulate up the food chain, traveling from marine organisms to fish then to humans. The data clearly shows the most toxic areas are located adjacent to the 32nd Street Naval Station (7th St. Channel), NASSCO, Southwest Marine, Continental, and Campbell Shipyards."

Storm water runoff from DoD high risk industrial areas is not easily treated by commercial off-the-shelf (COTS) technology. Most COTS storm water technologies are designed for municipal applications such as trash, nutrients, and sediment removal, and are unable to meet ultra-low permit requirements for metals (i.e. 2.9 µg/L copper). Additionally, many storm water technologies are maintenance intensive or require large areas of land for detention basins and similar LID structures. Space is at a premium at many DoD sites, especially within high risk industrial areas.

1.2 OBJECTIVE OF THE DEMONSTRATION

The project objective was to demonstrate and validate a full scale, modular 100 gallon per minute (gpm) Hybrid LID/BMP System that decreases metal concentrations within storm water runoff from high risk industrial areas to ultra-low NPDES permit limitations. The innovative system merges sustainable LID with a structural BMP, and uses 1,100 gallons of underground water harvesting to autonomously irrigate LID plants with very low water requirements during dry summer months. The demonstration was conducted at the Fleet Readiness Center Metal Finishing Complex (FRC MFC) located on Naval Base Point Loma (NBPL) in San Diego, California.

Table 3-1 has the site-specific system performance objectives of the demonstration plan derived from the California Regional Water Quality Control Board (CRWQCB), San Diego Region Water Discharge Requirements for the United States Department of the Navy, Naval Base Point Loma Complex of San Diego County, NPDES Permit No. CA0109363.

It is of particular importance to reduce the concentration of copper and zinc within the storm water runoff at the project site to meet the whole effluent toxicity limitation requirement. The NBPL NPDES effluent limits and performance goals are to reduce total copper to less than 33.2

μg/L, and reduce total zinc to less than 260 μg/L. Prior to the demonstration, FRC MFC consistently exceeded their multi-sector discharge permit levels for copper, zinc, and total suspended solids. Specifically, the average copper concentration in storm water runoff from FRC MFC was 169 μg/L and the average zinc concentration was 745 μg/L.

There are many Navy activities in San Diego, CA, Norfolk, VA, Washington State, and elsewhere that can benefit from this storm water technology. Army and Air Force facilities will find broad application for this technology as well, as they too have activities in California, Washington and Hawaii that have stringent storm water limits.

Other objectives of the demonstration was to validate the Hybrid LID/BMP System advantages of improved pollutant removal performance at lower capital and operating costs over COTS structural BMPs. Naval Facilities Expeditionary Warfare Center (NAVFAC EXWC) and other organizations tested COTS storm water filter systems and found that they have a pollutant removal effectiveness of 60 to 70%. This level of removal may not be sufficient to reliably reduce pollutant concentrations to the levels required to meet NPDES permit limits and pass required toxicity tests. The pollutant removal media developed at EXWC has demonstrated removal effectiveness of more than 95% for many metals and more than 80% for petroleum hydrocarbons.

Capital cost performance objective was established at less than $100,000 per impervious acre. The filter materials used by EXWC are inexpensive procured in bulk at a cost less than $2.00 per pound. Annual maintenance consists of removing and replacing the first inch of BMP filter media and infrequent trimming of LID biofilter plants. Based on a similar project at the Naval Recycling Center in San Diego, the removed media is cost effectively managed as a solid waste and disposed of at local landfill in the same manner as storm water catch basin sediment. The removed engineered material and mulch from the LID is managed the same way.

Low maintenance is a key design element of the system and "ease of use" was included as a performance objective in the demonstration. The DoD has limited resources and manpower to fully maintain its critical utilities, and storm water infrastructure is often overlooked and considered a low priority. Historically, maintenance on storm water systems only occurs when there are major negative impacts to mission operations, pose a safety hazard, or if the activity is facing a fine.

1.3 REGULATORY DRIVERS

The Clean Water Act Sec 101(a)(3) declares "that it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited." The Order states, "By complying with the industrial storm water discharge specifications for toxicity in this Order, the discharges of industrial storm water will be non-toxic. The receiving waters are not expected to become toxic from the industrial storm water discharge."

Total Maximum Daily Load (TMDL) is the calculated maximum amount of a specific pollutant allowed to enter an impaired waterbody so that the receiving water will meet present and future water quality standards. Point source TMDL allocations for specific pollutants are generally implemented through the Environmental Protection Agency's (EPA) NPDES permits that include water quality based effluent limits. These NPDES discharge limits are designed to be "consistent with the assumptions and requirements" of waste load allocations in EPA-approved TMDLs. Additionally, special provisions within most NPDES permits contain reopener provisions to address new or revised water quality objectives that come into effect, or any TMDL that is adopted or revised, and is applicable to the discharger.

Each state is required to develop water quality standards that enumerate the designed use of its water bodies and develop criteria deemed necessary to protect those designated usages. NPDES permits establish a pollutant monitoring program and pollutant limits (not to exceed) to protect those water bodies during storm events. It has been determined that properly managing the "small storm events", those greater than 0.1 inches and less than 1 inch, effectively captures 90% of the pollutants entering oceans and lakes. Accordingly, managing runoff volume and pollutant removal from these small storms is the most important variable for water quality protection.

DoD installations in the San Diego region are prohibited from discharging first ¼ inch of storm water runoff from all designated Industrial High Risk (IHR) areas, except if the pollutants in the discharge are reduced to levels that comply the NPDES permits.

1.3.1 General Regulations

On November 16, 1990, the EPA issued Federal regulations for storm water discharges (40 CFR Parts 122, 123, and 124). These regulations require specific categories of facilities that discharge industrial storm water to obtain a NPDES permit. In addition, facilities are required to implement Best Available Technology Economically Achievable and Best Conventional Pollutant Control Technology to reduce or eliminate industrial storm water pollution. The EPA developed a four-tier permit issuance strategy for storm water discharges associated with industrial activities. These are:

Tier I, Baseline Permitting – One or more general permits will be developed to initially cover the majority of storm water discharges associated with industrial activity.

Tier II, Watershed Permitting – Facilities within watersheds shown to be adversely impacted by storm water discharges associated with industrial activity will be targeted for individual or watershed-specific general permits.

Tier III, Industry-Specific Permitting – Specific industry categories will be targeted for individual or industry-specific general permits.

Tier IV, Facility-Specific Permitting – A variety of factors will be used to target specific facilities for individual permits.

The regulations allow authorized states to issue general or individual permits to regulate storm water discharges. The permit normally requires dischargers to:

- Eliminate unauthorized, non-storm water discharges

- Develop and implement a Storm Water Pollution Prevention Plan (SWPPP)
- Perform monitoring of storm water discharges and authorized non-storm water discharges

1.3.1.1 Phase I NPDES Storm Water Program

In response to the 1987 Amendments to the Clean Water Act, the EPA developed Phase I of the NPDES Storm Water Program in 1990. The Phase I program addressed sources of storm water runoff that had the greatest potential to negatively impact water quality. Under Phase I, the EPA required NPDES permit coverage for storm water discharges from:

- "Medium" and "large" municipal separate storm sewer systems (MS4s) located in incorporated places or counties with populations of 100,000 or more
- Eleven categories of industrial activity, one of which is construction activity that disturbs five or more acres of land

Operators of the facilities, systems, and construction sites regulated under the Phase I NPDES Storm Water Program can obtain permit coverage under an individually tailored NPDES permit (developed for MS4s and some industrial facilities) or a general NPDES permit (used by most operators of industrial facilities and construction sites).

1.3.1.2 Phase II NPDES Storm Water Program

The Phase II Final Rule, published in the Federal Register on December 8, 1999, requires NPDES permit coverage for storm water discharges from:

- Certain regulated small municipal separate storm sewer systems
- Construction activity disturbing between one and five acres of land (i.e., small construction activities)

In addition to expanding the NPDES Storm Water Program, the Phase II Final Rule revises the "no exposure" exclusion and the temporary exemption for certain industrial facilities under Phase I of the NPDES Storm Water Program. The Phase I and II Programs together regulate three types of storm water discharges: industrial activities, construction activities, and MS4s.

1.3.1.3 Storm Water Discharges from Industrial Activities

Storm water is often exposed to activities such as material handling (cutting grinding and storage at industrial sites. The runoff from these activities discharge industrial pollutants into nearby storm sewer systems and water bodies. This may adversely affect water quality.

To limit pollutants in storm water discharge from industrial facilities, the NPDES Phase I Storm Water Program includes an industrial storm water permitting component. Operators of industrial facilities included in 1 of the 11 categories of "storm water discharges associated with industrial activity" (40 CFR 122.26 (b)(14)(I)-(xi)) that discharge storm water to an MS4 or directly to waters of the United States require authorization under a NPDES industrial storm water permit. If an industrial facility has a Standard Industrial Classification (SIC) code or meets the narrative description listed in the 11 categories, the facility operator must determine if the facility is eligible for coverage under a general or an individual NPDES industrial storm water permit. In some cases, a facility operator may be eligible for a conditional or temporary exclusion from permitting requirements.

Of the 11 categories of storm water discharges associated with industrial activity, those applicable to the DoD are described below:

Category 1: Facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards

Category 4: Hazardous waste treatment, storage, or disposal facilities

Category 5: Landfills, land application sites, and open dumps receiving industrial wastes

Category 6: Recycling facilities

Category 8: Transportation facilities

Category 9: Sewage or wastewater treatment works

Category 10: Construction activities including cleaning, grading, and excavation of areas over five acres

Category 11: Light industry where industrial materials, equipment, or activities are exposed to storm water

The EPA report *Overview of the Storm Water Program* (EPA 833-R-96-008) documents what is required under Federal regulations.

Many installations will also be affected by TMDLs being established by the EPA and states. Once a TMDL is established, responsibility for reducing pollution is assigned. Military installation's point and non-point sources may be subject to discharge limitations set by TMDLs. DoD activities must also be familiar with their own state and local regulations which may be more stringent than Federal ones.

1.3.2 Site Specific Regulations

The California Regional Water Quality Control Board San Diego Region Order No. R9-2014-0037 NPDES No. CA0109363 regulates discharges from the industrial areas of NBPL FRC MFC. The project site has a discharge permit, which became effective on August 1, 2014 and expires July 31, 2019. As defined in the discharge permit, the industrial areas at the project site are assigned risk level designations of Industrial No Exposure Area (INEA), Industrial Low Risk Area (ILRA), and Industrial High Risk Area (IHRA), based on the potential for each industrial area to contaminate storm water. These areas are required to be inspected on an annual basis to re-assign risk level designations as needed. All of the industrial areas must be covered under a site-specific SWPPP. The ILRAs and IHRAs are also subject to Numeric Action Levels (NALs), with additional effluent limitations assigned to IHRAs for acute toxicity.

The discharge permit requires the Navy to reduce pollutants in storm water discharges from all industrial areas in order to attain the Best Available Technology (BAT) standards for toxic and non-conventional pollutants, and Best Control Technology (BCT) standards for conventional pollutants.

The Navy must also comply with the receiving water's quality standards as defined in the discharge permit. The site-specific SWPPP must be kept up to date and include identification, assignment, and guidance for implementation of pollution prevention measures and BMPs required to prevent or control discharges from industrial areas. For all IHRAs, discharge from the first ¼ inch of each storm is prohibited if the effluent fails the Test of Significant Toxicity.

For the IHRAs and ILRAs, NALs are equivalent to those included in the California Industrial General Permit (IGP). In addition, the discharge permit includes the same Exceedance Response Actions (ERA) process when NALs are exceeded. One difference between the NPDES discharge permit and the IGP is that it provides an option to determine NAL compliance by calculating a flow-weighted average concentration. As defined previously, the discharge permit's ERA process includes assigning "Level 1" and "Level 2" status for pollutants that exceed and continue to exceed the NALs, with both levels requiring the same IGP deliverables including the Level 1 Evaluation and Report, and the Level 2 Action Plan and Technical Report.

Similar to many Navy facilities in San Diego, other storm water discharges from industrial areas have exceeded the NALs for copper and zinc during the 2014-2015 and 2015-2016 reporting years.

2.0 TECHNOLOGY

The technology is a four-component system consisting of a pretreatment filter gabion to reduce coarse solids and associated pollutants, LID biofilter to remove the bulk of pollutants, an underground post-LID water storage tank with irrigation system, and a dual-media filter BMP to further reduce copper and zinc concentrations.

The combination of a LID biofilter and a dual-media filter bed BMP represents a technological advancement and aims to meet increasingly stringent industrial storm water effluent benchmarks for copper and zinc which can be as low as 2.9 µg/L and 90 µg/L, respectively. The Hybrid LID/BMP System also aims to meet effluent benchmarks for other pollutants including total suspended solids (TSS), and oils and grease (O&G) while not exporting other potentially regulated pollutants.

The demonstration system at the NBPL site was sized for a design flow rate of 100 gpm, which was determined using the guidance provided in NPDES No. CA0109363. Typical design guidance ensures that treatment addresses the small storm events, which account for the majority of the pollutants found in storm water. This calculated design flow rate is approximately 10% higher than the calculated 90.5 gpm runoff flowrate that occurs under the 85th percentile hourly rainfall for San Diego and is required for a flow-through structural BMP. Site-specific permit and hydrology details are presented in Section 4.3. Flows exceeding the capacity of the system (greater than 100 gpm) overflow to a 6" diameter pipe and bypass the system. The Hybrid LID/BMP System is both modular and scalable, and can be adapted for other sites with different design flow rates.

Alternative approaches for meeting ultra-low copper and zinc effluent limits consist primarily of active coagulation or pressure filtration based methods, which are extremely expensive. These technologies also typically require frequent maintenance, may have high electricity demands, and the chemical additives may present other water quality and toxicity risks. The Hybrid LID/BMP System is a low maintenance, small footprint, and passive structural approach for meeting ultra-low discharge benchmarks at DoD facilities.

2.1 TECHNOLOGY DESCRIPTION

Figure 2-1 presents the Hybrid LID/BMP System flow diagram. Figure 2-2 and Figure 2-3 present cross-section and plan view schematics, respectively. Section 2.1.1 provides additional details on each of the four components and how storm water moves between them.

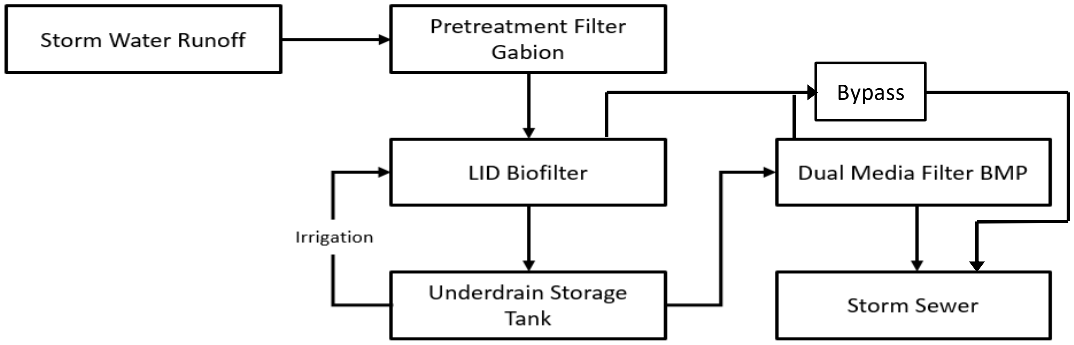


Figure 2-1. Technology Process Flow Diagram

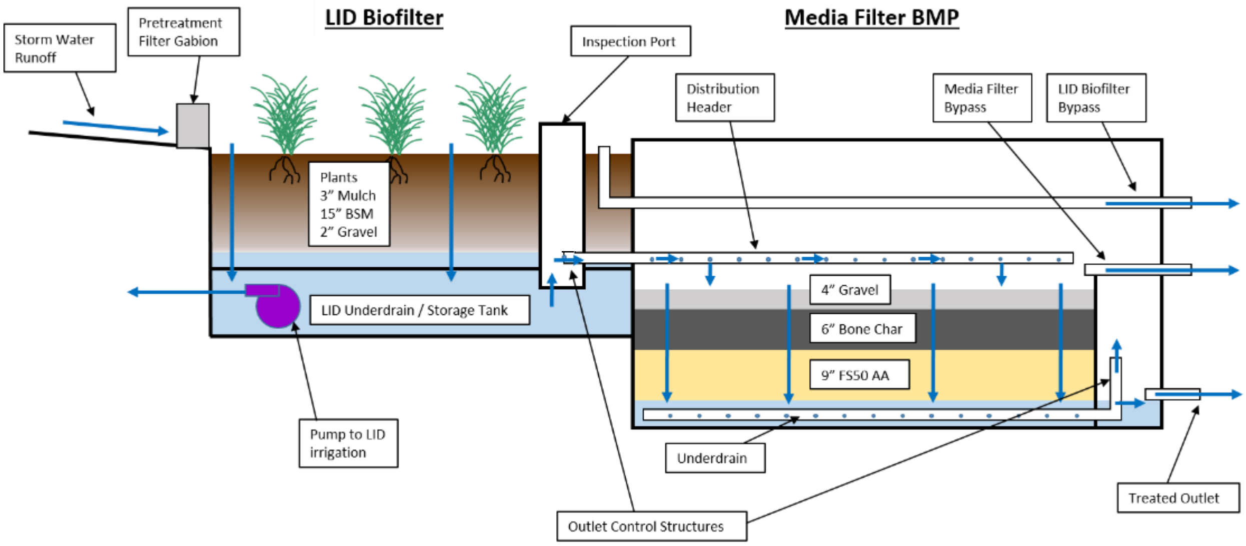


Figure 2-2. Conceptual Cross Section Diagram for Hybrid LID/BMP System

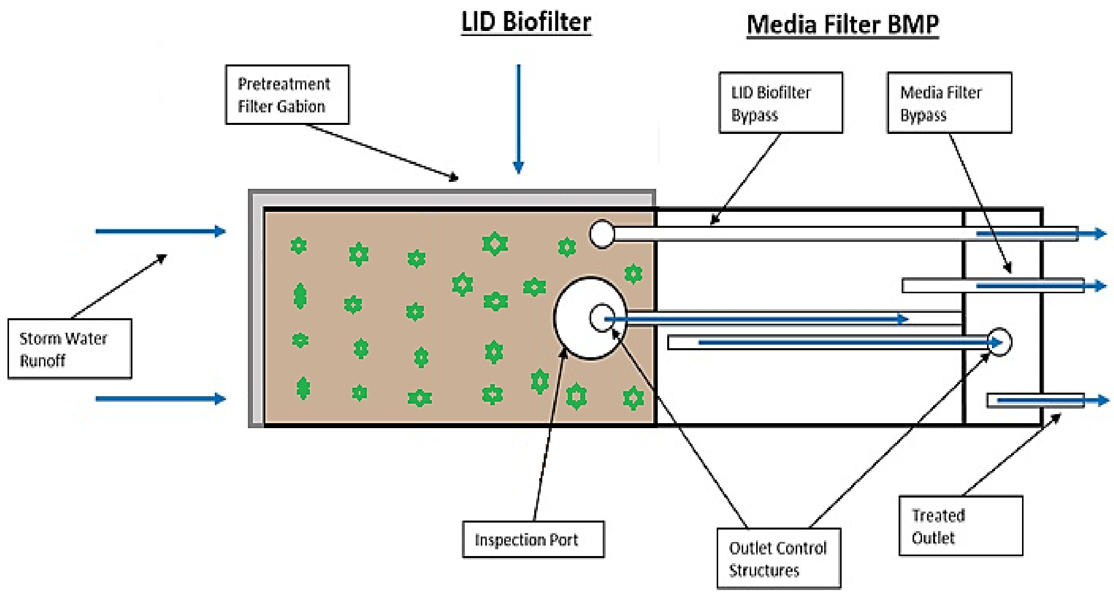


Figure 2-3. Conceptual Plan View Diagram for Hybrid LID / BMP System

2.1.1 Technology Components

2.1.1.1 Gabion Filter

The pretreatment filter gabion is intended to extend the life and improve the performance of the LID biofilter by acting as a roughing filter to remove gross solids, trash, and debris from storm water runoff. The twelve inch tall by six inch wide gabion is constructed of ¾ inch to 2 inch rail ballast (AREMA size No. 4A) enclosed within a UV resistant, plastic coated wire mesh wrapped within U.S. Fabrics 1540 woven geo-fabric. The gabion is oriented so that it extends across the upstream sides of the LID biofilter to intercept runoff. As the gabion wall fills in with gross solids over time, it creates a small pond upstream of the LID for solids to settle. Operations and maintenance (O&M) activities for the gabion include "as needed" sweeping of the asphalt settling area immediately upstream of the LID, sweeping of the upstream face of the woven geo-fabric, and disposal of the swept sediments.

2.1.1.2 LID Biofilter

The LID biofilter is the next stage of the Hybrid LID/BMP System, and features a proprietary high performance modular biofiltration product called FocalPoint purchased from California Filtration Specialists. The FocalPoint biofilter is designed to remove copper, zinc, TSS, O&G, and other pollutants of concern. The LID footprint for the demonstration is approximately 10 feet by 20 feet and has a design flow rate of approximately 1 gpm/ft^2 when clean, which equates to a 200 gpm maximum flow rate. However, the design flow rate is expected to diminish over the life cycle of the technology as the biofiltration soil media (BSM) filters TSS and other particulates. The LID biofilter was intentionally oversized to minimize the required preventative maintenance frequency and reduce the BSM replacement frequency.

Figure 2-4 shows the FocalPoint biofilter that consists of a modular underdrain system beneath filter fabric, bridging stone, BSM, and a thin layer of hardwood mulch. The entire biofilter is contained within an impermeable liner to prevent exfiltration of water to surrounding soils. Typical southern Californian native vegetation (Cleveland Sage, Purple Sage) with very low water demands are planted in the BSM. The native plants have appropriate root thickness, density, and length to prevent clogging and short-circuiting of the BSM. Table 2-1 details the constituents of each layer of the LID system.

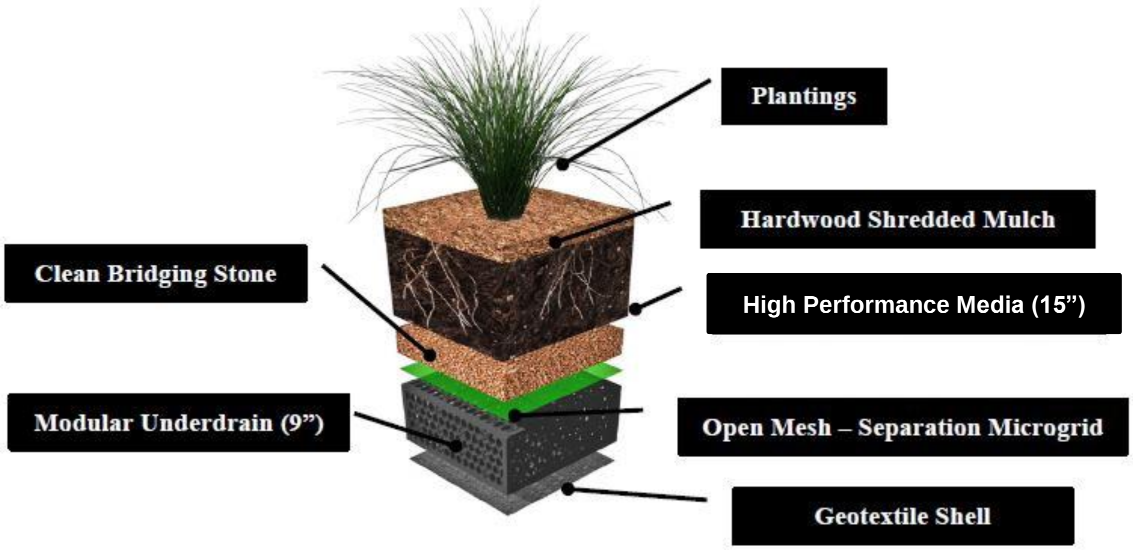


Figure 2-4. FocalPoint Biofilter Conceptual Diagram

Table 2-1. Components of the FocalPoint Biofilter

Biofilter Component	Purpose	Specification	Size/Dimensions
Plantings	Enhance biofilter pollutant removal and aesthetics; maintains long term flow rates	Native drought tolerant vegetation (Purple Sage and Cleveland Sage)	Plants grow up to 2 feet tall
Bypass	Prevent flooding and excessive surface ponding	Overflow schedule 80 PVC outlet control pipe	6 inch above mulch surface
Mulch	Remove solids and coarse TSS; improves plant health	Shredded hardwood and non-floatables	3 inch thick
High Performance Media	Primary pollutant removal component; high porosity; healthy plant growth medium	Sand and peat	15 inch thick
Bridging stone	Prevent migration of fine particles from BSM to underdrain	3/8" – ½" pea gravel	2 inch thick

Open Mesh	Prevent migration of fines from BSM and migration of bridging stone	Microgrid monofilament polypropylene woven geotextile mesh	Single layer
Modular underdrain	Drainage and temporary storage	High loading plastic frame	9 inch tall
Impermeable liner	Prevent infiltration of runoff into underlying soils	Typical durable liner	Single layer
Outlet control valve	Flow rate throttling to improve biofilter performance	LID PVC outlet ball valve	4 inch diameter

The FocalPoint biofilter receives sheet flow storm water runoff exiting the downstream side of the gabion filter. From the surface of the LID biofilter, runoff flows downwards through the biofilter soil media, first passing through mulch, which helps to remove oils and grease and a portion of coarse TSS, and associated pollutants. During high flow storm events, surface ponding may result in additional removal of suspended solids and associated pollutants through settling. If ponding exceeds 6 inches, water flows directly to the downstream outfall via the LID biofilter bypass pipe. The BSM is highly permeable and ponding in the biofilter is unlikely to occur during most storm events.

LID biofilter overflow pipes to Outfall 52. In the event of an overflow from a large rainfall-runoff condition, pollutant concentrations are generally assumed to be less than the smaller storms. Conventional design practices minimize the impact of the ultra-small and the large storm events:

- Rainfall events of 0.1 inch or less are frequent but are not significant in terms of pollutant loading because they generate very little, if any, runoff volume, even from impervious areas.
- Precipitation events greater than 1 inch are relatively infrequent, and although they generate large runoff volumes, most of the pollutant wash-off occurs during the early portion of the storms so that water quality BMPs sized for smaller storms (< 1 inch) are still highly effective at capturing the pollutant load.

EPA's Stormwater Best Management Practice Design Guide current philosophy assumes that large storms are not significant contributors to the overall mass loading. The system and bypass flows were monitored to ensure that the system was operating at the design flows and not bypassing untreated runoff, unless necessary.

The LID biofilter removes typical storm water pollutants at a high hydraulic conductivity of 100 inches per hour. Sand and gravel in the BSM remove particulate pollutants and provide structure for vegetation and some water retention. A small amount of peat in the BSM removes dissolved and organically-complexed copper, zinc, and other hydrophobic organics. The peat content also improves the nutrients and water holding capacity of the BSM for healthy plant growth.

Beneath the BSM, water passes through a two-inch bridging layer of pea gravel followed by a geotextile open mesh before entering the modular underdrain. These layers prevent migration of BSM and other components into the underdrain. Water entering the underdrain flows laterally through the underdrain cells to the 12 inch observation port, and then flows upwards through the port to an outlet leading to the BMP component of the system. The invert of the outlet control port is level with the top of the bridging layer to retain water within the bridging layer and underdrain between storms. The underdrain provides water storage for irrigation of the LID vegetation during dry summer months.

2.1.1.3 Storage Tank and Irrigation System

The storage tank, irrigation controller, and drip irrigation system are designed to provide sufficient water to meet LID biofilter vegetation needs during dry summer months. The FocalPoint modular underdrain performs as the storage tank and has an impermeable liner to prevent infiltration of water into underlying soils. The storage tank dimensions are approximately 10 feet wide by 20 feet long by 9 inches deep with a total storage volume of approximately 1,100 gallons. Table 2-2 details the irrigation demands of vegetation planted in the LID biofilter.

Table 2-2. Estimated Irrigation Demands of LID Biofilter Vegetation

Follow instructions A through F for each month.	A Enter the historical ET in inches for each month.	B Enter the crop coefficient	C Multiply "A" by "B" to obtain plant water needs in inches.	D Multiply "C" by 0.623 to convert inches to gallons per square foot.	E Enter the total square footage of the landscaping.	F Scheduling Coefficient	Multiply "E" by "D" and then by "F". This is your total landscaping demand in gallons.
JAN *	0.27	0.25	0.07	0.0421	200	1.25	11
FEB *	0.92	0.25	0.23	0.1433	200	1.25	36
MAR *	1.64	0.25	0.41	0.2554	200	1.25	64
APR	3.81	0.25	0.95	0.5934	200	1.25	148
MAY	4.77	0.25	1.19	0.7429	200	1.25	186
JUN	5.23	0.25	1.31	0.8146	200	1.25	204
JUL	5.66	0.25	1.42	0.8815	200	1.25	220
AUG	5.49	0.25	1.37	0.8551	200	1.25	214
SEP	4.03	0.25	1.01	0.6277	200	1.25	157
OCT	3.16	0.25	0.79	0.4922	200	1.25	123
NOV	0.89	0.25	0.22	0.1386	200	1.25	35
DEC *	0.43	0.25	0.11	0.0670	200	1.25	17
TOTALS	36.3		9.08				**1,286 gal**

* Irrigation not typically required in winter months as ET demands met by winter rains.

A submersible pump located at the bottom of the inspection port within the storage tank supplies water via drip irrigation piping located on the surface of LID biofilter. The drip irrigation ensures distribution of water across the very porous BSM (underneath the mulch layer). A Rain Bird ESP-SMT smart modular controller provides an adjustable irrigation schedule with a soil moisture sensor override to prevent overwatering during summer months.

2.1.1.4 Dual-Media Filter BMP

The dual-media filter BMP functions as a polishing stage downstream of the LID biofilter to further reduce copper and zinc concentrations below applicable benchmarks. The BMP consists of a two-chamber concrete vault with external dimensions of 16' long by 8' 3" wide and 5' 9" deep. The first chamber holds the adsorption media: (12 feet long and 7 feet 2 ¼ inch wide) filled with 6 inches of 8x30 mesh bone char on top of 9 inches of 28x48 mesh iron coated activate alumina (FS-50). The second chamber is a second clear well chamber (2 foot 7 ½ inch long by 7 feet 2 ¼ inch wide) for hydraulic controls and monitoring infrastructure. The subcomponents within the dual-media filter BMP include:

- A perforated distribution header to disperse water across the filtration media,
- A woven geotextile fabric on the media surface with a thin gravel layer on top to reduce scour (U.S. Fabrics 1540 woven geo-fabric),
- An underdrain media bed drainage manifold surrounded with ¾ inch washed river stone, and
- An outlet control structure.

Storm water exiting the LID biofilter flows directly into a 4 inch PVC distribution header, which is slightly sloped in the direction of flow and extends the length of the filter media bed. The distribution header has several dozen ½ inch holes drilled approximately 45 degrees from the bottom of the pipe on both sides to distribute flow evenly across the media. The distribution header sits atop of the media bed on top of the geofabric layer with a 2 inch layer of ¾ inch gravel for support and scour prevention. Water entering the BMP from the LID biofilter has low levels of TSS and associated particulate pollutants. The majority of the remaining pollutants are in the dissolved fraction or associated with very fine TSS. The bone char and FS-50 layers reduce the concentration of the dissolved contaminants. Both bone char and FS-50 are sorptive materials that were studied in previous research efforts detailed in Section 2.1.2. A ¾ inch washed river stone layer is included below the FS-50 to assist with drainage and prevent media from bleeding into the underdrain. Table 2-3 summarizes the layers in the media chamber.

Table 2-3. Dual-media Filter BMP Layers

Media Layer	Purpose	Specification	Thickness
Surface Geotextile	Prevent scouring from distribution header	U.S. Fabrics 1540 woven geo-fabric	Single Layer. On top of bone char, and on top of gravel drainage layer.
Bone Char	Copper and zinc removal	8x30 mesh	6 inches
Activated Alumina, FS-50	Copper and zinc removal	28x48 mesh, Iron Coated Activated Alumina	9 inches
Drainage Manifold	Drainage	SCH 40, 4 inch diameter slotted pipe with 0.025 inch slot	5 inches

		width and 0.125 inch spacing	
Drainage Layer	Drainage	¾ inch washed river stone	5 inches

The dual-media filter BMP is designed for a flow rate of 100 gpm. Previous NAVFAC EXWC research characterized the hydraulic conductivity of bone char and FS-50. The combined adsorbent layers are estimated to have a hydraulic conductivity of nearly 100 inches per hour. Flow through the dual-media filter BMP is moderated by a level control weir located within the clear well that maintains a 10 minute or greater contact time between the adsorbent media and storm water runoff. This level control weir can easily be modified to obtain a shorter or longer contact time. Discharge from the weir overflows into the clear well and then continues into the outlet pipe leading to Outfall 52. BMP overflow from a large rainfall-runoff condition will also drain to Outfall 52. Any remaining water within the adsorbent media bed and clear well drains through a weep hole over a 72-hour period. Appendix A provides a schematic of the prefabricated BMP vault and all other system components of the Hybrid LID/BMP System.

2.1.2 Expected Applications

The Hybrid LID/BMP System is expected to be implemented at DoD high risk industrial sites that are subject to low discharge benchmarks for copper and zinc. At coastal sites in California, Oregon, Washington, and Hawaii, low marine copper discharge criteria can be applied as numeric limits referred to as NALs. Potential sites that are subject to low NALs include graving docks, recycling yards, equipment dismantling yards, depots, and other industrial facilities designated as high risk. Additionally, ultra-low NALs for copper (2.9 µg/L) and other metals may more become common in the future at DoD industrial sites.

By documenting the performance of the Hybrid LID/BMP System, potential DoD industrial site end users can perform decision-making about implementing the Hybrid LID/BMP System.

2.2 TECHNOLOGY DEVELOPMENT

The combination of an LID biofilter with a dual-media filter BMP to meet ultra-low copper and zinc discharge benchmarks represents a technical innovation. Both technologies have been extensively tested individually but not in combination.

2.2.1 LID Biofilter

Bio-retention and detention style BMPs are commonly used for managing storm water effluent. Test results from many sites are stored in the International Storm Water BMP Database (www.bmpdatabase.org). This data includes a variety of biofiltration and bioretention designs, and adequately represents systems similar to the FocalPoint biofilter. Bioretention summary plots for paired influent and effluent data at a broad range of concentrations are presented in Figure 2-5 for TSS, total copper, and total zinc. These plots show that typical biofilter designs like the LID biofilter used in the Hybrid LID/BMP System are very effective for removing TSS and zinc from storm water, but less consistently effective for removing copper.

Many of the data pairs have influent values much lower than the influent value range at the project site. To support a more direct estimate of typical biofiltration performance at the project site, the data was filtered to retain only influent pollutant values that are within the ranges observed at the project site: 6-10,000 mg/L for TSS, 35-1,000 µg/L for copper, and 170-5,000 µg/L for zinc.

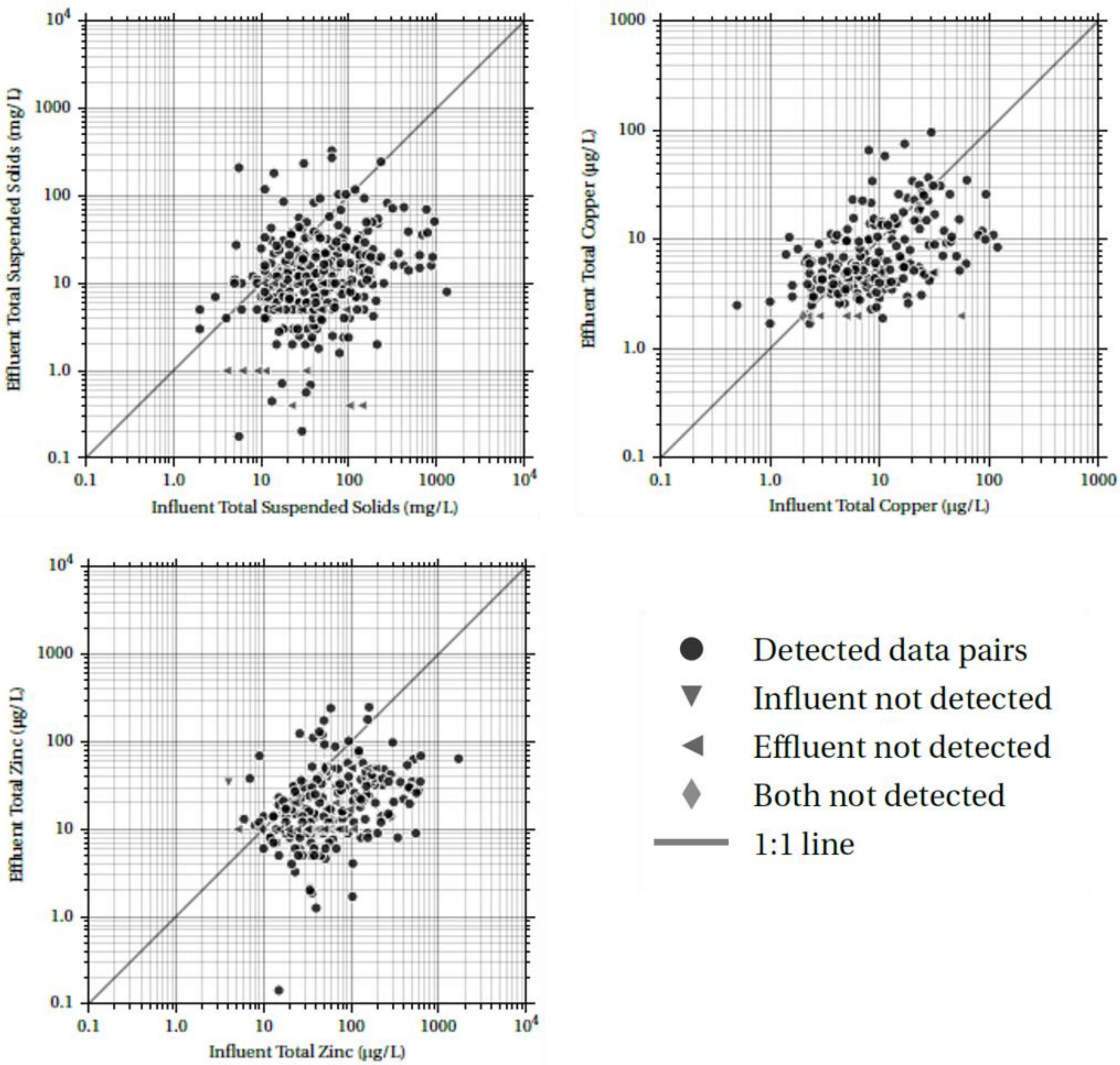


Figure 2-5. Paired Influent and Effluent Monitoring Data from the International Storm Water BMP Database For Bioretention BMPs

Table 2-4 presents summary statistics for this subset of data pairs. The data suggests that typical biofiltration would achieve excellent removal of TSS and zinc, likely meeting the lowest applicable discharge benchmarks even without the addition of the media filter polishing BMP. Summary statistics for total copper suggest that typical LID biofilters would meet the standard copper discharge benchmark most of the time, but would rarely meet the lowest discharge benchmark without the addition of the media filter BMP. However, it should be noted that space is a premium at industrial facilities and Bioretention BMPs require a substantial footprint.

Table 2-4. Paired Monitoring from the International Storm Water BMP Database for Bioretention BMPs

	TSS (mg/L)	**Copper** (µg/L)	**Zinc** (µg/L)
Inlet Maximum	2,410	880	1,698
Inlet Minimum	6	36	173
Inlet Median	46	50	270
Outlet Maximum	330	35	98
Outlet Minimum	0	1	3.0
Outlet Median	11	9.5	21
% Achieving Standard Benchmark	97%	96%	100%
% Achieving Lower Benchmark	82%	4%	100%
Standard Benchmark	100	33	260
Lower Benchmark	30	2.9	120

The FocalPoint biofilter is similar to typical LID biofilters but has a smaller footprint, greater flow rate, and a modular underdrain storage design. The LID biofilter has a specific BSM that permits very high flow rates while still achieving good pollutant removal. According to a FocalPoint vendor-supplied technical evaluation report (Civil & Environmental Consultants, Inc., 2016), the FocalPoint biofilter was field tested at a site in Pittsburgh, Pennsylvania according to Washington State Technology Assessment Protocol – Ecology (TAPE, Washington State Department of Ecology, 2011). TAPE is widely accepted outside of Washington including states such as Oregon, California, Colorado, New York, New Hampshire, Missouri, and Rhode Island (TAPE – Emerging Technologies, 2020).

Flow-weighted composite influent and effluent samples were collected during 20 storm events in Pittsburg, PA and submitted for laboratory analysis of common storm water quality parameters. Table 2-5 summarizes these results. This data from a single year of monitoring shows that that FocalPoint biofilter typically achieves the lowest discharge benchmarks for TSS and total zinc, but not for total copper. However, because influent concentrations from the Pittsburgh test site were lower than the project site, it is unclear whether the FocalPoint biofilter will achieve similar results at the test site. Overall, effluent concentration monitoring data for the FocalPoint biofilter is similar to those for typical biofiltration BMPs, albeit they are achieved at a higher than typical treatment flow rate. This data suggests that effluent from the FocalPoint biofilter will typically achieve the most stringent discharge benchmarks for TSS and total zinc but not for total copper.

Table 2-5. Performance Data for the FocalPoint Biofilter in Pittsburgh, Pennsylvania.

Constituent	N sample size	Mean Influent (mg/L)	Mean Effluent (mg/L)	Median Influent (mg/L)	Median Effluent (mg/L)	Influent Std. Dev. (mg/L)	Effluent Std. Dev. (mg/L)
Suspended Solids	20	305.14	12.73	147.50	10.75	393.10	7.47
TP	20	0.58	0.09	0.18	0.10	0.67	0.03
TKN	16	7.58	1.19	2.83	0.61	13.20	1.14
NO_3	17	0.23	*0.24	0.22	*0.19	0.15	*0.21
Total Cu	17	0.035	*0.006	0.015	*0.006	0.047	*0.002
Total Zn	20	0.253	*0.021	0.129	*0.017	0.355	*0.014
Total Pb	16	0.023	*0.001	0.011	*0.001	0.034	*0.001

*Summary statistics for censored effluent data calculated using Regression of Order Statistics (ROS) method and are rounded values

2.2.2 Dual-Media Filter BMP

The dual-media filter BMP has been extensively tested as part of previous Navy Environmental Sustainability Development to Integration (NESDI) and Environmental Security Technology Certification Program (ESTCP) projects (Anguiano & Foreman, 2009; Kirts et al. 2004). Initial NESDI development of this technology consisted of testing 24 different candidate filter media for heavy metals removal in bench scale column tests. Results from these tests suggested that a media bed of bone char and activated alumina would be the most effective filter media combination for removing heavy metals from storm water. Table 2-6 shows that both materials have exceptional removal capacities for copper, lead, and zinc, and are estimated to last for up to 40 years at a typical recycling center before exhausting material sorption capacity (Anguiano and Foreman, 2009).

Table 2-6. Adsorption Capacities for Iron Activated Alumina (FS-50) and Bone Char

Constituent	Iron Coated Activated Alumina (mg metal/g media)	Bone Char (mg metal/g media)
Copper	3.96	6.29
Zinc	3.58	6.18
Lead	0.74	2.22

Following bench scale tests, two full-scale demonstrations were conducted at the Navy Regional Recycling Center in San Diego, California and at the Anniston Army Depot in Alabama. Results from these tests indicated excellent copper and zinc removal.

The full-scale dual-media filter demonstration BMPs were installed and monitored as part of ESTCP Project RC 200405, *Low Impact Technologies to Reduce Pollution from Storm water Runoff* (Anguiano and Foreman, 2009). The San Diego and Alabama systems had design storm water runoff flows of 265 and 500 gpm, respectively. The design of the dual media BMP stage of

Hybrid LID/BMP System is very similar to the technology implemented at the San Diego and Alabama demonstration sites.

Both systems were monitored using flow-weighted composite sampling methods, and samples were submitted for laboratory analysis of selected parameters. Table 2-7 shows results from the San Diego Navy Regional Recycling Center and indicates that the media filter achieved mean removal of 65% and 66% for total copper and total zinc, respectively. Removal for all heavy metals actually improved over the course of the monitoring period. The mean removal of total copper and total zinc improved to 80% and 83% respectively over the last five rain events of 2007 as a result of minor adjustments to the thickness of the top geo-fabric layer. However, lack of maintenance in subsequent years showed diminished hydraulic and pollutant removal performance due to clogging. Stricter permit limits for copper and lack of resources to perform preventative maintenance prompted a need to develop a more robust, less maintenance intensive system.

Table 2-7. Heavy Metals Removal Performance Summary for Dual-Filter Media BMP

	Influent / Effluent, Average Event Mean Concentration (µg/L) [1]						
Date	**Al**	**Cd**	**Cu**	**Fe**	**Pb**	**Ni**	**Zn**
3/28/2006	1946 / 191	4 / 2	314 / 97	3262 / 290	44 / 7	83 / 24	488 / 184
4/14/2006	1993 / 988	7 / 4	380 / 207	3469 / 1524	50 / 22	73 / 33	799 / 615
4/23/2006	1516 / 907	6 / 6	278 / 189	2401 / 1486	40 / 20	48 / 30	1004 / 767
5/22/2006	1384 / 589	13 / 6	403 / 176	2851 / 1204	69 / 27	39 / 18	1187 / 582
10/16/2006	1650 / 389	10 / 3	435 / 119	2893 / 789	67 / 14	41 / 11	1572 / 313
1/29/2007	959 / 222	15 / 3	230 / 60	1375 / 406	38 / 8	19 / 6	874 / 199
2/18/2007	893 / 141	10 / 1	150 / 24	1229 / 219	43 / 5	11 / 2	561 / 74
2/22/2007	651 / 92	7 / 1	116 / 20	826 / 106	28 / 2	9 / 3	515 / 71
2/27/2007	952 / 220	13 / 2	181 / 29	1242 / 285	51 / 5	14 / 3	865 / 129
3/22/2007	3180 / 265	11 / 3	335 / 81	5350 / 524	66 / 9	29 / 8	928 / 122
4/20/2007	739 / 142	7 / 1	210 / 45	1084 / 208	38 / 5	15/ 3	738 / 113
Seasonal Efficiency Ratio	1442 / 377 (74)	9 / 3 (69)	276 / 95 (65)	2362 / 640 (73)	49 / 11 (77)	35 / 13 (63)	866 / 297 (66)
Last 5 Storm Events Efficiency Ratio	1283 / 172 (87)	10 / 2 (83)	198 / 40 (80)	1946 / 268 (86)	45 / 5 (88)	16 / 4 (75)	721 / 122 (83)

1. ER in parenthesis.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Advantages

The proposed Hybrid LID/BMP System represents a smaller footprint and relatively low cost option for meeting increasingly low storm water discharge permit benchmarks for copper and zinc. By combining the well documented pollutant and sediment removal performance of a LID biofilter with a highly effective sorptive media filter, it may be possible to meet ultra-low discharge benchmarks. The combination of these two processes results in a hybrid design that can achieve pollutant removal by multiple mechanisms including:

- Sedimentation and settling on the LID biofilter surface
- Physical straining in the LID biofilter
- Plant uptake in the LID biofilter
- Hydrophobic adsorption in LID biofilter
- Mineral complexation and hydrophobic adsorption in dual-media filter
- The combination of multiple mechanisms and redundancy of some mechanisms decreases maintenance and increases the likelihood that the technology will be able to achieve ultra-low discharge benchmarks.

This Hybrid LID/BMP System is designed as a passive filtration system that requires very little maintenance when compared to active treatment systems.

2.3.2 Limitations

The potential for media clogging is a possible limitation of this technology. Storm water filtration systems commonly fail due to clogging long before pollutant removal capacity is exhausted. To reduce the risk of clogging, several important design elements are added including: a gabion filter upstream of the LID biofilter, planting appropriate native vegetation to help aerate the soil, oversizing the LID biofilter to account for potential clogging, and the sacrificial surface media layer (hardwood mulch) to the LID biofilter.

2.3.3 Alternative Technologies

There are many types of storm water technologies including proprietary structural systems and non-proprietary systems such as LID biofiltration. Few, if any of these alternatives are likely to consistently achieve ultra-low discharge benchmarks for copper at high influent concentrations sites like NBPL. Any vendor-supplied approach to meet ultra-low copper discharge benchmarks would likely consist of an active treatment train approach based on some combination of the following technology types:

- Physical hydrodynamics separators
- Pressure sand filtration
- Sorptive media filtration
- Chitosan enhanced sand filtration
- Chemical coagulation and flocculation
- Electro coagulation
- Chemical oxidation

Any such treatment train is likely to have high capital and long-term O&M costs. These treatment train approaches are also likely to require active management and frequent O&M that requires time and training of onsite personnel or hiring long-term maintenance contractors.

3.0 PERFORMANCE OBJECTIVES

The effectiveness of the Hybrid LID/BMP System is assessed by whether the storm water technology achieves the identified discharge benchmarks for specific pollutants, notably copper and zinc. Other objectives include preventing the export of other potential storm water pollutants, limiting the toxicity of effluent, achieving specific cost metrics, maintaining the health of LID biofilter vegetation, and minimal O&M effort by site personnel. Table 3-1 presents all the demonstration performance objectives.

Table 3-1. Demonstration Plan Performance Objectives

Performance Objective		Data Requirements	Success Criteria	Results
Quantitative				
Reduce Pollutants In Effluent	Whole Effluent Acute Toxicity Limitation	Hybrid LID/BMP effluent sampling data according to "Methods for Estimating the Acute Toxicity of Effluent and Receiving Waters to Freshwater and Marine Organisms", EPA Method 821-R-02-012	80% survival in 100% effluent from Hybrid LID/BMP outlet	Met
	Reduce total copper in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total copper to less than 33.2 µg/L[1]	Met
			(or 2.9 µg/L ultra-low secondary success criteria)	Not Met
	Reduce total zinc in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total zinc to less than 260 µg/L[1]	Met
			(or 95 µg/L ultra-low secondary success criteria)	Met
	Reduce oils and grease in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 1664, Revision A (TAPE TPH-dx Method EPA 8015 B)	Reduce Hybrid LID/BMP effluent concentration of oil and grease grab samples to less than 15 mg/L (TAPE 0.25 – 0.50 mg/L)	Met
	Reduce TSS in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 2540.B	Reduce Hybrid LID/BMP effluent concentration of TSS to less than 100 mg/L[1] (secondary success criteria: reduce TSS concentration across LID stage by 80%)	Met

Performance Objective		Data Requirements	Success Criteria	Results
	Limit export of other storm water pollutants	Storm water influent, LID biofilter effluent, and dual-media filter BMP effluent sampling data. Lab analysis according to various EPA methods.	Limit other potentially regulated storm pollutants that could be exported by treatment components (orthophosphate and total phosphorus)	Met
Limit Capital Cost		Watershed Acreage and actual Capital Cost	Less than $100,000 per acre of drainage	Not Met
Vegetation Health		Observational data and photos during field demonstration	Plants maintain health and do not dieback during dry summer months	Met
Qualitative				
Reduce Preventative Maintenance	Ease of use	Field photographs, field technician feedback, and maintenance log input	Minimal annual maintenance requirement (inspection, sweeping and particulate cleanup)	Met
[1] TMDL mass load reduction criteria is included within the NBPL NPDES permit via compliance with NAL and acute toxicity requirements.				

3.1 REDUCE POLLUTANTS IN EFFLUENT

The primary quantitative performance objective for the Hybrid LID/BMP System is to reduce storm water runoff pollutant concentrations below NBPL site specific NALs. Secondary success criteria are to meet ultra-low criteria-based copper and zinc limits that apply to other coastal DoD bases. TSS, total copper, total zinc, oils and grease are the primary pollutants of concern since they are commonly found in high concentrations at DoD industrial sites.

3.1.1 Data Requirements

The ability of the technology to remove and/or limit the export of pollutants was evaluated on the basis of pollutant concentrations in composite storm water samples collected at the influent and effluent of the Hybrid LID/BMP System. Additional samples were collected at the inlet and outlet of each component of the LID biofilter stage to better understand the pollutant removal process (and efficiency) for TSS and targeted metals. Effluent concentrations in the LID biofilter and media filter samples were compared to influent concentrations to assess removal or export of pollutants by each system component.

3.1.2 Success Criteria

The primary success criteria for the Hybrid LID/BMP System is to meet site-specific effluent NALs designated in the NBPL NPDES storm water permit. Table 3-1 displays the primary NALs for TSS, total copper, and total zinc of 100 mg/L, 33 µg/L, and 260 µg/L respectively. Secondary success criteria includes meeting ultra-low discharge benchmarks for TSS, total copper, and total zinc of 50 mg/L, 2.9 µg/L, and 95 µg/L respectively. Providing both levels of success criteria may allow results from this demonstration to be extrapolated to other DoD sites nationwide.

It is important to note that there are regional differences in how metals (copper and zinc) are assessed. In the Pacific Northwest, permit limits assess dissolved metals in lieu of total metals. Washington State's Ecology Department developed a process for evaluating and approving storm water treatment BMPs for general use known as Technology Assessment Protocol Ecology (TAPE). The protocol assesses dissolved metals in lieu of total metals. If the technology meets TAPE performance goals the technology can seek approval and be regionally deployed. Where appropriate, TAPE assessment criteria, (i.e. dissolved copper and zinc results) are included in the body of this report to augment the established performance objective found in Section 3.0. TAPE sampling and analysis was performed with the intent of submitting the results for TAPE certification, which provides better acceptance of the technology. The stand-alone TAPE data results can be found in Appendix B.

Pollutant concentration data was assessed to determine the summary statistics for the primary monitoring location (system influent and effluent). Specifically, 95% confidence intervals were generated for each combination to estimate likely pollutant ranges, which were compared with applicable benchmarks. In addition, statistical summaries of the BMP's performance using the collected paired data (influent and effluent) were developed using the non-parametric one-tailed sign test (Wilcox one-tailed signed rank test). This test evaluates statistical differences between paired data points, or in this case, between influent and effluent storm water samples. The null hypothesis is that effluent pollutant concentrations are equal to or greater that influent concentrations. The alternative hypothesis is effluent concentrations are less than influent concentrations. The Wilcox one-tailed signed test is a required statistical approach used for TAPE certification. Calculations are provided in Appendix C.

3.2 LIMIT CAPITAL COSTS

An important performance objective is to limit system capital costs to $100,000 per acre of drainage. Meeting this objective makes the technology cost competitive with alternatives. Meeting stringent discharge benchmarks has typically required significant implementation cost; therefore, meeting this performance objective could provide an example of a more cost effective solution to remove pollutants from storm water runoff. It is important to note that BMP cost can be highly variable based on site complexities and regional construction cost factors.

3.2.1 Data Requirements

Costs for equipment and installation were collected and summarized. These costs exclude the costs for monitoring infrastructure.

3.2.2 Success Criteria

A total cost equal to or less than $100,000 per acre of treated drainage area was used as the success criteria for capital costs. The value was estimated using the worksheet found in Appendix D that shows the upper and lower costs of a similar sand filter technology.

There are many variables that impact the cost of BMP installation including local site conditions, labor rates and whether the BMP is retrofit, or new construction. The California Department of Transportation (Caltrans) has incurred BMP retrofit costs that were 10 times greater than similar new construction.

It is anticipated that the Hybrid LID/BMP System cost will be above the average sand filter cost due to high labor rates in southern California, the extra burden placed on contractors working on government facilities, and the likelihood that most DoD applications will be retrofits. Accordingly, the Performance Objective for installing the hybrid BMP to treat flow from a one-acre site was set to $100K, which is slightly higher than the average sand filter cost.

3.3 MINIMIZE O&M REQUIREMENTS

The Hybrid LID/BMP System is designed to have very low maintenance requirements. Ease of use, site housekeeping (sweeping and particulate removal), and vegetation health are important measures, particularly for systems managed by DoD personnel where resources are limited, and therefore receive insufficient maintenance. The LID biofilter vegetation consists of hardy native varieties that require minimal upkeep. The selected plants were Cleveland Sage (Salvia Clevelandii) and Purple Sage (Salvia Leucophylla).

3.3.1 Data Requirements

Time spent maintaining the system was logged. Observational and photographic documentation of system condition and vegetation health are required to validate the effectiveness of the low maintenance system. The condition of the system was assessed throughout the demonstration during each water qualifying sampling event. Vegetation health was documented throughout the year with emphasis in the summer months when drought conditions prevail. Documentation of vegetation health focused on repeated photographic documentation and assessment of whether specific plants are dead or alive.

3.3.2 Success Criteria

The hybrid system should function as designed without regular maintenance following storm events. Typical maintenance routines should be conducted annually, at most, so all system components must function during and between typical storm events without any maintenance other than minor sweeping of the gabion filter fabric.

Planted vegetation should survive the relatively harsh conditions that will be present in the LID biofilter. Specifically, the planted vegetation should survive both winter conditions (when repeated ponding will occur) and summer conditions (when prolonged drought may occur).

4.0 SITE DESCRIPTION

The demonstration site is located at the FRC MFC at NBPL, San Diego California. (85 Cabrillo Memorial Drive, San Diego, CA 92106)

4.1 SITE SELECTION

The following criterion was used to select the demonstration site:

- Geographic Criteria: DoD Installations in Southwestern California have some of the highest buildup of contaminants in storm water due to fewer rain events compared to other parts of the country. Validating success of the technology here with the regions higher first flush contaminate loading and stringent discharge limits can provide the DoD with a system that can be readily transferred to other DoD sites with similar copper and zinc compliance issues.
- Facility Representativeness: The FRC MFC was constructed in 1949 and is representative of the type of construction (roofing and siding materials protected by copper-laden paints or galvanized) and layout common to DoD industrial sites built up over the last several decades. Common sources of metal pollutants and micron size particulates found at industrial sites originate from corrosion and oxidation of exposed surfaces from buildings, fencing, equipment, and materials; vehicle operations (oil leaks, forklift tires wear on asphalt, concrete, and brake dust), and air deposition from neighboring facilities.

  The release of residue from painting and blasting operations is also common at industrial sites that perform corrosion control operations. Although the painting and blasting operations are contained inside dedicated buildings at the site, it is commonplace for blast material and associated contaminants to migrate outdoors with ingress and egress of equipment. Contaminants accumulate on asphalt and concrete surfaces, and then wash off during rain events and flow to outfalls via storm water runoff.
- Other Selection Criteria: NBPL had the available space to accommodate a full-scale technology with attendant infrastructure (electrical power to operate monitoring instrumentation and a nearby storm water outfall). Storm water managers highlighted this installation as a good demonstration site as it has exceeded NALs since issuance of their latest NPDES permit. The NBPL staff was very cooperative and agreed to support this demonstration effort. In addition, the site is in relatively close proximity to EXWC and accredited analytical laboratories for performance of sampling and instrumentation troubleshooting.

4.2 SITES LOCATION AND HISTORY

The FRC MFC is a mostly paved one-acre site with several buildings and equipment laydown areas. The primary corrosion control hanger was installed in 1949 and was originally constructed to serve as an aircraft manufacturing and repair depot. The operation of the hanger has evolved over the last few decades, and it is now used to fabricate prototypes. Activities in the hangar include painting and blasting equipment, and storage of materials used on naval vessels. Figure 4-1 shows the general location of the FRC MFC facility on the Point Loma peninsula in San Diego, and Figure 4-2 displays an aerial view of the demonstration site.

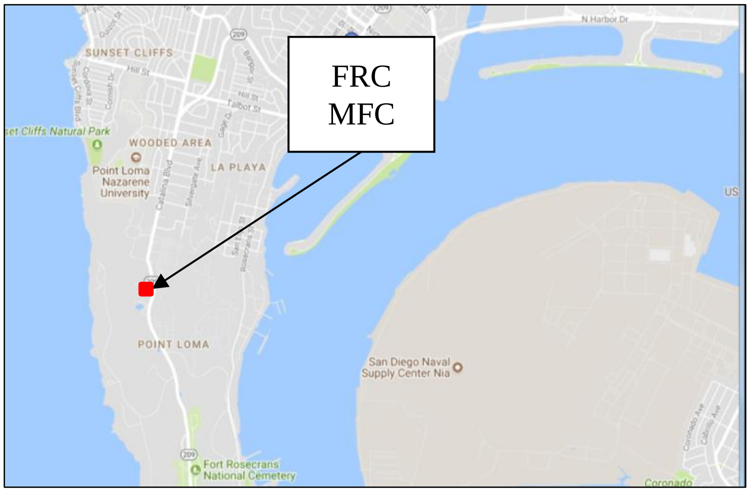


Figure 4-1. NBPL Location in San Diego

Figure 4-2. NBPL FRC MFC Demonstration Site

NPDES Permit No. CA0109363 regulates the FRC MFC storm water outfall. The permit requires NBPL to make provisions for either capturing the first ¼ inch of storm water runoff or treating the storm water runoff. All of the storm water sheet flows to the northwest corner of the site where it pools before making its way to a neighboring property and to Outfall 52, a 24” corrugated metal outfall pipe that leads to the Pacific Ocean. Regulations require sampling the storm water runoff from NBPL at Outfall 52 at a minimum frequency of two storms per semiannual period. Table 4-1 shows that samples taken in the last two years have exceeded NALs limits for copper and zinc.

Table 4-1. Outfall 52 Sampling Results

Date Sampled	Oil and Grease (mg/L)	pH neg log (H+)	TSS (mg/L)	Aluminum, Total (ug/L)	Copper, Total (ug/L)	Iron, Total (ug/L)	Zinc, Total (ug/L)
Range	ND-35	6.9-8.9	5.2-10,000	87-160,000	35-950	100-230,000	170 -3,900
Average	10.6	7.8	1,519	37,702	169	45,273	745
Maximum	35	8.9	10,000	160,000	950	230,000	3,900
Minimum	ND	6.9	5.2	87.0	35.0	100.0	170.0
Detection Limits	0.51	NA	1.1	1.9	0.064	21	0.37
Number of Events Sampled	14						

NBPL stores equipment and parts for processing outdoors on pallets inside their fence line. Like many facilities within the DoD, copper and zinc are ubiquitous on these parts due to their ability to resist corrosion of metal substrates. The Hazardous Waste Storage Facility depicted in Figure 4-3 is typical of building found at DoD installations with its exposed metal structures that contribute to storm water contamination.

Figure 4-3. Hazardous Storage Building at FRC MFC NBPL San Diego

4.3 WATERSHED HYDROGEOLOGY

NAVFAC EXWC personnel surveyed the approximately 1-acre FRC MFC site to determine if there was enough elevation drop to insure positive gravity flow through the system. Figure 4-4 displays the resulting elevation map. The numbers on the contour map are relative elevations to the corner of Building A36 (400.8 value). There is about a 4.5 foot drop in elevation from the asphalt area to the invert of the Outfall 52, which is considered adequate to install the hybrid LID/BMP for gravity flow.

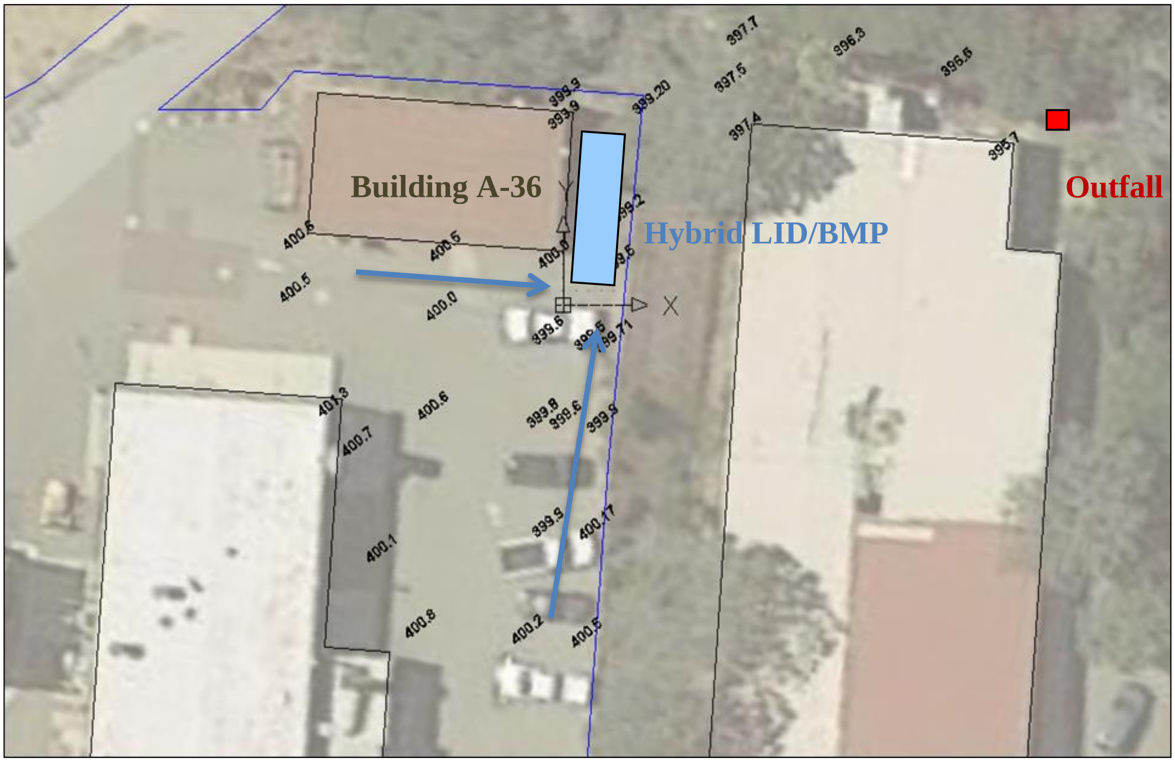


Figure 4-4. Map Showing Spot Elevations of Existing Site

The blue arrows in Figure 4-4 show the flow direction of the storm water runoff across the work area and parking lot to the low point in the parking lot near Building A-36. The blue rectangle is the location of the storm water technology demonstration. Outfall 52 is displayed as a red square in the top right corner of the figure. Figure 4-5 shows the pre and post construction conditions of the system at FRC MFC.

Figure 4-5. Hybrid LID/BMP System Demonstration Site (Before and After)

Figure 4-6 presents rainfall data from Naval Base Coronado (NBC), located across the bay from NBPL. It shows that storms of less than 0.5 inches (in 24 hours) provide over 90 percent of all rain. Fewer than 5% of storms deliver more than an inch of rain.

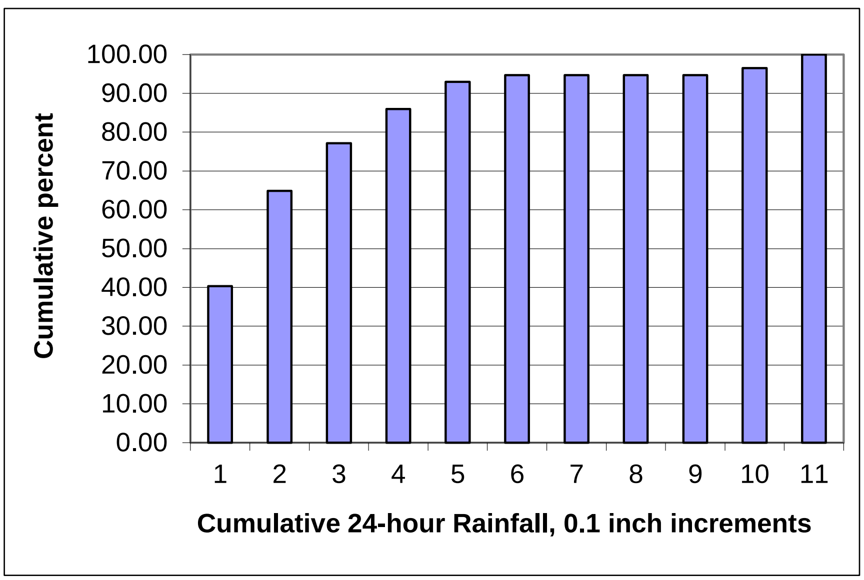


Figure 4-6. Cumulative Rainfall Data for San Diego

The NBPL NPDES permit provides design storm standards for new control BMPs. A Factor of Safety must be incorporated into the design of all control BMPs to ensure that storm water is sufficiently treated throughout the life of the control BMPs. The design storm standards and safety factors for treatment control BMPs at NBPL are as follows:

"*The maximum flow rate of runoff produced by the 85th percentile hourly rainfall intensity, as determined from local historical rainfall records, multiplied by a factor of two;*"

Figure 4-7 shows the San Diego County Isopluvial map. The 85th percentile storm at the FRC MFC site is approximately 0.55 inches for the 1-acre site and can be used for sizing volume-based BMPs. The 85^{th} percentile hourly rainfall intensity at San Diego Weather Service Office (WSO) (0.095 inches/hour) was used to estimate the design flow for the flow-based BMP demonstrated at the FRC MFC site. Rational formula flow calculations provided 85 gpm for the design storm, which was rounded up to 100 gpm to further increase the safety factor.

Where $Q = C \times I \times A$ (Equation 1)

Q	=	Flow (gpm)
C	=	Coefficient of perviousness (unit less)
I	=	Intensity (inches per hour provided by 85% isopluvial map)
A	=	Watershed Area (acres)

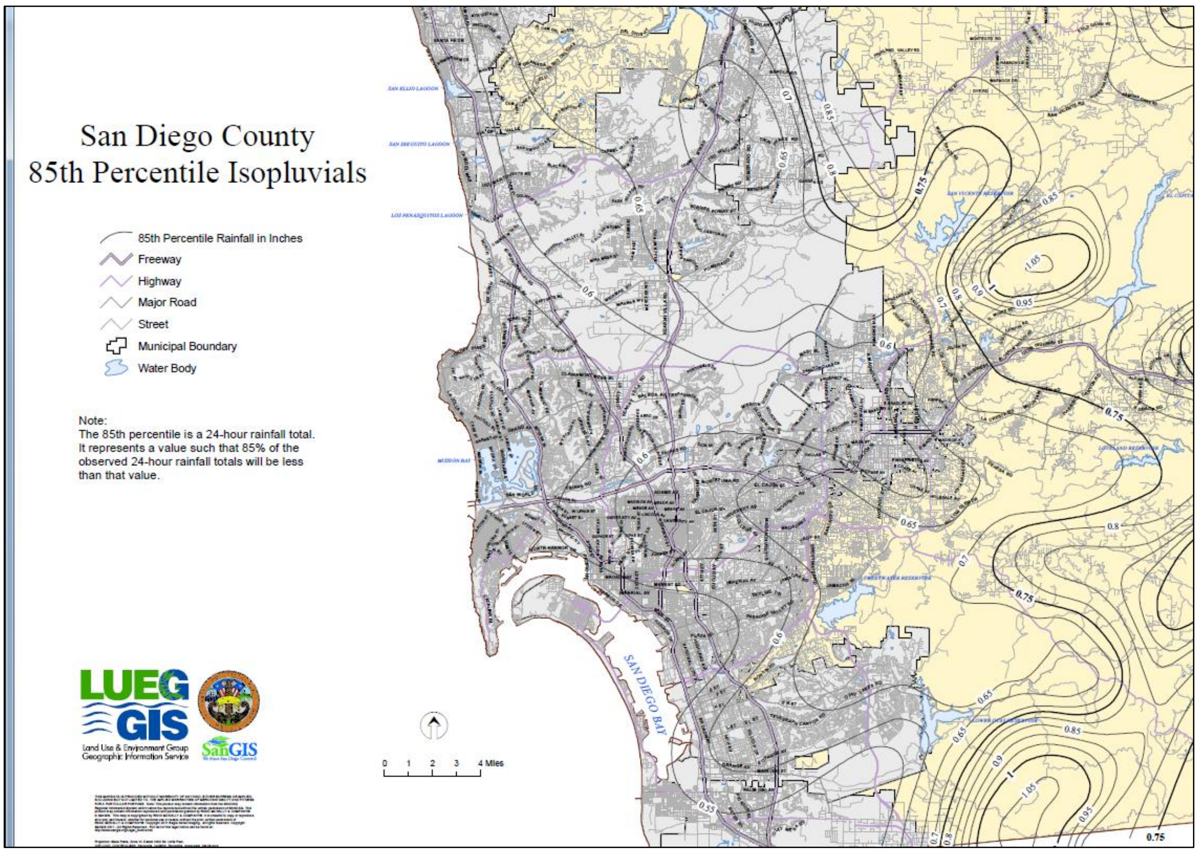


Figure 4-7. San Diego County 85^{th} Percentile Isopluvials

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

5.1.1 Flow Monitoring

The Hybrid LID/BMP System functions as a flow-through storm water BMP with limited volume reduction. Flow monitoring is a key element of the experimental design that supports acquisition of flow-weighted composite samples (influent and effluent) used to validate the systems' pollutant removal efficiency. The captured composite samples represents varying pollutant loads that exist throughout a storm event otherwise known as the event mean concentration (EMC). The EMC is a flow-weighted average pollutant concentration of influent or effluent that takes into account temporal and spatial variations of rain events. Pollutant loads can varies substantially during a storm event based on a number of factors including storm duration, intensity, site factors and season of the year (first flush). The flow monitoring equipment provides data to assess how much water is being treated and or bypassed (overflow). Accordingly, continuous velocity sensors were installed at these three locations:

- BMP media filter bypass,
- LID overflow bypass, and
- BMP media filter outlet

The BMP media filter outlet flow sensor served as the primary control to activate and pace the composite sampling equipment. For the demonstration we assumed steady state conditions whereby the BMP system flowrate provided a reasonable flowrate estimate at the LID biofilter inlet (in the absence of LID or BMP overflow).

5.1.2 Water Quality Sampling

Water quality monitoring focused on documenting the pollutant removal performance of the Hybrid LID/BMP System by comparing system influent (located prior to the gabion) and BMP effluent sample concentrations for pollutants of interest. Water quality sampling was conducted in accordance with the NBPL NPDES storm water permit and TAPE. In addition, water quality sampling was also conducted between the LID and BMP components to better understand subsystem performance characteristics. The results along with sketch showing the sampling locations are provided in Appendix E.

Water quality monitoring was conducted by collecting composite water quality samples to calculate event mean concentrations (EMCs) for pollutants of interest using a flow-weighted composite sampling approach at the system influent and BMP media filter effluent.

Composite water quality samples were collected from 14 storms during the demonstration period. NAVFAC Environmental Laboratory located at NBC in San Diego collected the storm water samples, and sample analysis was conducted by an accredited laboratory, ALS Environmental Services Laboratory located in Kelso, Washington. ALS Environmental Services Laboratory was able to meet the lower metals detection limits required for this demonstration project. APTIM Federal Services has the NAVFAC Environmental Laboratory Services contract.

5.2 BASELINE CHARACTERIZATION

Table 4-1 provides historical storm water sampling data required by the NBPL NPDES Permit for select pollutants from 2003 through 2016. The table characterizes the concentration of selected contaminants by providing the range, average, maximum, and minimum concentration of contaminants found at the demonstration site that are pertinent to this project.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 Flow Monitoring

Flow monitoring with flow pacing enables the collection of composite water quality samples necessary for the accurate calculation of EMCs for selected Constituents of Interest (COIs) during targeted storm events. Specific components of the flow monitoring approach are presented in the following sections and are presented in Figure 5-1.

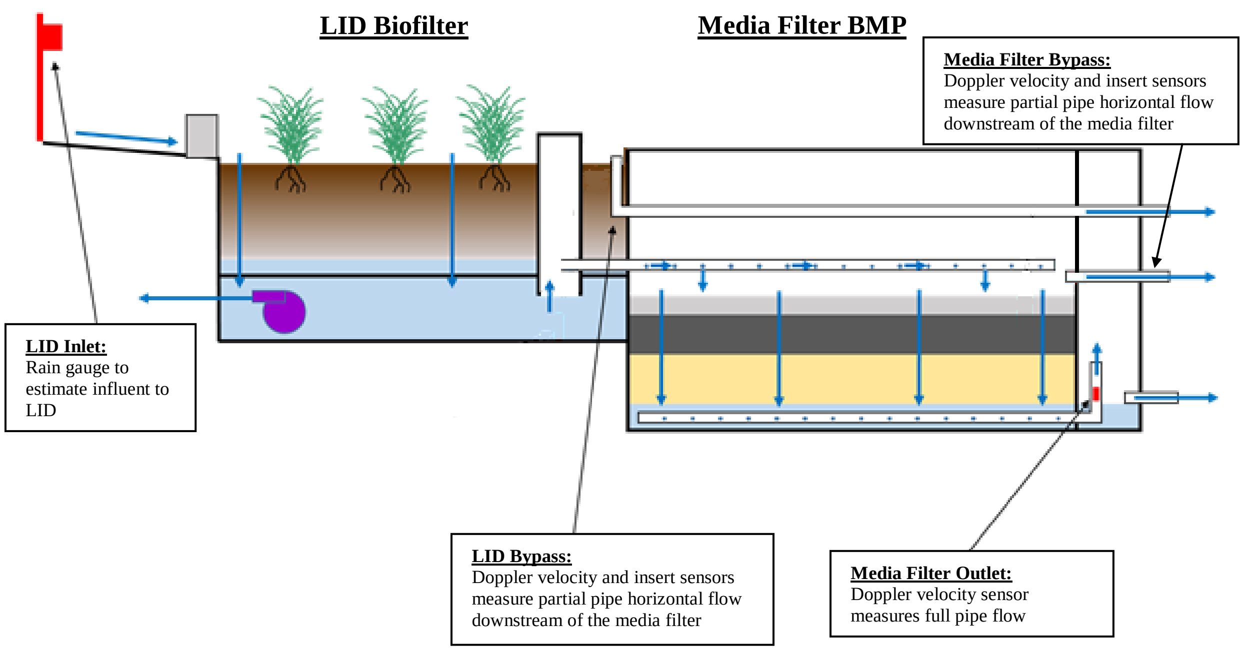


Figure 5-1. Layout of Flow Monitoring Equipment.

5.3.1.1 LID Inlet

Steady state system flow is assumed for the Hybrid LID/BMP System. Therefore, the LID biofilter inlet flowrate is assumed to be equal to the measured BMP outlet flowrate in the absence of LID or BMP bypass. Equation 2 shows this relationship:

$$Q_{inlet} = Q_{outlet} + Q_{LID\ overflow} + Q_{BMP\ overflow} \quad \text{(Equation 2)}$$

The BMP outlet flowrate is measured with a Mace Area/Velocity Sensor within a horizontal pipe under full flow conditions as shown in Figure 5-1. A Mace FloPro XCi data logger averaged and logged flow values on a 4-minute interval.

In addition, runoff from the 1-acre demonstration site was estimated using continuous precipitation depth measurements from an onsite rain gauge in conjunction with Equation 1. The calculated values for peak runoff rate and cumulative flow entering the LID biofilter were then compared with measured values at the BMP outlet, as not all runoff from the demonstration site flows to the LID biofilter inlet.

Precipitation was measured using an Adcon Telemetry RG1 tipping bucket rain gauge. This rain gauge is factory calibrated with a tip resolution of 0.01 inch. It has an accuracy of +/- 1% when installed and operating properly. The rain gauge is fully compatible with the Mace FloPro XCi data logger which averaged and logged precipitation values on a 4 minute interval.

5.3.1.2 LID Bypass

The LID biofilter has a hydraulic conductivity of 100 inches per hour, and the biofilter footprint was intentionally oversized to guarantee design flow and minimize the required maintenance frequency. In the unlikely event that LID biofilter surface ponding exceeded 6 inches, standing water overflows into the LID bypass pipe and discharges to Outfall 52. LID biofilter bypass was measured downstream of the Hybrid LID/BMP technology using the combination of a Doppler velocity sensor and ultrasonic depth sensor under partial flow conditions. The Mace FloPro XCi data logger averaged and logged flow values on a 4 minute interval.

5.3.1.3 Media Filter Bypass

The media filter BMP has a maximum design flow of 100 gpm. In the unlikely event that media filter BMP flow rate exceeds 100 gpm for an extended period of time, standing water overflows into the BMP bypass pipe and discharges to Outfall 52. BMP bypass was measured downstream of the Hybrid LID/BMP System using the combination of a Doppler velocity sensor and ultrasonic depth sensor under partial flow conditions. The Mace FloPro XCi data logger averaged and logged flow values on a 4 minute interval.

5.3.1.4 Media Filter Outlet

The BMP media filter outlet flowrate was measured with a Doppler area/velocity sensor within a vertical stand pipe under full flow conditions as shown in Figure 5-1. The Doppler meter was repositioned on December 12, 2018 to a horizontal position. The team made this change because of erratic negative and zero flow readings from the Doppler sensor. The water exiting the BMP media bed did not have enough particles in it for the Doppler sensor to read the water velocity, which resulted in the negative and zero readings. To correct this problem, the team introduced a water stone bubbler on January 10, 2019 that is triggered by a depth (float) sensor located in the system clearwell indicative of flow. The water stone creates air bubbles that the repositioned Doppler sensor is able to read to get a more reliable and accurate water velocity reading. Figure 5-2 shows the corrected positioning of the Doppler sensor and added “T” where the air stone and float valve are located. A Mace FloPro XCi data logger averaged and logged flow values on a 4 minute interval. Flow through the media filter was calculated by multiplying measured velocity by the cross-sectional area of horizontal pipe.

The BMP media filter and underdrain slowly drain (over 72 hours) into the BMP clear well after a rain event through small weep holes in the clear well piping, but this only represents a very small fraction of total flow during rain events.

Figure 5-2. Corrected Effluent Flow Monitoring Sensor with Integrated Air Stone

5.3.2 Data Logging

All rain, flow, and power data was recorded using a FloPro XCI data logger and accompanying sensors. The FloPro XCI was configured to provide simultaneous flow pacing output pulses for two (influent and effluent) American Sigma 900 Max refrigerated auto samplers. The data logger was configured with a solar panel and external battery, and the recorded data was manually collected using a legacy computer on a quarterly basis.

5.3.3 Water Quality Monitoring

Water quality monitoring is intended to document EMCs of specific pollutants in system influent and effluent from the Hybrid LID/BMP System. The collected data was used to characterize the overall performance of the hybrid system. Specific components of the water quality monitoring approach are presented in the following text and presented in Figure 5-3.

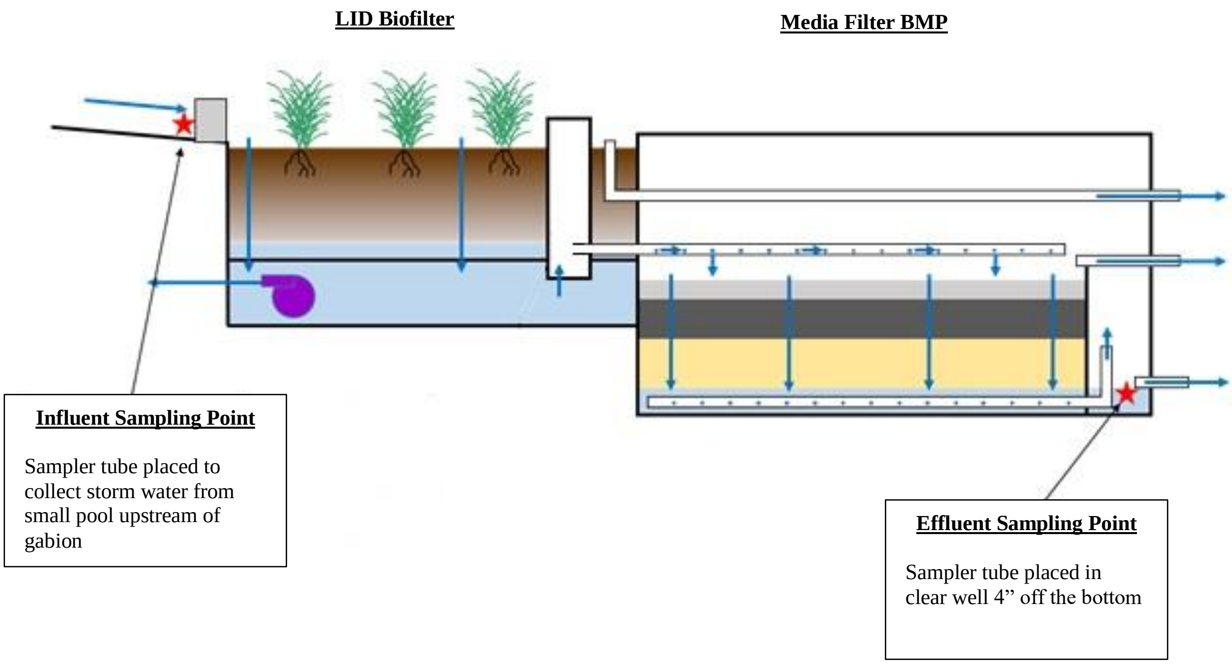


Figure 5-3. Layout of Water Quality Monitoring Equipment

5.3.3.1 LID Biofilter Influent

LID biofilter influent samples were collected using a dedicated American Sigma 900 Max refrigerated auto sampler, with flow pacing provided via the FloPro XCI data logger. In lieu of adjusting the FloPro XCI data logger (flow paced sampling) based on individual forecasted rain events, the data logger was programmed to generate an outlet flow pulse every 250 gallons of treated water. In short, the Sigma 900 and Data logger were programmed to capture a 1 liter sample of influent after each pulse or 250 gallons of water treated. The 250 gallon was determined based on average storm event duration in the San Diego area with the goal of acquiring a minimum of 10 discrete samples per storm. The constant flow pacing was required due to a wide variability of rainfall in the San Diego area and the requirement to eliminate reprograming the software each storm event. Reprogramming the FloPro XCI data logger before each storm was not practical based on a lack of accessibility of the site during non-working hours, the need to minimize human error, and the unpredictability of rain in southern California.

Figure 5-3 shows the sampling location just upstream of the filter gabion. Representative samples were collected via an intake tube located within a small (6” x 8” x 1”) sump in the asphalt surface adjacent to the gabion inlet. The sump was created for the sample tube to properly capture runoff.

5.3.3.2 LID Biofilter Effluent / Media Filter Influent

A Global Water WS750 auto sampler was used to collect a limited number of time weighted composite samples downstream of the gabion wall and at the LID biofilter outlet. The auto sampler intake tube for the LID biofilter outlet pipe was located within the inspection port just below the invert elevation. The purpose of the limited sampling at this location was to gain additional LID performance information on TSS removal, metals removal, pH, and particle size distribution while conserving the sampling budget. The data from these location was included for informational purposes only to better assess removal mechanism during the onset of a storm. Data from this effort is included in Appendix E as requested by the ESTCP committee. It was not intended to meet TAPE certification requirements, nor will it be submitted as part of the application for TAPE certification of the Hybrid LID/BMP System.

In additions to the time weighted samples, one of the rain events was sampled with three diffusive gradient in thin film (DGT) devices; one at the inlet before the gabion wall, a second one at the biofilter outlet and the third at the media filter effluent. The DGTs have the potential to provide simple, accurate and low cost sampling method for measuring dissolved metals in storm water. The devises were co-located with our traditional sampling equipment to provide direct comparison. The DGTs were deployed a few hours before the storm event and were collected at the conclusion of the February 14, 2019 storm for analysis. The results of the limited DGT study are found in Appendix F.

5.3.3.3 Media Filter Effluent

BMP media filter effluent samples were collected using another American Sigma 900 Max refrigerated auto sampler, with flow pacing provided via the FloPro XCI data logger generating outlet flow pulses every 250 gallons from the BMP outlet. Flow pacing for effluent was based on the same premise as the influent sampler.

Figure 5-3 displays the media filter effluent sampling location. Representative samples were collected via an intake tube located in the structural clear well several inches above the floor to avoid any accumulated sediments.

5.4 FIELD TESTING

5.4.1 Installation and Startup

Monitoring system installation, startup, and calibration was completed in February 2018. The following monitoring equipment was installed at the site:

- FloPro XCI data logger with battery (1)
- Mace FloSeries 3 solar panel (1)
- Adcon RG1 rain gauge (1)
- Insert Doppler velocity sensors at the LID and BMP bypass (2)
- Doppler area/velocity sensor at the media filter outlet (1)

- Ultrasonic depth sensors at the LID and BMP bypass (2)
- Dedicated American Sigma 900 Max refrigerated auto samplers for LID biofilter inlet and media filter outlet (2)
- Global Water WS750 auto samplers (2)

Flow calibration was conducted at the LID bypass, BMP bypass, and media filter outlet locations by introducing a known rate of potable water to each dedicated conveyance of the Hybrid LID/BMP System. The tipping bucket rain gauge was tested with a small water volume to ensure individual pulses were recorded by the data logger.

5.4.1.1 Field Sampling

Field sampling began immediately following the installation and startup activities in Spring of 2018. Sampling was conducted throughout the Winter of 2018/19, and was completed after 14 storms were sampled. Field sampling activities consisted of collecting grab and composite samples for qualifying storm events (≥ 0.15" rain), data management, and any unforeseen monitoring system maintenance.

5.4.2 Monitoring System Decommissioning

Monitoring system decommissioning was completed within 3 months of field sampling completion. Decommissioning entailed removal of all monitoring equipment and associated ancillary equipment.

5.5 SAMPLING PLAN

Field sampling was conducted at the inlet and outlet of the technology to document the pollutant removal performance of the Hybrid LID/BMP System. The sampling plan was designed to address the established performance objective focused on the CRWQCB, San Diego Region Water Discharge Requirements for the United States Department of the Navy, Naval Base Point Loma Complex of San Diego County, NPDES Permit No. CA0109363. Where appropriate the sampling design also included addressing requirement in the Washington State TAPE protocol (Washington State Department of Ecology, 2011).

5.5.1 Flow Monitoring Plan

All Hybrid LID/BMP System flows were continuously monitored and logged during the technology demonstration period. The data logger was configured to log data on 4-minute intervals, which was sufficient for flow characterization through filtration-type storm water BMPs. Data stored on the demonstration site data logger was manually collected on a quarterly basis using a legacy computer, and burned to disk to provide multiple data backups

Calibration of Analytical Equipment: All analytical equipment was factory calibrated. Flow equipment included controller/data logger software that allowed for user customized field settings to match known flow rates during quality assurance (QA), quality control (QC) tests.

Quality Assurance: Quality assurance (QA) for analytical equipment included the following activities:

- Regular inspection of site monitoring equipment to ensure proper functioning after each qualifying rain event.
- Monthly rain gauge inspections with annual calibration.
- Purge and rinse of sampling equipment lines. Replace tubing at least once during the monitoring period.

Data reviews were conducted periodically by comparing flows at the media filter outlet during different storm events. The same general relationships between flows should be present during each storm event, so in the event that any relationship changes dramatically, the flow measuring equipment was inspected. Through this comparison QA process, the Doppler velocity sensor error in the clear stand pipe was discovered and then corrected.

5.5.2 Water Quality Monitoring Plan

Storm Targeting and Qualifying Events: Given the intent of documenting pollutant removal performance, sampling was intended to document statistical measures for inlet and outlet (influent and effluent) of the Hybrid LID/BMP System. As such, the goal was to collect samples from a minimum of 12 individual storm events according to TAPE requirements.

Figure 5-4 provides guidance for determining the number of samples that are required to support statistical significance between paired sampling (Burton and Pitt, 2001). Assuming a coefficient of variation between 0.75 and 1, each component would need to achieve an 80% or greater mean reduction in a given COI to achieve statistically significant removal (at the 95% confidence level) during 12 storm events. This level of statistical significance is generally recommended to document the performance of storm water systems (Geosyntec Consultants and Wright Water Engineers, Inc., 2009), and is required to receive approval under the TAPE protocol.

Table 5-1 displays several meteorological resources that were used to estimate the auto sampler pacing during the demonstration period. The collection of discrete storm event data can prove difficult to achieve when actual precipitation significantly differs from forecasted precipitation.

Table 5-2 details criteria that was used in conjunction with the meteorological data to estimate the appropriate auto sampler pacing. Pacing was calculated for each auto sampler to collect at least 7 to 10 aliquots and 1 gallon of sample without exceeding the refrigerated auto sampler capacity. Pacing was set at the 250 gallons to account for most storm events occurring at NBPL. Laboratory field technicians were available 5-days a week to conduct sampling activities during normal work hours. Storms occurring during weekend and off hours were collected on the next working day in an attempt to capture at least 12 qualifying storms.

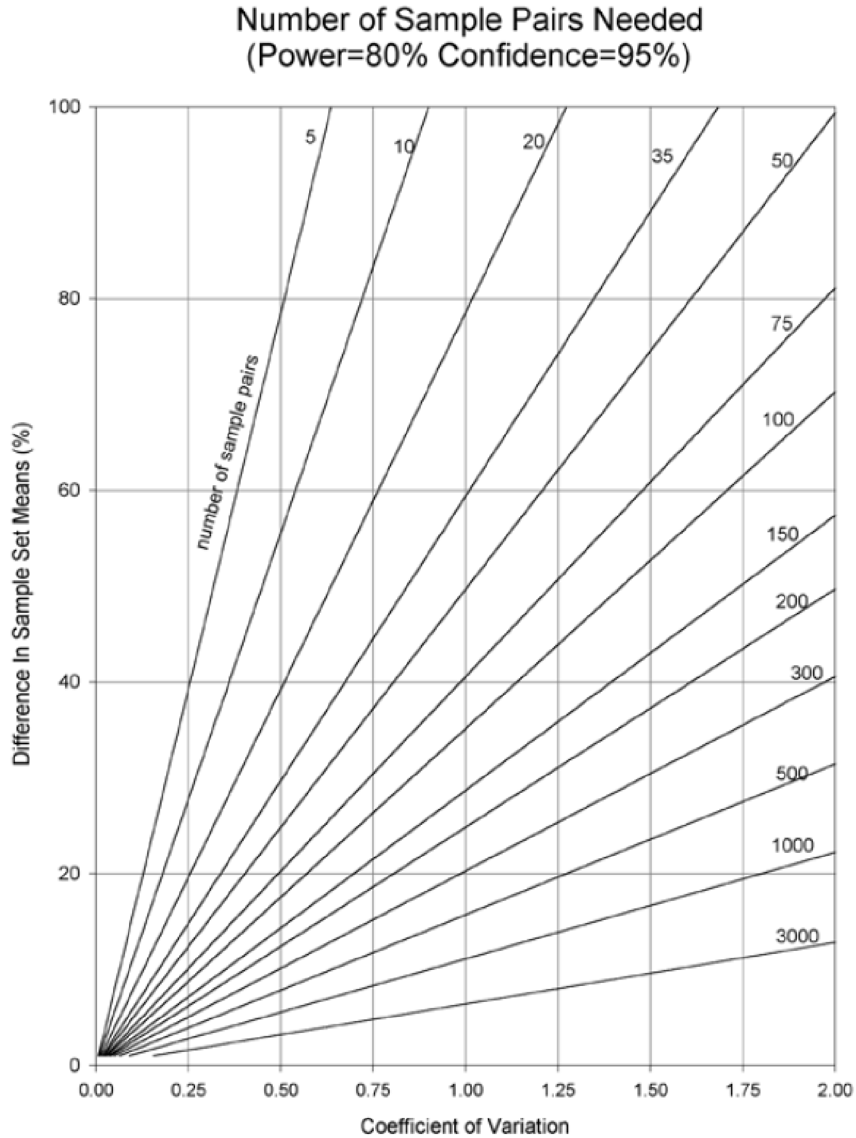


Figure 5-4. Number of Samples Required for 80% Power and 95% Statistical Significance

Table 5-1. Weather Resources For Storm Targeting and Auto Sampler Pacing

Resource	Product	Timeframe	Website
National Weather Service	Probabilistic precipitation guidance	Medium to long for planning	http://www.wpc.ncep.noaa.gov/pqpf/conus_hpc_pqpf.php
Weather Canada (includes San Diego)	Probabilistic quantitative precipitation forecasts	Medium to long for planning	https://weather.gc.ca/ensemble/naefs/EPSgrams_e.html?station=SAN
Weather Underground	Short term quantitative precipitation estimates	Short term for sampler pacing	https://www.wunderground.com/us/ca/san-diego/zmw:92101.1.99999/precipitation

Table 5-2 summarizes criteria for qualifying storm events. Based on TAPE requirements (2011 revision) qualifying storm events require 0.15 inches of rain during the storm event with an antecedent dry period of at least 6 hours during which no more than 0.04" of precipitation falls. The required minimum storm duration is 1 hour. A minimum of 7 to 10 sample aliquots were required to represent at least 75% of the total storm hydrograph during the first 24 hours of a given storm event to be considered a qualifying sample.

Table 5-2. Criteria for Qualifying Water Quality Storm Events

Parameter	Definition	Criteria
Storm events	Minimum number of storm events successfully sampled	12
Minimum storm precipitation depth	Total rainfall during a storm event	0.15 inches
Antecedent dry period	Number of hours before the start of a sampling event without significant precipitation	6 hours with no more than 0.04 inches
Sample aliquots	Minimum number of aliquots in each composite sample	7 to 10 aliquots
Composite sample volume	Minimum composite sample volume required to complete required analyses	1 gallon
Storm event coverage	Percentage of the total storm volume that the aliquots represent	At least 75% of the first 24 hours of a given storm

Calibration of Field and Analytical Equipment: Auto samplers were calibrated before they were deployed and programmed for an average storm water sampling event. Auto sampler calibration is required to setup input signaling from the flow loggers and to calibrate the sample aliquot volume. All calibration was completed according to manufacturer recommendations.

Calibration of laboratory analytical instruments was completed by the selected analytical laboratory. Such calibration is required for laboratory permitting and will not be described further here.

Sample Collection, Documentation, and Decontamination: Field samples were collected by third party laboratory field sampling crews according to the following protocol:

Auto sampler logs, precipitation data, and the volume of sample in the composite sampling containers were inspected to ensure that a storm meets the criteria for qualifying events (Table 5-2). Auto sampler data were uploaded to a field laptop. This data was then transferred to servers and stored in project folders.

- Field data sheets were completed and included at a minimum: date and time, names of field crew members, weather conditions, number of sample aliquots for each composite sample, and other field observations.
- Prior to collecting the samples, a fresh pair of nitrile gloves are worn for each sample.
- Each of the HDPE sample containers were removed from the auto samplers, thoroughly swirled to ensure homogeneity (especially for TSS and associated COIs) and poured into a new 20 liter HDPE container to create a composite.
- A portion of the composite sample was then immediately poured into each required laboratory-supplied sample container. These pre-labeled sample containers were clean, sealed, and contain required preservative from the laboratory prior to use.
- No field filtering was completed. All required filtering was completed at the analytical laboratory.
- The samples were then placed in ice-filled coolers and delivered to the laboratory as soon as possible or within 36 hours of the conclusion of flow events to avoid exceeding any COI hold times.

The auto sampling containers were brought back to the sampling mobilization site and thoroughly cleaned and rinsed with de-ionized water.

The captured samples were delivered to the laboratory in person and transferred with chain-of-custody forms.

Laboratory Analyses: All samples from the four sampling locations (gabion wall inlet, gabion wall effluent / LID influent, LID effluent / media filter influent, and media filter effluent) were submitted for laboratory analysis of all COIs listed in Table 5-3. All samples were water samples. Fourteen sampling events were completed during the demonstration to fully document the performance of the hybrid system. A minimum of approximately 4 L (~1 gallon) was required to complete required laboratory analyses.

Table 5-3. Required Laboratory Analyses and Method Details

Analysis	Method	MDL	MRL	Annual Storm Water NAL Permit Value	Units
Conventional					
Total Suspended Solids (TSS)	SM 2540 D	-	1	100	mg/L
Particle Size Distribution (PSD)	Modified ASTM D3977-97	NA	NA	NA	NA
pH	EPA 150.2 (In Situ)		0.2	6.0 – 9.0 Instantaneous Max	pH Units
Total Hardness as $CaCO_3$	SM 2340 C	0.8	2.0	NA	mg/L
Nutrients					
Total Phosphorous (TP)	EPA 365.3	0.004	0.010	2.0	mg/L
Orthophosphate	SM 4500-P E	0.020	0.050	NA	mg/L
Metals					
Total and Dissolved Copper	EPA 200.8	0.05	0.10	33.2 Total	µg/L
Total and Dissolved Zinc	EPA 200.8	0.5	2.0	260 Total	µg/L
Petroleum Hydrocarbons					
Total Oil and Grease (O&G)	EPA 1664 A	0.7	5.0	15	mg/L
Diesel Range Organics (DRO)	NWTPH-Dx	24	550	NA	µg/L
Residual Range Organics (RRO)	NWTPH-Dx	42	1100	NA	µg/L
Toxicity					
Acute Toxicity: Test of Significant Toxicity, 96-hr Mysidopsis Bahia	EPA Method 821-R-02-012	NA	NA	MDEL, 80% survival in 100% effluent	NA

Quality Assurance Sampling: Field sampling crews periodically collected quality assurance samples. The selected analytical laboratory conducted quality assurance sampling as required under laboratory accreditation. Table 5-4 presents quality assurance sampling methods.

Table 5-4. Quality Assurance Sampling Methods

Sample Type	Rationale	Method	Frequency
Field Duplicates	Check precision of field samples and analytical methods	Collect duplicate sample from any sampling point and submit for analytical suite	10% of total samples
Field Blanks	Confirm that rinsing and sample handling methods do not introduce contaminants	Pour de-ionized water blanks into sampling containers and collect as a typical sample	3 times during sampling campaign including during first sampling event
Laboratory Methods	Check accuracy and precision of analytical methods	Various	As required by laboratory protocols

Event Coordination: Standard event coordination procedures were followed to increase the likelihood of successfully completing sampling events. The following coordination procedures were followed for each potentially qualifying storm event:

- If the 5-day forecast calls for a qualifying storm event, the monitoring coordinator notifies the field sampling crew and the analytical laboratory.
- If the forecast changes dramatically and a qualifying event is no longer likely the sampling coordinator will alert the field sampling crew and the laboratory.
- If the 24-hour forecast continues to call for a qualifying storm event, sampling activities commence.
- The field sampling team prepares field equipment, bottles, and field sheets, decontaminate and rinse all auto sampler bottles, and complete routine field equipment checks.
- After the storm event concluded, the field sampling crew conduct routine field equipment checks and inspect auto sampler logs. If the log indicates that the sampling event qualifies, the sampling field crew partition the samples into laboratory-supplied bottles, clean all sampling equipment, and submit samples to the laboratory within appropriate hold times. If the sampling event did not qualify, collected samples were disposed of on site and all sampling equipment cleaned.

5.6 DATA ANALYSES

Effluent concentration and removal efficiency data was statistically assessed using regression analysis and a “Bootstrapping” program provided by the Washington State Department of Ecology. The Bootstrapping program calculates the one-tailed upper 95% confidence interval around the mean effluent concentration and the lower 95% confidence limit for removal efficiency. The program is used to qualify BMPs under the TAPE program. The calculated limits can estimate likely system performance at other sites given historical outfall data. Excel worksheets showing the parameters used in the calculations as well as the one-tailed Wilcox signed ranking test are in Appendix C.

5.7 SAMPLING RESULTS

5.7.1 Storm Event Summary

While the Hybrid LID/BMP System was in the demonstration phase at NBPL, all storm events were captured and sent for lab analysis. In the Southern California region, rainfall is unpredictable and varies each year due to different weather systems such as El Niño, this verified the need to capture as many rain events as possible during the demonstration period.

Due to the number of aliquots, storms 1, 2, and 14 do not meet the TAPE requirements. These storms had inaccurate flow readings, which led to a lower amount of aliquots. The water quality lab analysis from these storms are accurate.

Storm 5 is highlighted with green because that is when Doppler sensor was repositioned to achieve laminar flow. This was done to try to correct the inconsistent (often negative) flow readings. The yellow highlight on storm 6 denotes the addition of the air bubbling stone. This addition solved the incorrect flow readings previously experienced. After installation, the flow pacing was accurate at every 225 gallons.

For storm 8 on January 31, 2019, the red text for the number of influent aliquots represent an inlet composite sampler malfunction. The sampler distribution arm was incorrectly positioned resulting in less aliquots.

The storm event on May 16, 2019 subsided before instrumentation reached steady state, so only in situ samples were collected for pH, diesel, and toxicity. There are instances where the effluent values for metals and TSS exceeded influent values across the gabion. This is predominantly due to the influent being a paced composite sample at the influent for the entire storm, and the effluent being a grab sample at first flush. In the first few storms, the sampling locations across the gabion wall were not adjacent to one another. This was corrected after storm 3. All global sampler data is for internal performance evaluation and not for TAPE certification, only the paced refrigerated samples are for TAPE submission.

Table 5-5. Storm Event Summary

Hybrid LID/BMP Storm Event Summary							
Rain Event Date	Rain (inch)	Number Aliquots for Composite (Influent/Effluent)	Peak flow (GPM)	Total Flow (Gallons)	Storm Duration (Hours)	Avg Storm Intensity (Inch/Hour)	Overflow LID/BMP (Gallons)
2/27/18	0.15	4/4	27	514	3.5	0.043	0/0
3/10/18	0.29	4/3	5	705	9.75	0.030	0/0
11/29/18[1]	0.67	10/10	60	2,270	25.5	0.026	0/0
12/5/18[1]	1.47	11/11	35	2,171	33.75	0.043	0/0
1/5/19[3]	0.71	11/11	51	2,924	11.5	0.062	234/292
1/12/19[4]	0.34	11/11	43	2,595	4.5	0.076	0/0
1/14/19	0.40	24/24	45	5,944	6.5	0.062	0/0
1/31/19[5]	0.71	3.5/24	49	4,632	4.16	0.170	0/0
2/13/19	1.15	24/24	54	22,700	26.67	0.043	0/21
2/20/19[1]	0.09	9/11	14	2,200	21.16	0.004	0/0
3/2/19	0.15	10/10	12	2,164	7.16	0.021	0/0
3/11/19	0.47	24/24	41	11,859	11.33	0.042	0/0
3/20/19[1,2]	0.43	18/18	58	4,683	4.75	0.091	774/199
4/29/19[1]	0.19	5/6	11	1,359	22.5	0.008	0/0
5/10/19[1]	0.32	12/14	36	3,530	37	0.009	0/0
5/16/19	0.04	In Situ Sample	0	0	1.8	0.022	0/0
5/19/19	0.20	10/12	31	2,856	3.25	0.062	0/0

[1] Rain event includes one or more intervals of 6 hours with less than 0.04 inches of rain
[2] Data is the combination of 3/20-3/21/19 distinct rain events.
[3] Velocity sensor moved to horizontal position of outlet control pipe
[4] Bubbler added prior to Doppler sensor to improve flow readings
[5] Influent refrigerated sampler rotating arm malfunctioned.

5.7.2 Water Quality Laboratory Data

Table 5-6 contains all sampling results for the Hybrid LID/BMP System. Full sampling for each stage of the technology is in Appendix E. However, the data for each stage is intended only for internal information and is not part of the required TAPE sampling protocol.

Table 5-6. Hybrid LID/BMP Lab Analysis

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	29 Nov 2018+	5 Dec 2018+	5 Jan 2019	29 Nov 2018+	5 Dec 2018+	5 Jan 2019	
Hybrid LID/BMP							
Total Copper	308	112	39.3	5.79	5.71	3.2	µg/L
Dissolved Copper	98.5	49.3	31.8	1.82	1.87	0.95	µg/L
Total Zinc	769	320	156	8.5	10	4.5	µg/L
Dissolved Zinc	433	223	140	4.8	6.1	2.5	µg/L
Particle Size Distribution (PSD), < 63 microns	NA	NA	7.9	NA	NA	3.6	mg/L
PSD, > 63 microns	NA	NA	3.8	NA	NA	2.0	mg/L
TSS	280	82.6	7.4	6.4	5.2	2.4	mg/L
Total Phosphorous	0.356	0.145	0.043	0.021	0.019	0.011	mg/L
Total Hardness (CaCO3)	24.8	7.6	5.2	90	39.2	67.2	mg/L
Orthophosphate	0.110	0.044^J	ND^U	ND^U	ND^U	ND^U	mg/L
Diesel Range Organics (DRO)	430^J	NA	NA	320^J	NA	NA	µg/L
Residual Range Organics (RRO)	950^J	NA	NA	380^J	NA	NA	µg/L
Total O&G (1664A)	ND^U	2.7^J	3.6^J	ND^U	1.8^J	3.7^J	mg/L
pH	6.3	NA	NA	6.5	NA	NA	S.U.
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	12 Jan 2019	**14 Jan 2019**	**31 Jan 2019**	**12 Jan 2019**	**14 Jan 2019**	**31 Jan 2019**	
Hybrid LID/BMP							
Total Copper	84.9	66.5	118	5.97	4.23	6.32	µg/L
Dissolved Copper	78.8	64.5	75.5	6.14	3.90	2.07	µg/L
Total Zinc	246	204	473	5.3	13.2	7.1	µg/L
Dissolved Zinc	242	203	404	9.2	14.7	4.2	µg/L
PSD, < 63 microns	21.7	24	31.7	3.7	5.8	3.5	mg/L
PSD, > 63 microns	1.9	2.9	30.6	1.2	2.5	3.2	mg/L
TSS	25	26.5	30.7	2.5	2.2	4.2	mg/L
Total Phosphorous	0.125	0.084	0.072	0.064	0.032	0.015	mg/L
Total Hardness (CaCO3)	8	10.8	14.4	52.4	34.8	34.4	mg/L
Orthophosphate	0.059	0.030^J	ND^U	0.070	ND^U	ND^U	mg/L

Total O&G (1664A)	3.7[J]	3.3[J]	3.6[J]	2.8[J]	2.8[J]	2.1[J]	mg/L
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	13 Feb 2019	**20 Feb 2019+**	**2 Mar 2019**	**13 Feb 2019**	**20 Feb 2019+**	**2 Mar 2019**	
Hybrid LID/BMP							
Total Copper	82.3	176	218	5.02	1.49	5.29	µg/L
Dissolved Copper	53.8	88.3	35.8	2.31	0.80	2.87	µg/L
Total Zinc	241	702	424	6.2	2.5	3.2	µg/L
Dissolved Zinc	207	625	94.5	5.0	1.9	4.4	µg/L
PSD, < 63 microns	13	NA	NA	3.4	NA	NA	mg/L
PSD, > 63 microns	6.3	NA	NA	2.6	NA	NA	mg/L
TSS	15.3	58.0	16.8	3.5	1.2	ND[U]	mg/L
Total Phosphorous	0.044	0.102	0.095	0.025	0.010[J]	0.008[J]	mg/L
DRO	430[Y]	NA	NA	180[J]	NA	NA	µg/L
RRO	1000[O]	NA	NA	190[J]	NA	NA	µg/L
pH	7.72	NA	NA	7.03	NA	NA	S.U.
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	11 Mar 2019	**20 and 21 Mar 2019**	**29 April 2019**	**11 Mar 2019**	**20 and 21 Mar 2019**	**29 April 2019**	
Hybrid LID/BMP							
Total Copper	67.8	217	379	4.05	6.01	5.64	µg/L
Dissolved Copper	50.4	63.7	298	1.83	2.90	3.08	µg/L
Total Zinc	240	379	599	4.3	4.2	7.5	µg/L
Dissolved Zinc	204	291	539	2.1	2.2	5.9	µg/L
TSS	4	99.6	33.6	1.2	2.7	2.2	mg/L
Total O&G (1664A)	1.7[J]	3.9[J]	NA	2.3[J]	1.6[J]	NA	mg/L
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	10 May 2019	**16 May 2019**	**19 May 2019**	**10 May 2019**	**16 May 2019**	**19 May 2019**	
Hybrid LID/BMP							
Total Copper	134	NA	137	4.61	NA	9.32	µg/L
Dissolved Copper	102	NA	116	2.37	NA	5.59	µg/L
Total Zinc	217	NA	265	6.1	NA	9.2	µg/L
Dissolved Zinc	181	NA	239	4.7	NA	7.2	µg/L
TSS	16.5	NA	9.0	ND[U]	NA	1.2	mg/L
DRO	NA	2200[Y]	NA	NA	550[Z]	NA	µg/L
RRO	NA	1900[L]	NA	NA	580[L]	NA	µg/L
pH	NA	7.3	NA	NA	8.0	NA	S.U.

* TAPE qualifying rain event requirements not met. Data will not be included in TAPE application. Gabion influent and effluent sample collection location not adjacent to one another.

\+ Rain event has time period greater than 6 hours without 0.04 inches of rain. Data will be included in TAPE application.

[J] < Minimum Reporting Limit (MRL), estimated value.

[H] The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard.

[O] The chromatographic fingerprint of the sample resembles an oil, but does not match the calibration standard.

[Y] The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL

[Z] The chromatographic fingerprint does not resemble a petroleum product.

[L] The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard.

ND Non Detect

HF Non in situ analysis

5.7.3 Flowrate and Rain Event Data

Figure 5-5 displays a rain event on January 12, 2019. Data for each rain event is located in Appendix G with data for totalized flow, peak flow and total rain.

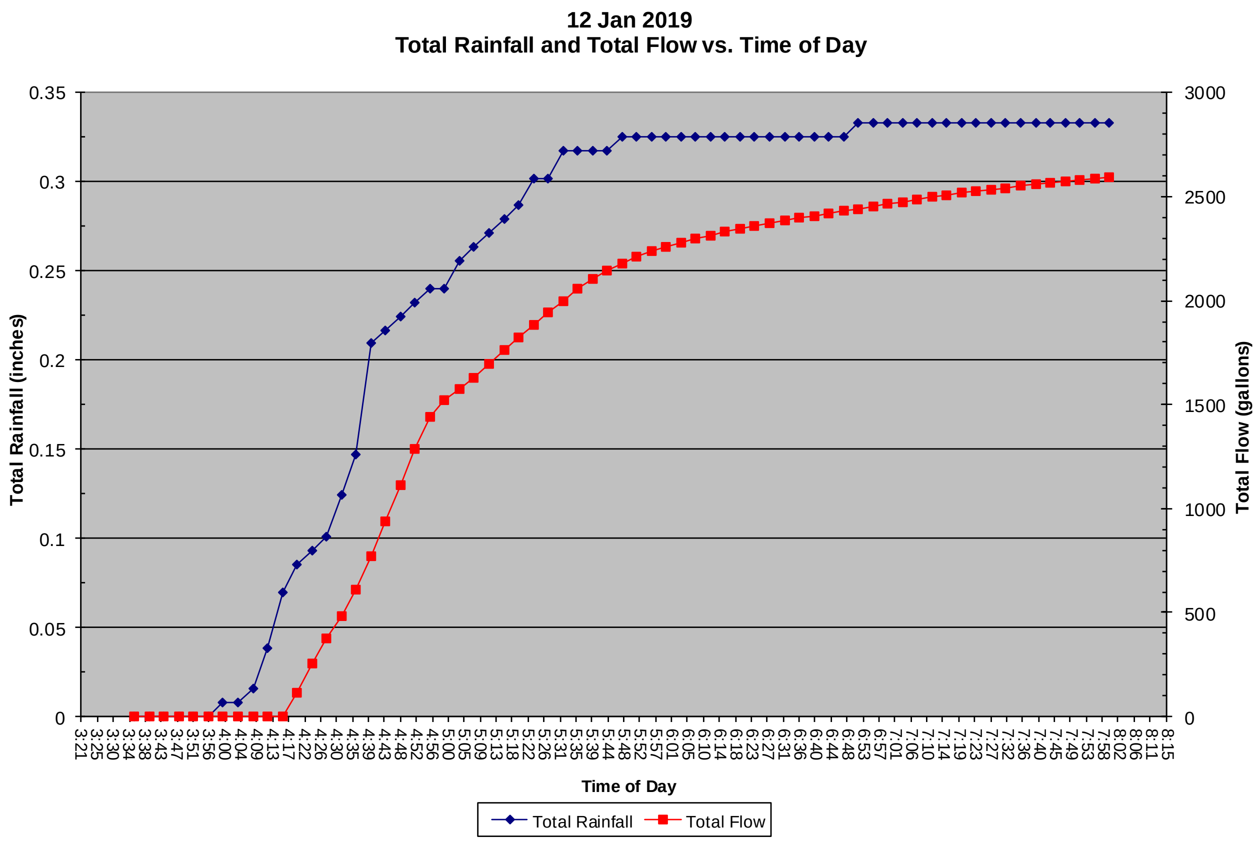


Figure 5-5. Flow Data Graph Sample from January 12, 2019

5.7.3.1 In Situ pH Measurements

Table 5-7. In Situ pH Measurements

Hybrid LID/BMP In-Situ pH		
Rain Event Date	**pH Influent (S.I.)**	**pH Effluent (S.I.)**
11/29/18	6.3	6.5
2/13/19	7.72	7.03
5/16/19	7.3	8.0
Seasonal Average	7.1	7.2

5.7.3.2 Orthophosphate Measurements

Table 5-8. Orthophosphate Measurements

Hybrid LID/BMP Orthophosphate, EMC		
Rain Event Date	**Orthophosphate Influent EMC (mg/L)**	**Orthophosphate Effluent EMC (mg/L)**
11/29/18	0.110	0.050[U]
12/5/18	0.044[J]	0.050[U]
1/5/19	0.050[U]	0.050[U]
1/12/19	0.059	0.070
1/14/19	0.030[J]	0.050[U]
1/31/19	0.050[U]	0.050[U]
Seasonal EMC	0.057	0.053

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL. Substituted MRL value for calculation

[J] < Minimum Reporting Limit, estimated value.

5.7.3.3 Hardness Measurements

Table 5-9. Hardness Measurements

Hybrid LID/BMP Hardness (CaCO3), EMC		
Rain Event Date	**Hardness Influent EMC (mg/L)**	**Hardness Effluent EMC (mg/L)**
11/29/18	24.8	90.0
12/5/18	7.6	39.2
1/5/19	5.2	67.2
1/12/19	8.0	52.4
1/14/19	10.8	34.8
1/31/19	14.4	34.4
Seasonal EMC	11.8	53.0

6.0 PERFORMANCE ASSESSMENT

The primary performance objectives focus on meeting the NBPL NPDES permit effluent limits for copper, zinc, acute toxicity, and TSS removal. These were successfully met as listed in Table 6-1 below. In addition, the secondary objective for meeting ultra-low requirements for zinc and TSS removal were met. The secondary objective for meeting ultra-low requirements for copper removal was not fully met but it should be noted that the influent concentrations are substantially higher than those at sites having these ultra-low limits. Fair assessment would require evaluation at a site such as those in the northwest or in Hawaii. The cost performance objective was judged "not met" but because of the complexity of the site and it being in a high cost region should not be considered as a major barrier to follow-on implementation. Other performance objectives regarding maintenance and ease of use were met and are discussed in detail below.

Table 6-1. Quantitative and Qualitative Performance Requirements

Performance Objective		Data Requirements	Success Criteria	Results
Quantitative				
Reduce Pollutants In Effluent	Whole Effluent Acute Toxicity Limitation	Hybrid LID/BMP effluent sampling data according to "Methods for Estimating the Acute Toxicity of Effluent and Receiving Waters to Freshwater and Marine Organisms", EPA Method 821-R-02-012	80% survival in 100% effluent from Hybrid LID/BMP outlet	Met
	Reduce total copper in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total copper to less than 33.2 µg/L[1]	Met
			(or 2.9 µg/L ultra-low secondary success criteria)	Not Met
	Reduce total zinc in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 200.8	Reduce Hybrid LID/BMP effluent concentration of total zinc to less than 260 µg/L[1]	Met
			(or 95 µg/L ultra-low secondary success criteria)	Met
	Reduce oils and grease in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 1664, Revision A (TAPE TPH-dx Method EPA 8015 B)	Reduce Hybrid LID/BMP effluent concentration of oil and grease grab samples to less than 15 mg/L (TAPE 0.25 – 0.50 mg/L)	Met

Performance Objective		Data Requirements	Success Criteria	Results
	Reduce TSS in storm water runoff	Hybrid LID/BMP influent and effluent sampling data, EPA Method 2540.B	Reduce Hybrid LID/BMP effluent concentration of TSS to less than 100 mg/L[1] (secondary success criteria: reduce TSS concentration across LID stage by 80%)	Met
	Limit export of other storm water pollutants	Storm water influent, LID biofilter effluent, and dual-media filter BMP effluent sampling data. Lab analysis according to various EPA methods.	Limit other potentially regulated storm pollutants that could be exported by treatment components (orthophosphate and total phosphorus)	Met
Limit Capital Cost		Watershed Acreage and actual Capital Cost	Less than $100,000 per acre of drainage	Not Met
Vegetation Health		Observational data and photos during field demonstration	Plants maintain health and do not dieback during dry summer months	Met
Qualitative				
Reduce Preventative Maintenance	Ease of use	Field technician feedback and maintenance log input	Minimal annual maintenance requirement (inspection, sweeping and particulate cleanup)	Met
[1] TMDL mass load reduction criteria is included within the NBPL NPDES permit via compliance with NAL and acute toxicity requirements. Analysis will include mass load reduction calculations.				

6.1 QUANTITATIVE PERFORMANCE OBJECTIVES

Effluent concentration and removal efficiency data was statistically assessed using regression analysis and a "Bootstrapping" program provided by the Washington State Department of Ecology. The Bootstrapping program calculates the one-tailed upper 95% confidence interval around the mean effluent concentration and the lower 95% confidence limit for removal efficiency. The program is used to qualify BMPs under the TAPE program. The calculated limits can estimate likely system performance at other sites given historical outfall data. Excel worksheets showing the parameters used in the calculations as well as the one-tailed Wilcox signed ranking test are in Appendix C.

6.1.1 Whole Effluent Acute Toxicity Limitation

6.1.1.1 Background

Passing the whole effluent acute toxicity test ensures that water quality standards are achieved in the receiving water body. Passage is determined using the EPA methods manual, Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organism. Determination of "pass" or "fail" from a single effluent concentration acute toxicity test at the in-stream waste concentration (IWC) of 100 percent effluent is determined using the

Test of Significant Toxicity (TST) approach described in the NPDES TST implementation document. The test was performed by Nautilus Environmental laboratory using mysid shrimp (*Americamysis bahia*) as the test species. The NBPL NPDES Permit No. CA0109363 does not require chronic toxicity testing for Industrial Low Risk Areas (NPDES Permit No. CA0109363 Table E-7), such as Outfall 52. The acute toxicity test was performed to meet the performance objective.

6.1.1.2 Assessment Criteria:

Pass - An acute toxicity test result that rejects the null hypothesis (Ho) below is reported as "pass" in accordance with the TST approach.

Ho: Mean response (100 percent effluent) $\leq$ .80 x Control mean response

Fail - An acute toxicity test result that does not reject the null hypothesis (Ho) above is reported as "fail" in accordance with the TST approach.

6.1.1.3 Results and Assessment

The effluent from two sampling events met the acute toxicity performance objective as shown in Table 6-2. The full laboratory toxicity testing reports for each rain event are in Appendix E.

Table 6-2. Acute Toxicity Sampling Laboratory Results

Acute Toxicity		
Rain Event Date	**Mean Survival**	**TST Result**
2/13/2019	97%	Pass
5/16/2019	100%	Pass

The treatment system consistently removed over 90% of the dissolved copper and 98% of dissolved zinc from all rain events. Removal of these toxic metals to levels below the NPDES permit limits assures a high probability of passage of toxicity tests. Passage of acute toxicity tests from previous studies and this demonstration validate a positive outcome for protecting receiving water bodies.

6.1.2 Reduce Copper in Storm Water Runoff

6.1.2.1 Background

The EMC and ER are key analytical parameters used to evaluate BMP effectiveness. For this demonstration, the effluent EMC is used to compare against the NPDES permit limit (primary objective) and ultra-low benchmarks (secondary objective). The ER assesses how well the system could work at other similar sites with similar influent characteristics.

6.1.2.2 Assessment Criteria

The primary success criteria for the Hybrid LID/BMP System is to meet site-specific effluent NALs designated in the site NPDES storm water permit. Table 6-1 displays the primary NAL for copper at 33.2 µg/L, and the secondary success criteria for ultra-low permits at 2.9 µg/L. Meeting the primary success criteria provides assures that the technology can be successfully applied at most DoD industrial sites nationwide. There are a few DoD sites in Hawaii and the Northwestern United States that require design adaptation to the system to meet their ultra-low permit limits (secondary success criteria).

6.1.2.3 Results and Assessment

The table below shows the results of the 14 storm events captured during the yearlong demonstration. All effluent EMC values for copper were below the NBPL permit limit of 33.2 µg/L. For total copper, only one out of fourteen effluent results met the ultra-low limit of 2.9 µg/L. The seasonal effluent EMC was 5.2 µg/L and seasonal ER was 97%. For dissolved copper, which is thought to be the more toxic fraction, the average seasonal effluent EMC was 2.8 µg/L and the average seasonal ER was 97%. Using the statistical efficiency ratio from the "Bootstrapping" methodology of 95.1% (representing the lower 95% confidence level), influent total copper concentration less than 58 µg/L would likely meet the ultra-low benchmark of 2.9 µg/L. For total copper meeting the NBPL permit limit 33 µg/L, influent copper concentrations as high as 355 µg/L would still meet the permit limit.

Table 6-3. System Copper Reduction Data

Hybrid LID/BMP Copper Reduction, Event Mean Concentration (EMC)					
Rain Event Date	**Total Copper Influent/Effluent EMC (µg/L)**	**Dissolved Copper Influent/Effluent EMC (µg/L)**	**Total Copper Efficiency Ratio (%)**	**Dissolved Copper Efficiency Ratio (%)**	**Modified TAPE Dissolved Copper Efficiency Ratio (%)***
11/29/18	308/5.79	98.5/1.82	98	98	91
12/5/18	112.0/5.71	49.3/1.87	95	96	91
1/5/19	39.3/3.2	31.8/0.95	92	97	95
1/12/19	84.9/5.97	78.8/6.14	93	92	69
1/14/19	66.5/4.23	64.5/3.9	94	94	81
1/31/19	118.0/6.32	75.5/2.07	95	97	90
2/13/19	82.3/5.02	53.8/2.31	94	96	88
2/20/19	176/1.49	88.3/0.80	99	99	96
3/2/19	218/5.29	35.8/2.87	98	92	86
3/11/19	67.8/4.05	50.4/1.83	94	96	91
3/20-21/19	217/6.01	63.7/2.9	97	95	86
4/29/19	379/5.64	298/3.08	99	99	85
5/10/19	134/4.61	102/2.37	97	98	88
5/19/19	137/9.32	116/5.59	93	95	72
Seasonal Efficiency Ratio	153/5.2	86.2/2.8	97	97	86

* 20 µg/L is substituted into influent value for modified TAPE dissolved ER calculation when dissolved influent concentration is >20 µg/L.

Regression analysis of the total copper metal showed that there is a relationship with higher influent concentration and removal efficiency while no relationship with dissolved metals. Table 6-4 shows the results of the statistical analysis.

Table 6-4. Lower 95% Confidence Limit for Removal Efficiency for Copper

	Total Copper using Regression (Lower 95% confidence limit)	Total Copper using Bootstrap (Lower 95% confidence limit)	Dissolved Copper using Regression (Lower 95% confidence limit)	Dissolved Copper using Bootstrap (Lower 95% confidence limit)
p-Value	0.0009	-	0.1136	-
Relationship with Influent [1]	Yes	Yes	No	No
Removal Efficiency	90.7%	94.5%	92.6%	95.1%
Effluent Concentration (µg/L)	-	5.954*	-	3.437*

* Upper 95% confidence interval using Bootstrap Program

[1] Percent removal is often higher for higher influent concentrations, so linear regression is used to determine if such a relationship exists.

6.1.3 Reduce Zinc in Storm Water Runoff

6.1.3.1 Background

The EMC and ER are key analytical parameters used to evaluate BMP effectiveness. For this demonstration, the effluent EMC is used to compare against the NPDES permit limit (primary objective) and ultra-low benchmarks (secondary objective). The ER assesses how well the system could work at other similar sites with similar influent characteristics.

6.1.3.2 Assessment Criteria

The primary success criteria for the Hybrid LID/BMP System is to meet site-specific effluent NALs designated in the NBPL NPDES storm water permit. Table 6-1 displays the primary NAL for Zinc at 260 µg/L, and the secondary success criteria at 95 µg/L. The system met both success criteria, providing assurance that the technology can be successfully applied/extrapolated to other DoD industrial sites nationwide.

6.1.3.3 Results and Assessment

The table below shows the results of the 14 storm events captured during the yearlong demonstration. All effluent EMC values for total zinc were well below the NBPL permit limit of 260 µg/L. The average seasonal ER for both total and dissolved zinc was 98%. Using the statistical efficiency ratio from the "Bootstrapping" methodology of 96.7% (representing the lower 95% confidence limit), influent zinc concentration less than 2,880 µg/L would likely meet the ultra-low benchmark of 95 µg/L.

Table 6-5. System Zinc Reduction Data

Hybrid LID/BMP Zinc Reduction, EMC					
Rain Event Date	**Total Zinc Influent/Effluent EMC (µg/L)**	**Dissolved Zinc Influent/Effluent EMC (µg/L)***	**Total Zinc Efficiency Ratio (%)**	**Dissolved Zinc Efficiency Ratio (%)**	**Modified TAPE Dissolved Zinc Efficiency Ratio (%)***
11/29/18	769/8.5	433/4.8	99	99	98
12/5/18	320.0/10.0	223.0/6.1	97	97	NA
1/5/19	156/4.5	140.0/2.5	97	98	NA
1/12/19	246.0/5.3	242.0/9.2	98	96	NA
1/14/19	204.0/13.2	203.0/14.7	94	93	NA
1/31/19	473.0/7.1	404.0/4.2	99	99	99
2/13/19	241.0/6.2	207.0/5.0	97	98	NA
2/20/19	702/2.5	625/1.9	99	99	99
3/2/19	424/3.2	94.5/4.4	99	95	NA
3/11/19	240/4.3	204/2.1	98	99	NA
3/20-21/19	379/4.2	291/2.2	99	99	NA
4/29/19	599/7.5	539/5.9	99	99	98
5/10/19	217/6.1	181/4.7	97	97	NA
5/19/19	265/9.2	239/7.2	97	97	NA
Seasonal Efficiency Ratio	374/6.6	288/5.4	98	98	98.5

* 300 µg/L is substituted into influent value for modified TAPE dissolved ER calculation when dissolved influent concentration is >300 µg/L.

Regression analysis of the total and dissolved zinc showed that there is a relationship with higher influent concentration and removal efficiency. Table 6-6 shows the results of the statistical analysis.

Table 6-6. Lower 95% Confidence Limit for Removal Efficiency for Zinc

	Total Zinc using Regression (Lower 95% confidence limit)	Total Zinc using Bootstrap (Lower 95% confidence limit)	Dissolved Zinc using Regression (Lower 95% confidence limit)	Dissolved Zinc using Bootstrap (Lower 95% confidence limit)
p-Value	0.009	-	0.03	-
Relationship with Influent [1]	Yes	-	Yes	-

Removal Efficiency	94.4%	96.9%	95.6%	96.7%
Effluent Concentration (µg/L)	-	7.8*	-	6.9*

* Upper 95% confidence interval using Bootstrap Program

[1] Percent removal is often higher for higher influent concentrations, so linear regression is used to determine if such a relationship exists.

6.1.4 Reduce Oils and Grease in Storm Water Runoff

Table 6-7 shows the results of the 8 grab sampling events captured manually during the yearlong demonstration. None of the influent exceeded the permit limit. For practical purposes, no assessment can be made regarding O&G pollutant due to the low initial concentrations.

Table 6-7. System Oil & Grease Reduction Data

Hybrid LID/BMP Oil & Grease Reduction (1664), EMC			
Rain Event Date	**O&G Influent EMC (mg/L)**	**O&G Effluent EMC (mg/L)**	**O&G Efficiency Ratio (%)**
11/29/18	4^{U}	4^{U}	0
12/5/18	2.7^{J}	1.8^{J}	34
1/5/19	3.6^{J}	3.7^{J}	0
1/12/19	3.7^{J}	2.8^{J}	24
1/14/19	3.3^{J}	2.8^{J}	15
1/31/19	3.6^{J}	2.1^{J}	42
3/11/19	1.7^{J}	2.3^{J}	0
3/20-21/19	3.9^{J}	1.6^{J}	59
Seasonal EMC and Efficiency Ratio	3.31	2.64	20

[J] < Minimum Reporting Limit, estimated value.

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL. Substituted MRL value for calculation

6.1.5 Reduce TSS in Storm Water Runoff

6.1.5.1 Background

The EMC and ER are key analytical parameters used to evaluate BMP effectiveness. For this demonstration, the effluent EMC is used to compare against the NPDES permit limit (primary objective) and ultra-low benchmarks (secondary objective). The ER assesses how well the system could work at other similar sites with similar influent characteristics.

6.1.5.2 Assessment Criteria

The primary success criteria for the Hybrid LID/BMP System is to meet site-specific effluent NALs designated in the NBPL NPDES storm water permit. Table 6-1 displays the primary NAL for TSS at 100 mg/L, and the secondary success criteria at 50 mg/L. The system met both success criteria, providing assurance that the technology can be successfully applied/extrapolated to other DoD industrial sites nationwide.

6.1.5.3 Results and Assessment

The table below shows the results of the 14 storm events captured during the yearlong demonstration. All effluent EMC values for TSS were well below the NBPL permit limit of 100 mg/L and the ultra-low benchmark of 50 mg/L. The average seasonal ER was 95%. Using the statistical efficiency ratio from the "Bootstrapping" methodology of 84.1% (representing the lower 95% confidence limit), influent TSS concentration less than 310 mg/L would likely meet the ultra-low benchmark of 50 mg/L.

Table 6-8. System Total Suspended Solids Reduction Data

Hybrid LID/BMP TSS Reduction, EMC			
Rain Event Date	**TSS Influent EMC (mg/L)**	**TSS Effluent EMC (mg/L)**	**TSS Efficiency Ratio (%)**
11/29/18	280	6.4	98
12/5/18	82.6	5.2	94
1/5/19	7.4	2.4	68
1/12/19	25	2.5	90
1/14/19	26.5	2.2	92
1/31/19	30.7	4.2	86
2/13/19	15.3	3.5	77
2/20/19	58	1.2	98
3/2/19	16.8	1^U	94
3/11/19	4	1.2	70
3/20-21/19	99.6	2.7	97
4/29/19	33.6	2.2	94
5/10/19	16.5	1^U	94
5/19/19	9.0	1.2	87
Seasonal Efficiency Ratio	50.4	2.6	95

[U] The analyte was analyzed for, but was not detected at or above the MRL. Substituted MRL value for calculation.

Regression analysis of the TSS showed that there may be a relationship with higher influent concentrations and removal efficiency. Table 6-9 and

Figure 6-1 show the results of the statistical analysis.

Table 6-9. Lower 95% Confidence Limit for Removal Efficiency for TSS

	TSS using Regression (Lower 95% confidence limit)	Total TSS using Bootstrap (Lower 95% confidence limit)
p-Value	0.08	-
Relationship with Influent [1]	Yes	-
Removal Efficiency	78.4%	84.1%
Effluent Concentration (µg/L)	-	3.4*

* Upper 95% confidence interval using Bootstrap Program

[1] Percent removal is often higher for higher influent concentrations, so linear regression is used to determine if such a relationship exists.

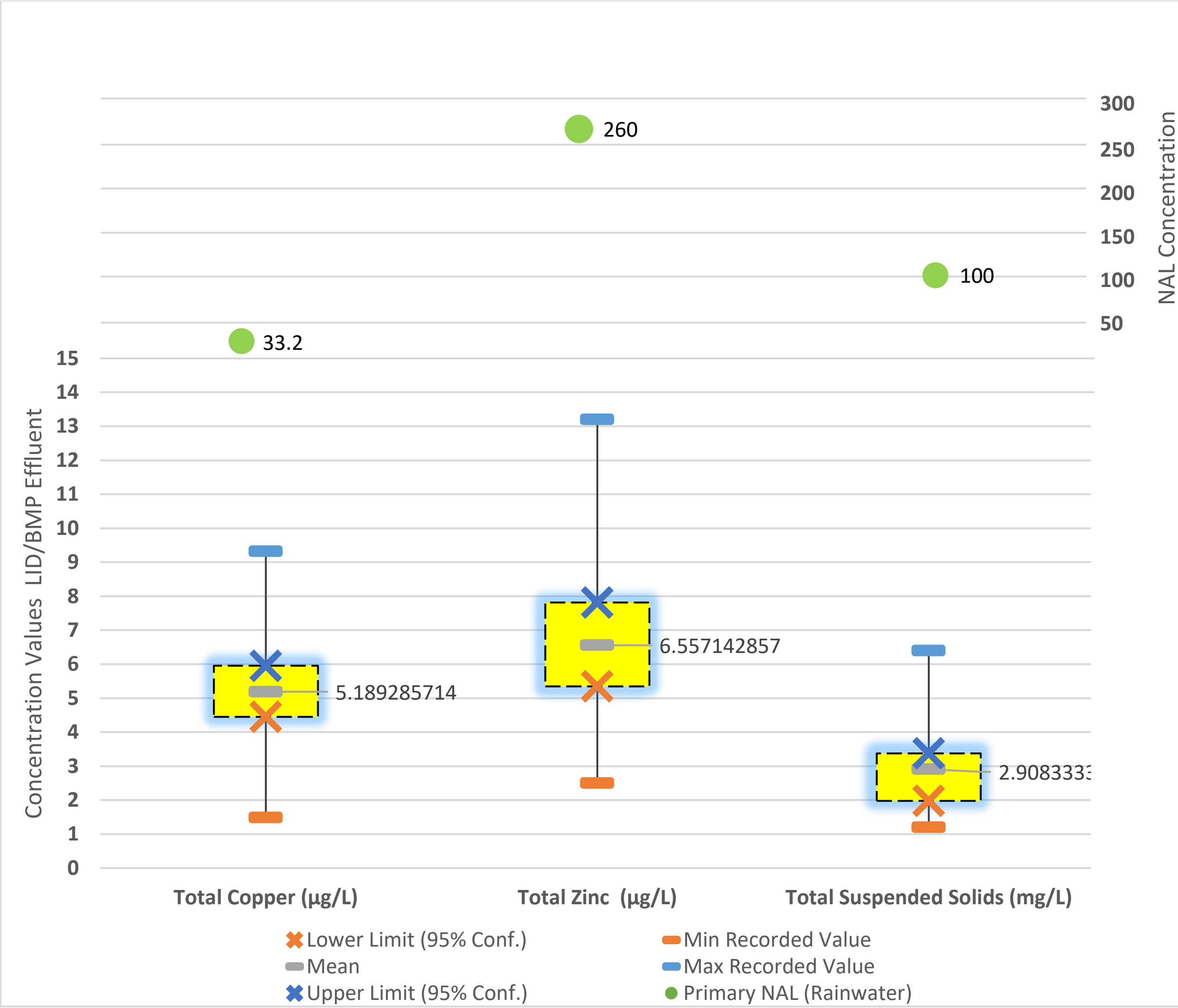


Figure 6-1. **Statistical Analysis on Copper, Zinc, and Total Suspended Solids**

6.1.6 Limit Export of Total Phosphorus

The table below shows the total phosphorus results for 9 storm events captured during the early months of the demonstration. Since the requirement to assess release of pollutants from treatment components was for the TAPE requirement, only 9 events were captured to conserve the sampling budget. All effluent EMC values for phosphorus were below the influent EMC values demonstrating that media was not releasing this regulated pollutants but actually removing significant levels of it. The average seasonal phosphorus reduction ER was 81%.

Table 6-10. System Total Phosphorus Reduction Data

Hybrid LID/BMP Total Phosphorus Reduction, EMC			
Rain Event Date	**Total Phosphorus Influent EMC (mg/L)**	**Total Phosphorus Effluent EMC (mg/L)**	**Total Phosphorus Efficiency Ratio (%)**
11/29/18	0.356	0.021	94
12/5/18	0.145	0.019	87
1/5/19	0.043	0.011	74
1/12/19	0.125	0.064	49
1/14/19	0.084	0.032	62
1/31/19	0.072	0.015	79
2/13/19	0.044	0.025	43
2/20/19	0.102	0.010[J]	90
3/2/19	0.095	0.008[J]	92
Seasonal Efficiency Ratio	0.118	0.023	81

[J] < Minimum Reporting Limit, estimated value.

6.1.7 Limit Capital Cost

The actual cost to implement the Hybrid LID/BMP System was higher than the established performance objective of less than $100,000 per acre. The system capital cost was $157,010 for the one-acre site. The cost exceedance is due to the construction complexity of the site, San Diego's high regional construction cost, and the built-in uncertainties with installing a prototype system on a government installation. Although we did not meet the objective for capital cost it falls within the variability range of $60K to $258K described in Appendix D for sand filters. When assessing the system's ability to meet the most stringent permit requirements, its small footprint, minimal maintenance requirements, and the total lifecycle cost (discussion in Section 7.0) still makes the system a feasible option. Sites that do not have as many physical restraints as the NBPL site (limited accessibility – i.e., buildings, fences and underground utilities) should be more affordable. Furthermore, there is some economy of scale with larger watershed areas that reduce overall capital cost. The cost model and full assessment in Section 7.0 further describe this.

6.2 QUALITATIVE PERFORMANCE OBJECTIVES

6.2.1 Minimize Operations and Maintenance Requirements

6.2.1.1 Background

The hybrid treatment system functioned properly without any significant maintenance throughout the demonstration period. The minor maintenance performed by NAVFAC EXWC was preventative and based on the environment, not the Hybrid LID/BMP System. An example of this is rats chewing through the data logger wiring.

6.2.1.2 Assessment Criteria

Minimal annual maintenance requirements include inspection, sweeping and particulate cleanup. See Section 6.2.2 for LID plant maintenance.

6.2.1.3 Results

One maintenance cycle was performed on 7 February 2019 during the demonstration period consisting of removing the top layer of mulch as described in the installation contract with Whitson Contracting & Management, Inc (Whitson). The work was easy to perform with two laborers in a 4-hour period. Per the contract, the second maintenance cycle was completed on 18 December 2019.

- Perform a hydraulic conductivity test on the LID media to verify filtration rate
- Rake the top 3" of mulch into small piles then shovel into a pickup truck
- Turn the irrigation system on to determine proper operation of drip irrigation
- Prune dead branches from plants
- Remove excess growth, leaves, and trash
- Inspect and clean overflow screen if necessary
- Broom gabion forebay and gabion filter fabric followed by shop vacuum cleaning
- Manually reapplying new hardwood mulch with shovels and rake
- Haul debris in pickup truck to local landfill

6.2.2 Plant Health

The system does not require operators to be present while it is operational. Minimal annual maintenance is required to keep the plants in good health. Regular maintenance includes plant trimming worked into the installations existing landscaping contract. During the demonstration period, the plants were only trimmed once.

6.2.2.1 Assessment Criteria

The criteria for success is that the plants must be healthy during the dry summer months.

6.2.2.2 Results

All 32 plants survived the demonstration period with no die off. Plants appear in good health as shown in the chronological photos below.

February 2018

May 2018

October 2018

January 2019

June 2019

Figure 6-2. Photographs of Plants During the Demonstration Period

7.0 COST ASSESSMENT

DoD storm water managers unable to meet permit requirements with low cost non-structural BMPs (housekeeping) and source reduction should consider structural BMPs as a way to achieve compliance. Unfortunately, there is a significant cost associated with retrofitting existing storm water systems (outfalls) at industrial sites due to the requirement for demolition and excavation on concrete or asphalt surfaces. Most existing storm water system were deigned to divert water away from a site as quickly as possible without treatment. Installation of a passive (gravity fed) treatment system, such as the hybrid LID/BMP, presents new cost challenges to DoD installations who have historically had minimal budget to maintain and clean storm water conveyance systems and outfalls. Compliance with NPDES permits will require capital investment costs along with a small budget to perform annual and periodic maintenance.

7.1 COST MODEL

The cost model below provides the total lifecycle cost associated with installing the passive hybrid LID/BMP treatment system on a one-acre industrial site in a relatively high wage region of the United States. Storm water managers can use the model to evaluate the cost of implementing the technology at other industrial sites simply by scaling up or down based on watershed area or flow and adjusting for regional construction/labor costs. For example, a two-acre site in San Diego would cost roughly double that of the NBPL site.

The model also includes a rough estimate on the cost associated with containing and disposing the first ¼-inch of rain as a point of comparison, which is an alternative approach available to DoD installation in San Diego, California. However, this option requires substantial laydown area for tanks and pumps needed for large volumes of water. This option is not attainable for many industrial sites with limited space. The model includes a comparison of the costs associated with a comparable commercial off-the-shelf (COTS) technology. Although there may be some cost advantageous, COTS have not shown the ability to reduce metal contaminants to the low levels needed for compliance in stringent locations such as Hawaii, California and Washington. Ultimately, many of these systems do not meet the performance goals of this project.

During the demonstration, comprehensive records were kept of all materials, construction and maintenance costs so that cost of ownership could be accurately presented in the cost model (Table 7-1).

Table 7-1. Cost Model for the Hybrid LID/BMP

Cost Element	Data Tracked During the Demonstration	Cost	
Underground utilities survey	Time and cost to perform service Equipment requirement - Ground Penetrating Radar (GPR)	Technician and GPR equipment, 4 h	$650

Elevation Survey	Time and cost to perform service and prepare plot drawing	Survey, 4 h	$800
		Draftsman, 8 h	$1,200
Design	Personnel required and associated labor	Designer, 8 h	$800
Media Filter BMP (Materials)	Major subcomponent cost, Media unit cost: $ per pound Data requirements: Initial amount of material required based on flow rate	Vault	$15,340
		FS-50 (4000 lbs)	$4,560
		Bone Char (1635 lbs)	$3,270
		Plumbing	$3,000
		Aggregate (washed)	$1,800
		Slotted pipe	$590
BioFilter (Materials)	Major Subcomponent cost: Estimate about $235/ft^2. (LID - water harvest, media, plumbing, and plants)	Harvest tank modules	$3,500
		Irrigation system	$9,650
		Mulch and plants	$3,500
		Engineered soil matrix	$27,650
		Gabion	$1,200
		Plumbing Overflow	$1,500
Installation** (Cost data extracted from contract cost estimate prepared by Whitson	Personnel Requirements: Superintendent (safety) Laborers Equipment Operator Landscapers Electrical Equipment requirement: Crane Backhoe	Demolition	$78,000
		Excavation	
		Vault Placement	
		Plumbing, media installation and general conditions	

	Concrete saw cut Spoils Disposal	Gabion Installation	
Long-term monitoring	Not included – performed as standard site protocol	NA	
Total Capital Cost (NBPL)		$157,010	
Recurring Annual Maintenance cost (every 10 years)		$16,200	

** Note: Installation cost can vary substantially depending on region of country and complexity of site. NBPL is a high cost area and the site was substantially challenging due to physical constraints near the outfall.

7.1.1 Underground Utilities and Field Survey

The cost model includes a one-time service charge to confirm the location of underground utilities and acquire elevations at key points prior to designing and installing a system. Base utility maps showing the location of underground utilities are a good starting point but must be verified, as they are often inaccurate. To prevent collision and disruption of critical infrastructure during construction, it is important to locate the utilities using magnetic/radio frequency or ground penetrating radar in the immediate vicinity. Prior to construction, the team hired a local pipe and utility locator company to mark out the underground utilities using ground penetrating radar technology. The task took less than 2 hours but a minimum ½ day was charged for the effort at a cost of $650. The survey to capture ground elevation and coordinates at the demonstration site took about 4 hours to complete and another 8 hours to reduce the data and create a plan view topography map needed for design. The cost of the survey and creation of a topographic map was about $2,500. It should be noted that any BMP technology implemented, other than above ground storage, would require these fundamental costs.

7.1.2 Design

The design of the BMP requires a simple hydraulic study and calculation to determine the required treatment flow through the system to meet NPDES permit requirements. In addition, the overall design must account for overflow conditions beyond the required system treatment capacity. Most public works offices have civil / hydraulic engineers that can complete the work in-house. The task took about 8 man-hours at a cost of $800.

7.1.3 Materials

The model includes the cost of materials including: vault, media (engineered media for LID, bone char, and ferrous coated activated alumina), LID water storage, plumbing hardware, and plants. Cost does not include any of the equipment or plumbing used for determining flow rates and sampling since it was only required for the demonstration and not germane to most implementations. Table 7-2 tracks the data used for scaling the system to varying watersheds and flow requirements.

7.1.4 Installation

The one-time cost to install the system at NBPL FRC MFC came from the cost estimate provided by Whitson during contract award. The contract to install the Hybrid LID/BMP System included installation of electrical power and instrumentation needed to assess flow rates and initiate sampling equipment for the demonstration but is not in the cost model since it is not relevant for new systems. Invoices and quotes for high cost items such as the concrete vault and media were compiled in an Excel spreadsheet (Table 7-2). Demolition costs to remove existing pavement and dispose of soil are included.

7.1.5 BioFilter First Year Plant Establishment

The cost model includes a first year maintenance cost of $2,500 to insure establishment of a healthy plant population along with routine annual maintenance. The first year maintenance consisted of the contractor performing:

1. Two site assessments, one during the summer and one at the start of the rainy season to ensure plants were well established and healthy (replace and prune as necessary),
2. Inspection of the autonomous irrigation system to insure it was operating properly, and
3. Replacement of the top layer of mulch.

As planned, the contractor assessed plant conditions during the summer and fall finding all plants in good health. At the start of the 2018/2019 rainy season, the contractor sent two landscapers to the site to evaluate the infiltration and irrigation system and replace the mulch. The two-man crew found the plants to be in good health with only minor pruning required. The drip irrigation at the base of each plant was in good working condition as each drip emitter was functioning properly. The crew removed and replaced the hardwood mulch with hand tools, swept the gabion geofabric, and paved area upstream of the gabion. This maintenance took 4 hours to complete. The hardwood mulch (1.6 yards) cost $25/yard from a local compost and mulch company. The old hardwood mulch and debris was loaded on a pickup truck and hauled away to a local landfill as solid waste. The cost to maintain the system during the first year was $2,500, and is considered slightly high for the on-site effort, however, this cost includes off-site travel to obtain new mulch and dispose at local landfill.

7.1.6 Annual Maintenance

The cost model includes an annual maintenance cost of $2,500 throughout the lifecycle to perform tasks including: removal of debris and trash, mulch replacement, minor pruning, and raking/removal of the top layer of bone char. It is envisioned that some maintenance, such as sweeping the gabion and adjacent area would be accomplished by on-site personnel (self-help) a few times per year. This element is required but is not included in the cost model because it should take less than 15 minutes per rain event. Labor hours and costs were tracked throughout the demonstration process to validate the estimated cost.

7.2 ECONOMIC LIFE CYCLE COST

The life cycle cost model of the Hybrid LID/BMP System consists of three elements: 1) capital investment costs, 2) annual costs and 3) periodic maintenance costs. The model evaluates a 20-

year period and compares the life cycle cost of the system against the cost associated with capture and disposal of the first ¼” rainfall at the FRC site. There are often site constraints and operational consideration that often preclude the use of tanks to implement this option. For future implementation, the model can be easily be scaled up based on acreage.

The cost to implement the alternative tank and pump package to capture and dispose the first ¼” of rain will vary based on site-specific conditions. The major cost parameters for this option include the capital cost to capture the storm-water (typically consisting of a sump and pump), storage tank (below or aboveground storage tank), electrical power, disposal cost of the captured water, and maintenance costs. The volume of water is one of the major drivers influencing the tank and pump size needed. The volume of water is derived from the watershed area and projected rain. Since rain events vary annually, the analysis uses the average volume of rain experienced in San Diego over the last 30 years. From the US Climate Data website, the months of December, January, February, and March receive, on average, no less than 1.5 inches of rain and 5 rainy days. To be conservative, 4 days of rain was assumed for the four months. For the one-acre site, a ¼” rain event computes to 6,800 gallons per storm event. Based on 16 storms per year the total amount of water to be disposed per year is 108,800 gallons. At a cost of $0.10 per gallon (derived from current haul rates of $250 per 2,500-gallon truck and sewer disposal rate of $10 per 1000 gallons) the total annual disposal cost is $27,000 per year. The capital investment for a 6,800 gallon holding tank is estimated to be $6 per gallon or $40,000. A pump package would cost approximately $5,000 if electrical power is nearby such as the case at NBPL site. Appendix D has a cost model showing the capital and operational cost associated with this option.

Added to the annualized capital cost of the Hybrid LID/BMP System are the actual annual operating and maintenance costs of $2,500 per year. Based on prior demonstration of the dual media filter the media should last at least 10 years (Anguiano, G., Foreman, M. *Low Impact Technologies to Reduce Pollution from Storm Water Runoff.* ESTCP Project SI-0405, Document Number TR-2300-ENV. January, 2009). Periodic replacement of the media (FS-50 and Bone Char) at year 10 was added to the model. The model assumes the filter system has no salvage value.

Based on the cost model, the total lifecycle cost for the hybrid system is $217,000 and the cost for capturing and treating is $282,000.

Table 7-2. Cost Model Excel Spreadsheet

(Located on Next Page)

Site Cost Model Spreadsheet			
Site Information	Watershed Runoff Area (acres)	1	Determined from site drawings
	Watershed Runoff Area (acres, rounded up)	1	
	Hydraulic Surface Coefficient	0.95	Typically .85 or higher for industrial areas
	Regional Labor Cost Factor (high 1, med 0.9, low 0 .8)	1	Estimate
	Available Hydraulic Head (ft)	4.5	Top surface to invert (catch basin flow line)
Design Constraint	Hydraulic Head (ft)	4.5	Must be equal or greater than 4.5 feet
Regulatory Requirements	Design flow rate (gpm)	86.0	Using NPDES Permit formula to determine design flo
Hydraulic Data	Annual Rainfall (in/year)	10.34	From San Diego County Water Authority
	Design Rainfall Intensity (in/hr)	0.2	From NPDES Permit design formula
	Average 24 hour rain event from Isopluvial chart (in)	0.5	From 85% Isopluvials Charts
	Storm Water Volume generated per ave. year (gallons)	266,718	Total volume of stormwater per year
	Average Number of Storms per Year	16	Historical data from NOAA website
Calculations	Volume of water for pump and treat (gallons)	108,610	Capture first 0.25"
	Square footage needed for installation (ft^2)	345	Minimum area needed
	Tank size (0.25") for capture and dispose (gallons)	6,788	Tank size
	Cost of pump skid for capture and dispose ($)	$ 4,000.00	Estimate
LID/BMP Design Criteria	LID infiltration rate (inches/hour)	100	Per manufacturers data on new material
	Size of LID based on infiltration rate and watershed (ft^2)	136	Calculated based on 100 in/hr infiltration rate
	LID Area (ft^2 per acre)	200	Use this value per acre to adjust for clogging
	Area of LID needed (ft^2)	200	Includes a Safety Factor of 2.0
	Flow rate through single dual media vault (gpm)	86.0	Standard Vault (16' x 8.5' x 5'-9")
	BMP Length (ft)	16	Outer dimension
	BMP Width (ft)	8.5	Outer dimension
	Required Dual Media Filter contact time (minutes)	8	Reference EXWC Study
	Number of Vaults needed	1	
Economic Criteria	Electrical cost (Per kW-hr)	$0.1653	January 2020, U.S. Energy Information Administratio
	Life cycle (years)	20	
	Cost to dispose ($/gallon)	$0.10	Based on NRRC data
	Unit cost of holding tank ($5-10 per gallon)	$6.00	
	Cost of holding tank ($5-10 per gallon)	$ 40,729	
	Cost to operate pump (assume 1.5 HP pump)	$ 120	Negligible
	Cost of pump skid 1-2 HP motor 50 gpm	$ 4,000	Estimated
Hybrid LID/BMP System Cost Data			
Design	Utilities Survey	$ 650.00	
	Elevation Survey	$ 2,000.00	
	Design	$ 800.00	
Media Filter	FS-50	$ 1.14	Unit Cost per lb (Axens North America)
	Amount of FS-50 needed per vault (lbs)	4,000	
	Cost of FS-50 for site	$ 4,560.00	Total Cost (2.2 cubic yards per vault, 9" deep)
	Bone Char	$ 2.00	Unit Cost per lb (Procured by contractor)
	Amount of Bone Char needed per vault (lbs)	1,635	
	Cost of Bone Char for site	$ 3,270.00	Total Cost (1.5 cubic yards per vault, 6" deep)
	Vault	$ 15,340.00	Made by Jensen Precast
	Miscellaneous	$ 5,390.00	
	Vault and Media Cost	$ 28,560.00	
Biofilter	Unit Cost for LID Biofilter Materials	$ 235.00	Unit Cost includes water harvest tank modules, gabion, hard wood mulch, engineered soil matrix, miscellaneous plumbing and irrigation
	LID Biofilter (SF)	200	
	Cost of Biofilter Material for site	$ 47,000.00	
Installation	Shipping	$ 8,000.00	
	Cost of System Installation	$ 70,000.00	$70,000 per acre
	Total Capital Cost	**$ 157,010.00**	
Hybrid LID/BMP System - Total Lifecycle Cost (20 years)			
Hybrid LID/BMP System	**Capital Cost**	**$ 157,010.00**	
	Annual Maintenance Cost (@ $2500/yr)	**$ 50,000.00**	Total cost for entire lifecycle (Cell D30)
	Periodic Maintenance	**$ 10,030.00**	Replacement of media
	Total Cost	**$ 217,040.00**	
Capture and Dispose Alternative - Total Lifecycle Cost (20 years)			
Capture and Dispose	Capital Cost	**$ 44,728.60**	
	Annual Maintenance Cost ($1,000 per acre)	**$ 20,000.00**	
	Disposal Cost (20 years)	**$ 217,219.20**	
	Total Cost	**$ 281,947.80**	

8.0 IMPLEMENTATION CONSIDERATIONS AND ISSUES

DoD storm water managers unable to meet storm water permit requirements at their industrial sites with conventional non-structural BMPs (housekeeping) and source reduction should consider implementing structural treatment technologies to achieve compliance. Commercial vendors offer structural technologies designed for removing suspended solids and metal contaminants, which vary in both configuration, treatment process and effectiveness. In some circumstances, they may be viable options, but for those activities with stringent NPDES metals effluent limits such as those located in California, Washington and Hawaii, the hybrid LID/BMP's technology may be the best option to comply. The technology demonstration has shown high contaminant removal efficiency for both dissolved and particulate metals, helping activities achieve stringent metal permit effluent limits. The technology is easy to maintain and the filter media is easy to replace with no confined space entry required. One of the key questions for implementation is whether the technology will match the site hydraulic conditions and site constraints.

8.1 MODULAR DESIGN

The hybrid system consists of two major components; the scalable biofilter and standard media vault which allows for maximum construction flexibility. The LID biofilter can be built to any size footprint to meet flow requirements. The standard media vault design (treatment flow of 100 gpm) can be put together in parallel to match the industrial watershed area flow requirements in 100 gpm increments. It is a fixed unit size to allow for efficient shipping and low construction costs.

The concrete vault (fixed size and configuration) is the largest and most expensive component to procure and install. Constructing a built-in-place vault would be substantially more expensive than simply fabricating with a concrete precast manufacturer. For the demonstration at NBPL, a local precast concrete manufacturer, Jensen Precast, fabricated the vault to keep cost as low as possible. Their facility was fully equipped with standard forms for storm water structures that allowed for expedient and economical construction. The team provided Jensen Precast with engineering drawings for a vault designed to achieve 100 gpm treatment flow rate with the following parameters:

1) the smallest surface footprint and shallowest media profile allowing for 8-minute storm water contact time with the media, and
2) the lowest shipping and handling logistics burden to support shipping with a standard 8-foot wide tractor trailer flatbed.

A wider vault greater than 8 feet would require a redesign and ship as a wide load. The concrete vault drawing is in Appendix A.

8.2 DECISION MAKING FACTORS AND CONSIDERATIONS

A number of factors influence the effectiveness of the Hybrid LID/BMP System. These factors and their influence on the structural system design to meet discharge requirements are summarized in Table 8-1.

Table 8-1. Site Design Factors

Site Factors	Design Considerations
Regulatory Permits	• Permit provides contaminant effluent limits and provides guidance on how to determine design flow.
Historical rainfall data, isopluvial maps	• Data used to determine the required treatment flow. • Data used to design the biofilter, media vault cumulative capacity and overflow system.
Storm Water Monitoring Data	• Contaminant influent concentration levels. • Determine if system is likely to meet regulatory limits based on potential contaminant load and system removal efficiency. • Estimate media service life.
Site Survey (Site boundaries, structures, and topography)	• Define watershed and flow pathways. • Identify barriers to system implementation.
Review of existing storm water drainage plans and site surveys	• Define watershed and flow pathways. • Identify barriers to system implementation. • Study invert elevations to support system design.
Site Constraints - high groundwater, flooding, tidal zone (backflow), negative impacts to site operations, etc.	• Determine if there are barriers that may prevent successful operation of system. • Incorporate site conditions in system design.
Existing utilities drawings	• Avoidance of underground utilities. • Avoidance of overhead utilities/obstructions for crane access during installation. • Determine best location for implementation to avoid additional construction cost and disrupting services.
System Installation Equipment Requirements	• Installation requires crane, backhoe, and skip loader. • Evaluate impact of system installation to site operations.
Economic Considerations	• Use cost model (Appendix D) to estimate overall cost and required budgets for implementation, operation support, and maintenance.
Maintenance and Frequency (Contracted vs. Self-Help)	• Need to ensure funding is budgeted and a contract is in place to support maintenance of the system. • Does host activity have personnel to perform basic maintenance and take on ownership? Is funding budgeted to support these activities?

8.3 SITE SELECTION FOR PASSIVE TREATMENT

One of the challenges with implementing the Hybrid LID/BMP System at an industrial site is finding an ideal installation location that:

1. does not negatively impact the industrial operations,
2. has the least amount of impact on nearby facilities/utilities, and
3. allows for passive flow through the system.

To leverage the existing topography, the chosen area should be at the lowest elevation of the facility. The key question is whether there is enough depth at that lowest point between the top surface to the outfall exit (flowline). The selected site must have at least 4.5 feet of elevation difference between the top surface and the outlet flowline (invert). This head is required to maintain a minimum 8 minute contact time (also referred to as the hydraulic retention time) within the media. If not, a custom vault design would be required.

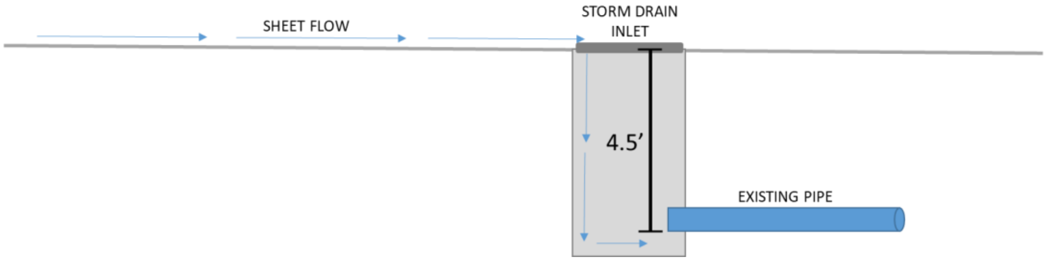


Figure 8-1. Typical Storm Drain Inlet Elevation Configuration

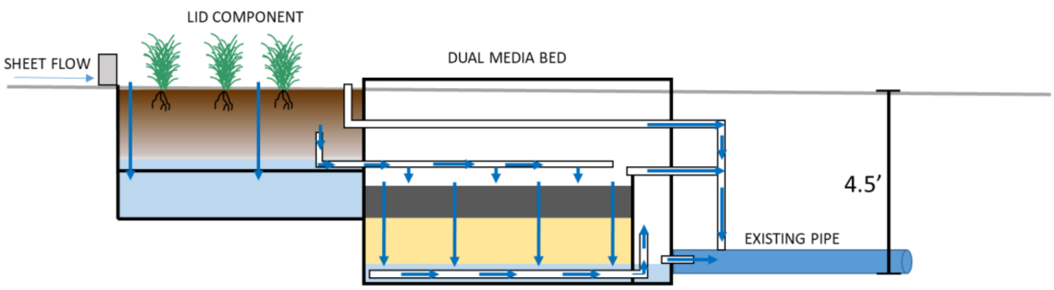


Figure 8-2. Hybrid LID/BMP Elevation Configuration

The EXWC team can assist in the circumstance where a standard vault will not match with flowlines of the existing water conveyance system. A proprietary hydraulic loading model was developed for designing the media combination.

8.4 END USER CONCERNS

The DoD is required to establish and maintain an official record of financial and physical data of land, buildings, structures, and utilities on DoD real property. The Navy uses a program known as the internet Navy Facilities Asset Data Store (iNFADS) to manage its facilities and serves in the development of a funding program for the maintenance of real property, recording maintenance responsibility, and funding source. Air Force and Army have similar programs to ensure their facilities are properly operated and maintained.

One of the common concerns facing storm water managers implementing treatment technologies is maintenance. The maintenance concern is who will perform it and how will it be paid for. Historically, storm water utilities have not been included in the iNFADS program, except for storm water ponds. Maintenance and repairs on storm water pipes, drop inlets, and catch basins occur on an as-needed basis. For example, maintenance only happens when an outfall clogs and flooding negatively impacts operations. Storm water systems simply divert water away from critical facilities without treatment. The current vision for sustained maintenance of treatment assets such as the hybrid LID/BMP is for it to be included in the iNFADS system so that funds are programmed for future maintenance. There is an ongoing joint service effort involving the addition of different types of storm water BMPs into the iNFADS system.

8.5 ROUTINE MAINTENANCE

The gabion filter fabric and the biofilter forebay will likely need some maintenance after two or three storms to minimize sediment buildup and to ensure proper flow through the filter fabric. The filter fabric can simply be swept with a broom, which takes less than five minutes followed by removing the fore-bay buildup of fine silts using a brooms and dustpan (or shop vacuum). Through site ownership, the host site can take care of this minor maintenance. This task is a necessary step in the overall effectiveness of the technology.

Visual inspection and monitoring is also a self-help requirement. General upkeep such as trash removal and sweeping should already be part of a standard storm water program. Any abnormal die-off of plants should be reported and managed appropriately. A critical self-help requirement is to insure that the overflow outlet screen is clean to allow for overflow during extreme rain events. Any major flooding or bypass of storm water should be promptly reported to the storm water manager. Monitoring of the system outflow should also be performed to verify compliance with discharge permit requirements and to determine when the media is no longer effective.

8.6 COASTAL INDUSTRIAL ACTIVITIES

To determine whether the Hybrid LID/BMP System is a good fit at an industrial site along the coast, a storm water manager must determine if flooding, tidal waters or other water issues will submerge the media in the vault. Base personnel experienced with the local storm water conveyance system are best to complete this assessment. Installing a Hybrid LID/BMP System at a site with backflow issues is not recommended unless measures are taken to prevent submerging the media. For example, installing a tidal check valve would prevent the media from submerging.

8.7 LESSONS LEARNED

Using the most up to date utilities plans, survey crews marked-out all known below grade utilities at the NBPL demonstration site so that the underground components were properly designed and positioned to avoid disrupting services. For an added safeguard, the site was further assessed with ground penetrating radar to determine the existence of unknown objects that could hamper installation of the dual media vault that required excavation to a depth of 5 feet. The radar picked up two anomalies (unmarked lines at 2 and 4 foot depths) in the proximity of the selected site for the vault. Based on discussion with public works personnel these two unmarked lines were thought to be abandoned since they were not on any of the current drawings. As a precaution prior to excavation with a backhoe, these unknown lines were exposed using manual "pot-holing" techniques to verify that these lines were indeed abandoned.

Base utility experts assessed the exposed lines and one of the lines was determined to be an active communication line. This required the contractor to manually excavate around the line and move it as far away from the vault as possible, then relocate the vault and verify that the modification would not impact flows. Identifying the second unknown line was another challenge as it required examination by several specialist and ultimately by a base historian to determine that it was not an active line. Several days were lost determining what it was. Hours were spent pouring through drawing archives before finding an old drawing that showed that the line was indeed abandoned and could be safely removed.

Along with weather related delays the existence of these unmarked utilities caused significant delays to the project. For future implementation, it is prudent to start with a ground penetrating radar assessment prior to designing an unencumbered layout drawing.

The Doppler velocity sensor selected was unable to accurately measure the water velocity coming from the media bed. The effluent water did not contain enough particulates to register on the sensor. For future testing of similar systems, it is recommend to examine the particulate range of each sensor selected for demonstration. The team fixed this issue by installing a float activated air bubbling stone.

8.8 TECHNOLOGY TRANSFER

A non-exclusive license agreement between the Navy and California Filtration Specialists (CFS) was established to market the Hybrid LID/BMP System to the DoD and public entities. Contact CFS directly for follow-on system implementation. They have experience and are familiar with working safely on government sites. They have experience with the equipment needed for integrating the biofilter and the media filter subsystems as well as installation of the outlet control weir and overflow piping. Contact NAVFAC EXWC engineers for questions regarding implementation, review of statements of work, drawings, job oversite, and can be consulted for custom designs where the standard vault design does not match with site conditions. Multiple sites in the Southwest Region have already expressed interest in installing this system.

8.9 TAPE CERTIFICATION

The TAPE program is the Washington State Department of Ecology's process for evaluating and approving emerging storm water treatment BMPs. Although the demonstration of the hybrid system was in southern California it is believed that certification through the recognized TAPE storm water program would provide better acceptance of the technology. Accordingly additional sampling and analyses was performed in parallel with the established performance objectives. The resultant data is in Appendix B. To address TAPE requirements, the demonstration included additional assessments on dissolved metals removal whereas the NPDES permit for NBPL only focuses on total metals. The technology showed exceptional removal efficiency for both dissolved and total copper and zinc. The EXWC technology transition team has initiated discussions with Washington State Ecology to certify through the TAPE for Conditional Use level Designation (CULD) and then General Use Level Designation (GULD). Treatment BMPs certified via TAPE are designed and installed at new and re-development projects. The team is pursuing verification for the following types of treatment categories:

- Pretreatment
  - 50% removal of Total Suspended Solids
- Basic
  - 80% removal of Total Suspended Solids
- Enhanced
  - Dissolved Copper
  - Dissolved Zinc
- Oil
- Phosphorus

The system summary and data will be included in a Technical Evaluation Report (TER) and submitted to the Washington State Department of Ecology.

9.0 REFERENCES

Anguiano, G., Foreman, M. *Low Impact Technologies to Reduce Pollution from Storm Water Runoff.* ESTCP Project SI-0405, Document Number TR-2300-ENV. January, 2009.

Civil & Environmental Consultants, Inc. Final Technical Evaluation Report Field Evaluation of the FocalPoint High Performance Modular Biofiltration System. Prepared for ACF Environmental. July, 2016.

Geosyntec Consultants and Wright Water Engineers, Inc. *Urban Storm water BMP Performance Monitoring.* October, 2009.

Kirts, R., Foreman, M., Anguiano, G. *Removal of Toxic Heavy Metals from Storm Water Runoff at Naval Installations.* NAVFAC Technical Report TR-2256-ENV. November, 2004.

Nason, J., Sprick, M., Bloomquist, D. Determination of Copper Speciation in Highway Storm water Runoff Using Competitive Ligand Exchange – Adsorptive Cathodic Stripping Voltammetry. Water Research, volume 46. February, 2012.

TAPE – Emerging Technologies. *TAPE Outside of Washington State*. Washington Stormwater Center, 2020.

US Bureau of Reclamation. *Water Measurement Manual*. Water Resources Research Library, 2001.

Washington State Department of Ecology. *Technical Guidance Manual for Evaluating Emerging Storm water Treatment Technologies.* Publication number 11-10-061. August, 2011.

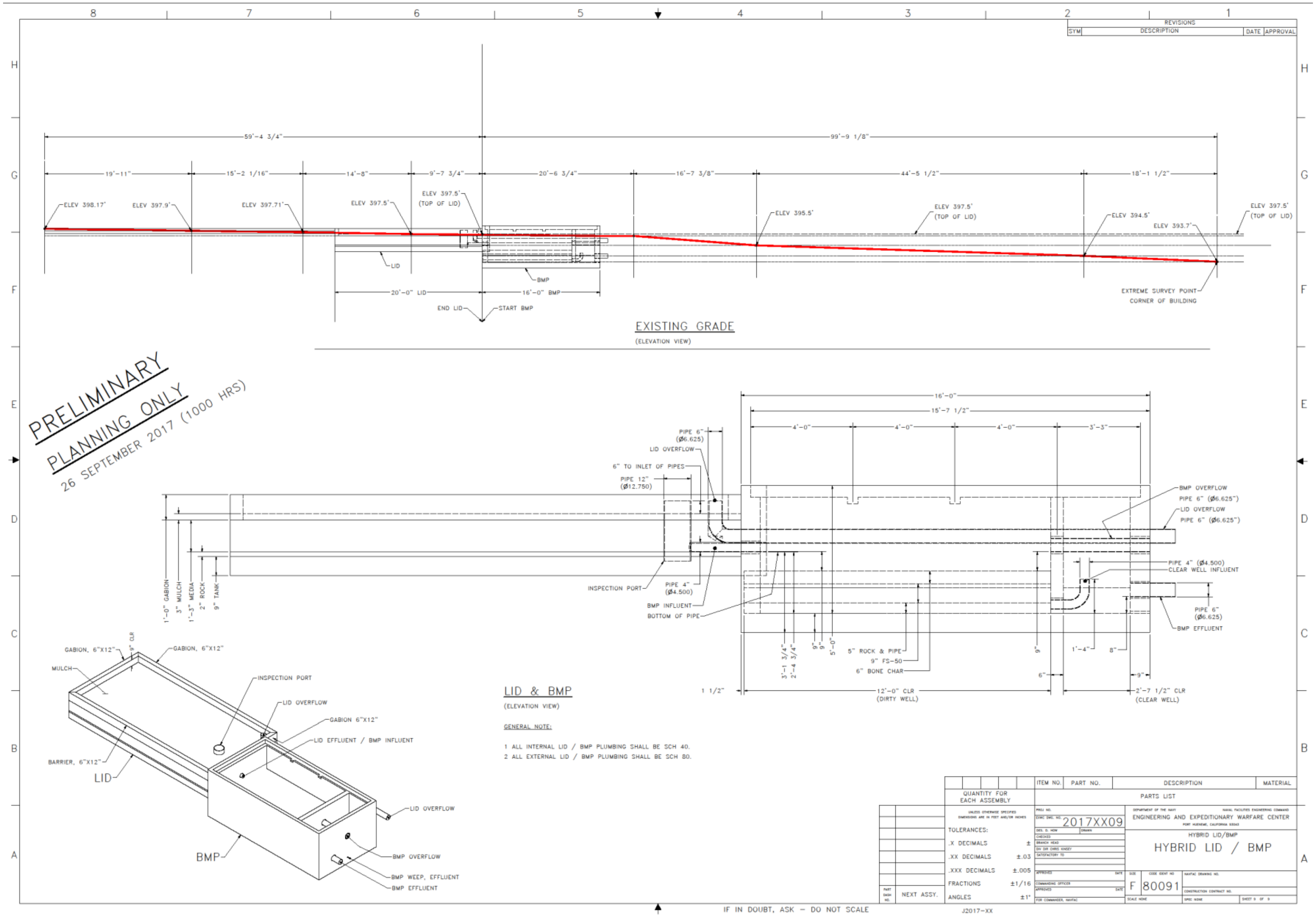
This Page Intentionally Blank

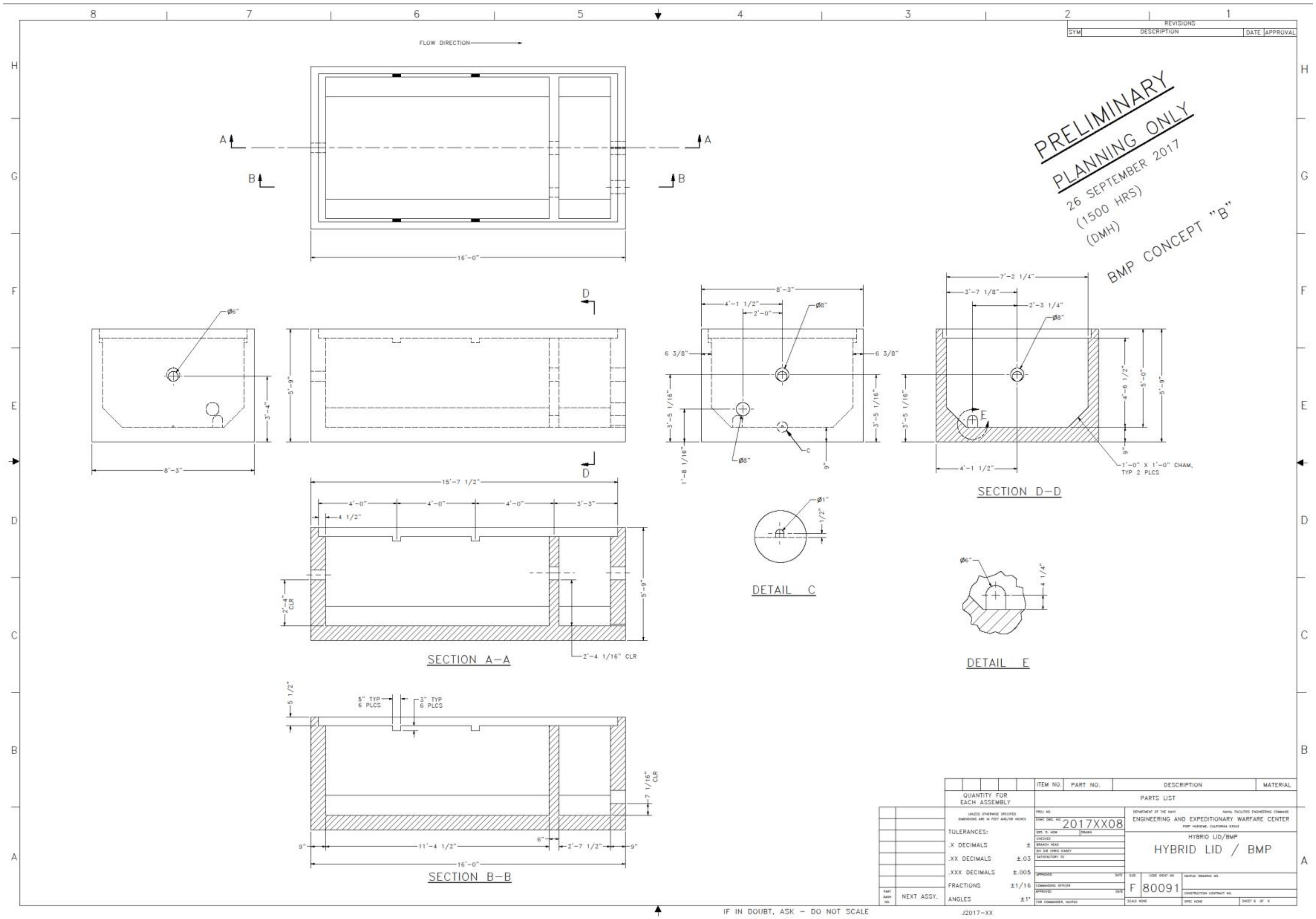
APPENDICES

This Page Intentionally Blank

Appendix A: Media Filter Drawings

This Page Intentionally Blank


PRELIMINARY
PLANNING ONLY
26 SEPTEMBER 2017 (1000 HRS)
EXISTING GRADE
(ELEVATION VIEW)
LID & BMP
(ELEVATION VIEW)
GENERAL NOTE:
1 ALL INTERNAL LID / BMP PLUMBING SHALL BE SCH 40.
2 ALL EXTERNAL LID / BMP PLUMBING SHALL BE SCH 80.
LID
BMP
INSPECTION PORT
LID OVERFLOW
LID EFFLUENT / BMP INFLUENT
BMP OVERFLOW
BMP WEEP, EFFLUENT
BMP EFFLUENT
ENGINEERING AND EXPEDITIONARY WARFARE CENTER
HYBRID LID / BMP
2017XX09
F 80091
IF IN DOUBT, ASK – DO NOT SCALE


FLOW DIRECTION
PRELIMINARY
PLANNING ONLY
26 SEPTEMBER 2017
(1500 HRS)
(DMH)
BMP CONCEPT "B"
SECTION A–A
SECTION B–B
SECTION D–D
DETAIL C
DETAIL E
IF IN DOUBT, ASK – DO NOT SCALE
ENGINEERING AND EXPEDITIONARY WARFARE CENTER
HYBRID LID / BMP
2017XX08
F 80091
J2017–XX

Appendix B: TAPE Certification Requirements and Data

1.0 Technology Assessment Protocol – Ecology (TAPE)

1.1 TAPE Criteria

Based on TAPE requirements qualifying storm events require 0.15 inches of rain during the storm event with an antecedent dry period of at least 6 hours during which no more than 0.04" of precipitation falls. The required minimum storm duration is 1 hour. A minimum of 7 to 10 sample aliquots were required to represent at least 75% of the total storm hydrograph during the first 24 hours of a given storm event to be considered a qualifying sample. Table B-1 summarizes criteria for qualifying storm events.

Table B-1. TAPE Criteria for Qualifying Water Quality Storm Events (TAPE 2011)

Parameter	Definition	Criteria
Storm events	Minimum number of storm events successfully sampled	12
Minimum storm precipitation depth	Total rainfall during a storm event	0.15 inches
Antecedent dry period	Number of hours before the start of a sampling event without significant precipitation	6 hours with no more than 0.04 inches
Sample aliquots	Minimum number of aliquots in each composite sample	7 to 10 aliquots
Composite sample volume	Minimum composite sample volume required to complete required analyses	1 gallon
Storm event coverage	Percentage of the total storm volume that the aliquots represent	At least 75% of the first 24 hours of a given storm

Table B-2. TAPE Water Quality Constituent Requirements

Performance Goal	Influent Range	Criteria
Basic Treatment	20-100 mg/L TSS	Effluent goal ≤ 20 mg/L TSS
	100-200 mg/L TSS	≥ 80% TSS removal
	> 200 mg/L TSS	> 80% TSS removal
Dissolved Metals Treatment	Dissolved copper 0.005 - 0.02 mg/L	Must meet basic treatment goal and better than basic treatment currently defined as >30% dissolved copper removal
	Dissolved zinc 0.02 - 0.3 mg/L	Must meet basic treatment goal and better than basic treatment currently defined as > 60% dissolved zinc removal
Phosphorus Treatment	Total phosphorus (TP) 0.1 to 0.5 mg/L	Must meet basic treatment goal and exhibit ≥ 50% TP removal

Oil Treatment	Total petroleum hydrocarbon (TPH) > 10 mg/L	1) No ongoing or recurring visible sheen in effluent 2) Daily average effluent TPH concentration < 10 mg/L 3) Maximum effluent TPH concentration of 15 mg/L for a discrete (grab) sample

1.2 Required Water Quality Screening Parameters

Table B-3 displays the TAPE Water Quality Screening Parameters required for the NBPL demonstration. The parameters were used to determine if the Hybrid LID/BMP system could potentially export phosphorous, metals, or cause a change in pH. Required screening parameters are analyzed on three of the composite samples (or three *in situ* samples for pH) collected during the monitoring period (preferably spread throughout the monitoring period). Northwest Total Petroleum Hydrocarbons-Motor Oil and Diesel fractions (NWTPH-Dx) samples were collected in situ as grab samples for the NBPL demonstration.

Table B-3. TAPE Required Water Quality Screening Parameters

Performance Goal	**Required Parameters**	**Required Screening Parameters a**
Basic and pretreatment	TSS	PSD, pH, TP, orthophosphate, hardness, total and dissolved Cu and Zn
Phosphorus	TSS, TP, orthophosphate	PSD, pH b, hardness, total and dissolved Cu and Zn
Dissolved metals	TSS, hardness, total and dissolved Cu and Zn	PSD, pH, TP, orthophosphate
Oil	NWTPH-Dx, visible sheen.	pH, TP, orthophosphate, hardness, total and dissolved Cu and Zn

Table B-4. Required Laboratory Analyses and Method Details for TAPE Certification

Analysis	Method	MDL	MRL	Annual Storm Water NAL Permit Value	Units
Conventional					
Total Suspended Solids (TSS)	SM 2540 D	-	1	100	mg/L
Particle Size Distribution (PSD)	Modified ASTM D3977-97	NA	NA	NA	NA
pH	EPA 150.2 (In Situ)		0.2	6.0 – 9.0 Instantaneous Max	pH Units
Total Hardness as $CaCO_3$	SM 2340 C	0.8	2.0	NA	mg/L
Nutrients					
Total Phosphorous (TP)	EPA 365.3	0.004	0.010	2.0	mg/L
Orthophosphate	SM 4500-P E	0.020	0.050	NA	mg/L
Metals					
Total and Dissolved Copper	EPA 200.8	0.05	0.10	33.2 Total	µg/L
Total and Dissolved Zinc	EPA 200.8	0.5	2.0	260 Total	µg/L
Petroleum Hydrocarbons					
Total Oil and Grease (O&G)	EPA 1664 A	0.7	5.0	15	mg/L
Diesel Range Organics (DRO)	NWTPH-Dx	24	550	NA	µg/L
Residual Range Organics (RRO)	NWTPH-Dx	42	1100	NA	µg/L

2.0 Sampling Results

2.1 Storm Event Summary

Table B-5. Storm Event Summary

Hybrid LID/BMP Storm Event Summary								
Rain Event Date	**Rain (inch)**	**Number Aliquots for Composite (Influent/Effluent)**	**Peak flow (gpm)**	**Total Flow (Gallons)**	**Storm Duration (Hours)**	**Avg Storm Intensity (Inch/Hour)**	**Overflow LID/BMP (Gallons)**	**TAPE Qualifying**
2/27/18	0.15	4/4	27	514	3.5	0.043	0/0	No
3/10/18	0.29	4/3	5	705	9.75	0.030	0/0	No
11/29/18[1]	0.67	10/10	60	2,270	25.5	0.026	0/0	Yes
12/5/18[1]	1.47	11/11	35	2,171	33.75	0.043	0/0	Yes
1/5/19	0.71	11/11	51	2,924	11.5	0.062	234/292	Yes
1/12/19	0.34	11/11	43	2,595	4.5	0.076	0/0	Yes
1/14/19	0.40	24/24	45	5,944	6.5	0.062	0/0	Yes
1/31/19	0.71	3.5/24	49	4,632	4.16	0.170	0/0	No
2/13/19	1.15	24/24	54	22,700	26.67	0.043	0/21	Yes
2/20/19[1]	0.09	9/11	14	2,200	21.16	0.004	0/0	Yes
3/2/19	0.15	10/10	12	2,164	7.16	0.021	0/0	Yes
3/11/19	0.47	24/24	41	11,859	11.33	0.042	0/0	Yes
3/20/19[1, 2]	0.43	18/18	58	4,683	4.75	0.091	774/199	Yes
4/29/19[1]	0.19	5/6	11	1,359	22.5	0.008	0/0	Yes
5/10/19[1]	0.32	12/14	36	3,530	37	0.009	0/0	Yes
5/16/19	0.04	In Situ Sample	0	0	1.8	0.022	0/0	No
5/19/19	0.20	10/12	31	2,856	3.25	0.062	0/0	Yes

[1] Rain event includes one or more intervals of 6 hours with less than 0.04 inches of rain
[2] Data is the combination of 3/20-3/21/19 distinct rain events.

2.2 Water Quality Laboratory Data

Table B-6 contains sampling results for the Hybrid LID/BMP system TAPE certification. Full sampling for each stage of the technology is in Appendix E. However, the data for each stage is intended only for internal information and is not part of the required TAPE sampling protocol.

Table B-6. Hybrid LID/BMP Lab Analysis

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	29 Nov 2018+	**5 Dec 2018+**	**5 Jan 2019**	**29 Nov 2018+**	**5 Dec 2018+**	**5 Jan 2019**	
Hybrid LID/BMP							
Total Copper	308	112	39.3	5.79	5.71	3.2	µg/L
Dissolved Copper	98.5	49.3	31.8	1.82	1.87	0.95	µg/L
Total Zinc	769	320	156	8.5	10	4.5	µg/L
Dissolved Zinc	433	223	140	4.8	6.1	2.5	µg/L
Particle Size Distribution (PSD), < 63 microns	NA	NA	7.9	NA	NA	3.6	mg/L
PSD, > 63 microns	NA	NA	3.8	NA	NA	2.0	mg/L
TSS	280	82.6	7.4	6.4	5.2	2.4	mg/L
Total Phosphorous	0.356	0.145	0.043	0.021	0.019	0.011	mg/L
Total Hardness (CaCO3)	24.8	7.6	5.2	90	39.2	67.2	mg/L
Orthophosphate	0.110	0.044[J]	ND[U]	ND[U]	ND[U]	ND[U]	mg/L
Diesel Range Organics (DRO)	430[J]	NA	NA	320[J]	NA	NA	µg/L
Residual Range Organics (RRO)	950[J]	NA	NA	380[J]	NA	NA	µg/L
Total O&G (1664A)	ND[U]	2.7[J]	3.6[J]	ND[U]	1.8[J]	3.7[J]	mg/L
pH	6.3	NA	NA	6.5	NA	NA	S.U.
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	12 Jan 2019	**14 Jan 2019**	**31 Jan 2019**	**12 Jan 2019**	**14 Jan 2019**	**31 Jan 2019**	
Hybrid LID/BMP							
Total Copper	84.9	66.5	118	5.97	4.23	6.32	µg/L
Dissolved Copper	78.8	64.5	75.5	6.14	3.90	2.07	µg/L
Total Zinc	246	204	473	5.3	13.2	7.1	µg/L
Dissolved Zinc	242	203	404	9.2	14.7	4.2	µg/L
PSD, < 63 microns	21.7	24	31.7	3.7	5.8	3.5	mg/L
PSD, > 63 microns	1.9	2.9	30.6	1.2	2.5	3.2	mg/L

TSS	25	26.5	30.7	2.5	2.2	4.2	mg/L
Total Phosphorous	0.125	0.084	0.072	0.064	0.032	0.015	mg/L
Total Hardness (CaCO3)	8	10.8	14.4	52.4	34.8	34.4	mg/L
Orthophosphate	0.059	0.030^{J}	ND^{U}	0.070	ND^{U}	ND^{U}	mg/L
Total O&G (1664A)	3.7^{J}	3.3^{J}	3.6^{J}	2.8^{J}	2.8^{J}	2.1^{J}	mg/L
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	13 Feb 2019	**20 Feb 2019+**	**2 Mar 2019**	**13 Feb 2019**	**20 Feb 2019+**	**2 Mar 2019**	
Hybrid LID/BMP							
Total Copper	82.3	176	218	5.02	1.49	5.29	µg/L
Dissolved Copper	53.8	88.3	35.8	2.31	0.80	2.87	µg/L
Total Zinc	241	702	424	6.2	2.5	3.2	µg/L
Dissolved Zinc	207	625	94.5	5.0	1.9	4.4	µg/L
PSD, < 63 microns	13	NA	NA	3.4	NA	NA	mg/L
PSD, > 63 microns	6.3	NA	NA	2.6	NA	NA	mg/L
TSS	15.3	58.0	16.8	3.5	1.2	ND^{U}	mg/L
Total Phosphorous	0.044	0.102	0.095	0.025	0.010^{J}	0.008^{J}	mg/L
DRO	430^{Y}	NA	NA	180^{J}	NA	NA	µg/L
RRO	1000^{O}	NA	NA	190^{J}	NA	NA	µg/L
pH	7.72	NA	NA	7.03	NA	NA	S.U.
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	11 Mar 2019	**20 and 21 Mar 2019**	**29 April 2019**	**11 Mar 2019**	**20 and 21 Mar 2019**	**29 April 2019**	
Hybrid LID/BMP							
Total Copper	67.8	217	379	4.05	6.01	5.64	µg/L
Dissolved Copper	50.4	63.7	298	1.83	2.90	3.08	µg/L
Total Zinc	240	379	599	4.3	4.2	7.5	µg/L
Dissolved Zinc	204	291	539	2.1	2.2	5.9	µg/L
TSS	4	99.6	33.6	1.2	2.7	2.2	mg/L
Total O&G (1664A)	1.7^{J}	3.9^{J}	NA	2.3^{J}	1.6^{J}	NA	mg/L
Pollutant	**NBPL Rain Event Analytical Results Summary**						**Units**
	Influent			**Effluent**			
	10 May 2019	**16 May 2019**	**19 May 2019**	**10 May 2019**	**16 May 2019**	**19 May 2019**	
Hybrid LID/BMP							
Total Copper	134	NA	137	4.61	NA	9.32	µg/L
Dissolved Copper	102	NA	116	2.37	NA	5.59	µg/L
Total Zinc	217	NA	265	6.1	NA	9.2	µg/L
Dissolved Zinc	181	NA	239	4.7	NA	7.2	µg/L
TSS	16.5	NA	9.0	ND^{U}	NA	1.2	mg/L

DRO	NA	2200[Y]	NA	NA	550[Z]	NA	µg/L
RRO	NA	1900[L]	NA	NA	580[L]	NA	µg/L
pH	NA	7.3	NA	NA	8.0	NA	S.U.

* TAPE qualifying rain event requirements not met. Data will not be included in TAPE application. Gabion influent and effluent sample collection location not adjacent to one another.
\+ Rain event has time period greater than 6 hours without 0.04 inch rain. Data will be included in TAPE application.
[J] < Minimum Reporting Limit (MRL), estimated value.
[H] The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard.
[O] The chromatographic fingerprint of the sample resembles an oil, but does not match the calibration standard.
[Y] The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.
[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL
[Z] The chromatographic fingerprint does not resemble a petroleum product.
[L] The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard.
ND Non Detect
HF Non in-situ analysis

2.3 Total Suspended Solids

The Hybrid LID/BMP system met the effluent goals of the TAPE TSS requirement (Table B-7). No TSS samples were in the 100-200 mg/L range therefor the criteria is not applicable. Table B-8 displays the TSS reduction for each storm event captured by the system.

Table B-7. TAPE Requirements for Total Suspended Solids

Performance Goal	Influent Range	Criteria	Criteria Met?
Basic Treatment	20-100 mg/L TSS	Effluent goal ≤ 20 mg/L TSS	Yes
	100-200 mg/L TSS	≥ 80% TSS removal	N/A
	> 200 mg/L TSS	> 80% TSS removal	Yes

Table B-8. Total Suspended Solids Reduction Data

Hybrid LID/BMP TSS Reduction, EMC			
Rain Event Date	**TSS Influent EMC (mg/L)**	**TSS Effluent EMC (mg/L)**	**TSS Efficiency Ratio (%)**
11/29/18	280	6.4	98
12/5/18	82.6	5.2	94
1/5/19	7.4	2.4	68
1/12/19	25	2.5	90
1/14/19	26.5	2.2	92
1/31/19	30.7	4.2	86
2/13/19	15.3	3.5	77
2/20/19	58	1.2	98
3/2/19	16.8	1[U]	94
3/11/19	4	1.2	70
3/20-21/19	99.6	2.7	97
4/29/19	33.6	2.2	94
5/10/19	16.5	1[U]	94
5/19/19	9.0	1.2	87
Seasonal EMC and Efficiency Ratio	50.4	2.6	95

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL. Substituted MRL value for calculation

2.4 Dissolved Metals

The Hybrid LID/BMP met the TAPE dissolved metals performance goal defined as >30% dissolved copper and zinc removal. Table B-10 displays the seasonal and rain event dissolved copper reduction. The modified dissolved copper removal column is for cases where the influent concentration is greater than the 0.005 - 0.02 mg/L range, so 0.02 mg/L is substituted for the influent value in the removal calculation.

Table B-9. TAPE Requirements for Dissolved Metals – Copper and Zinc

Performance Goal	Influent Range	Criteria	Criteria Met?
Dissolved Metals Treatment	Dissolved copper 0.005 - 0.02 mg/L	Must meet basic treatment goal and better than basic treatment currently defined as >30% dissolved copper removal	Yes

	Dissolved zinc 0.02 - 0.3 mg/L	Must meet basic treatment goal and better than basic treatment currently defined as > 60% dissolved zinc removal	Yes

Table B-10. Hybrid LID/BMP Dissolved Copper Reduction Data

Hybrid LID/BMP Dissolved Copper Reduction, EMC			
Rain Event Date	**Dissolved Copper Influent/Effluent EMC (µg/L)**	**Dissolved Copper Removal (%)**	**Modified Dissolved Copper Removal (%)***
11/29/18	98.5/1.82	98	91
12/5/18	49.3/1.87	96	91
1/5/19	31.8/0.95	97	95
1/12/19	78.8/6.14	92	69
1/14/19	64.5/3.9	94	81
1/31/19	75.5/2.07	97	90
2/13/19	53.8/2.31	96	88
2/20/19	88.3/0.80	99	96
3/2/19	35.8/2.87	92	86
3/11/19	50.4/1.83	96	91
3/20-21/19	63.7/2.9	95	86
4/29/19	298/3.08	99	85
5/10/19	102/2.37	98	88
5/19/19	116/5.59	95	72
Seasonal EMC and Efficiency Ratio	86.2/2.8	97	86

Table B-11 displays the seasonal and rain event dissolved zinc reduction. The Hybrid LID/BMP met the basic treatment goal, and the better than basic treatment defined as >60% dissolved copper removal. The modified dissolved zinc removal column is for cases where the influent concentration is greater than the 0.02 - 0.3 mg/L range, so the 0.3 mg/L value is substituted for the influent value in the removal calculation.

Table B-11. Hybrid LID/BMP Dissolved Copper Reduction Data

Hybrid LID/BMP Dissolved Zinc Reduction, EMC			
Rain Event Date	**Dissolved Zinc Influent/Effluent EMC (µg/L)***	**Dissolved Zinc Removal (%)**	**Modified TAPE Dissolved Zinc Removal (%)***
11/29/18	433/4.8	99	98
12/5/18	223.0/6.1	97	N-
1/5/19	140.0/2.5	98	N-
1/12/19	242.0/9.2	96	N-
1/14/19	203.0/14.7	93	N-
1/31/19	404.0/4.2	99	99
2/13/19	207.0/5.0	98	N-
2/20/19	625/1.9	99	99
3/2/19	94.5/4.4	95	N-
3/11/19	204/2.1	99	N-
3/20-21/19	291/2.2	99	N-
4/29/19	539/5.9	99	98
5/10/19	181/4.7	97	N-
5/19/19	239/7.2	97	N-
Seasonal EMC and Efficiency Ratio	288/5.4	98	98.5

2.5 Total Phosphorous

The Hybrid LID/BMP is limiting the export of total phosphorous to the environment and meeting the TAPE performance goal for phosphorus treatment (Table B-12). Table B-13 displays the seasonal and rain event total phosphorous reduction for the NBPL demonstration.

Table B-12. TAPE Requirements for Phosphorus Treatment

Performance Goal	Influent Range	Criteria	Criteria Met?
Phosphorus Treatment	Total phosphorus 0.1 to 0.5 mg/L	Must meet basic treatment goal and exhibit ≥ 50% TP removal	Yes

Table B-13. TAPE Total Phosphorous Reduction

Hybrid LID/BMP Total Phosphorus Reduction, EMC			
Rain Event Date	**Total Phosphorus Influent EMC (mg/L)**	**Total Phosphorus Effluent EMC (mg/L)**	**Total Phosphorus Efficiency Ratio (%)**
11/29/18	0.356	0.021	94
12/5/18	0.145	0.019	87
1/5/19	0.043	0.011	74
1/12/19	0.125	0.064	49
1/14/19	0.084	0.032	62
1/31/19	0.072	0.015	79
2/13/19	0.044	0.025	43
2/20/19	0.102	0.010[J]	90
3/2/19	0.095	0.008[J]	92
Seasonal EMC and Efficiency Ratio	0.118	0.023	81

[J] < Minimum Reporting Limit, estimated value.

2.6 Total Petroleum Hydrocarbons

Table B-15 displays the seasonal and rain event NWTPH-Dx reduction as Diesel Range Organics (DRO) and Residual Range Organics (RRO) for the NBPL demonstration. NWTPH-Dx samples were collected in situ as grab samples. Unfortunately, many of the storm events occurred during high demand hours or non-working hours for laboratory personnel, and limited samples were collected. In an attempt to display the technology's oil treatment performance, additional oil and grease (O&G Method 1664) samples were collected with the flow proportionate composite samplers.

Table B-14. TAPE Requirements for Oil Treatment

Performance Goal	Influent Range	Criteria	Criteria Met?
Oil Treatment	Total petroleum hydrocarbon (TPH) > 10 mg/L	1) No ongoing or recurring visible sheen in effluent 2) Daily average effluent TPH concentration < 10 mg/L 3) Maximum effluent TPH concentration of 15 mg/L for a discrete (grab) sample	Yes

Table B-15. TAPE In Situ NWTPH-Dx Reduction

Hybrid LID/BMP NWTPH-Dx Reduction, EMC						
Rain Event Date	**DRO Influent EMC (µg/L)**	**DRO Effluent EMC (µg/L)**	**DRO Efficiency Ratio (%)**	**RRO Influent EMC (µg/L)**	**RRO Effluent EMC (µg/L)**	**RRO Efficiency Ratio (%)**
11/29/18	430[J]	320[J]	26	950[J]	380[J]	60
2/13/19	430[Y]	180[J]	58	1000[O]	190[J]	81
5/16/19	2200[Y]	550[Z]	75	1900[L]	580[L]	69
Seasonal EMC and Efficiency Ratio	1020	350	66	1283	383	70

[J] < Minimum Reporting Limit, estimated value.

[Y] The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.

[Z] The chromatographic fingerprint does not resemble a petroleum product

[O] The chromatographic fingerprint of the sample resembles an oil, but does not match the calibration standard.

The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard

Table B-16 displays the seasonal and rain event O&G reduction for the NBPL demonstration. Note that O&G influent concentrations are very low.

Table B-16. TAPE O&G (1664) Reduction

Hybrid LID/BMP O&G (1664) Reduction, EMC			
Rain Event Date	**O&G Influent EMC (mg/L)**	**O&G Effluent EMC (mg/L)**	**O&G Efficiency Ratio (%)**
11/29/18	4^{U}	4^{U}	0
12/5/18	2.7^{J}	1.8^{J}	34
1/5/19	3.6^{J}	3.7^{J}	0
1/12/19	3.7^{J}	2.8^{J}	24
1/14/19	3.3^{J}	2.8^{J}	15
1/31/19	3.6^{J}	2.1^{J}	42
3/11/19	1.7^{J}	2.3^{J}	0
3/2-21/19	3.9^{J}	1.6^{J}	59
Seasonal EMC and Efficiency Ratio	3.31	2.64	20

^{U} The analyte was analyzed for, but was not detected at or above the MRL/MDL. Substituted MRL value for calculation

^{J} < Minimum Reporting Limit, estimated value.

2.7 Particle Size Distribution Reduction

The PSD analysis is used to determine if the influent to the Hybrid LID/BMP technology consists primarily of silt-sized particles, which are representative of Pacific Northwest storm water. The PSD removal ER helps to predict system performance based on the known runoff characteristics from different regions.

Table B-17. Particle Size Distribution Reduction

Hybrid LID/BMP Particle Size Distribution Reduction, EMC				
Rain Event Date	**< 63 microns Influent/Effluent EMC (mg/L)**	**< 63 microns ER (%)**	**> 63 microns Influent/Effluent EMC (mg/L)**	**> 63 microns ER (%)**
1/5/19	7.9/3.6	54	3.8/2.0	47
1/12/19	21.7/3.7	83	1.9/1.2	37
1/14/19	24/5.8	76	2.9/2.5	14
1/31/19	31.7/3.5	89	30.6/3.2	90
2/13/19	13/3.4	74	6.3/2.6	59
Seasonal EMC and Efficiency Ratio	19.7/4.0	80	9.1/2.3	75

2.8 In Situ pH Measurements

Table B-18. In Situ pH Measurements

Hybrid LID/BMP In-Situ pH		
Rain Event Date	**pH Influent (S.I.)**	**pH Effluent (S.I.)**
11/29/18	6.3	6.5
2/13/19	7.72	7.03
5/16/19	7.3	8.0
Seasonal Average	7.1	7.2

2.9 Orthophosphate Measurements

Table B-19. Orthophosphate Measurements

Hybrid LID/BMP Orthophosphate, EMC		
Rain Event Date	**Orthophosphate Influent EMC (mg/L)**	**Orthophosphate Effluent EMC (mg/L)**
11/29/18	0.110	0.050[U]
12/5/18	0.044[J]	0.050[U]
1/5/19	0.050[U]	0.050[U]
1/12/19	0.059	0.070
1/14/19	0.030[J]	0.050[U]
1/31/19	0.050[U]	0.050[U]
Seasonal EMC	0.057	0.053

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL. Substituted MRL value for calculation

[J] < Minimum Reporting Limit, estimated value.

2.10 Hardness Measurements

Table B-20. Hardness Measurements

Hybrid LID/BMP Hardness (CaCO3), EMC		
Rain Event Date	**Hardness Influent EMC (mg/L)**	**Hardness Effluent EMC (mg/L)**
11/29/18	24.8	90.0
12/5/18	7.6	39.2
1/5/19	5.2	67.2
1/12/19	8.0	52.4
1/14/19	10.8	34.8
1/31/19	14.4	34.4
Seasonal EMC	11.8	53.0

2.11 Quality Control Samples: Field Duplicates

Field duplicates are required for 10% of the total number influent and effluent samples (i.e. 5 storm events would result in 10 samples, therefore duplicate requirement is 1.

2.11.1 Metals Field Duplicates at Effluent

Table B-21. Metal Field Duplicates

TAPE Quality Control Samples: Metals Field Duplicates at Effluent				
Date	Total Copper (µg/L)	Dissolved Copper (µg/L)	Total Zinc (µg/L)	Dissolved Zinc (µg/L)
11/29/18	5.67	2.1	9.3	5.3
12/5/18	5.71	1.89	11.2	8.0
1/5/19	3.21	0.92	4.9	3.1

2.11.2 TSS Field Duplicates at Effluent

Table B-22. Total Suspended Solids Field Duplicates

TAPE Quality Control Samples: TSS Field Duplicates at Effluent	
Date	TSS (mg/L)
11/29/18	9.2
12/5/18	4.8
1/5/19	2.7

2.11.3 PSD Field Duplicates at Effluent

Table B- 23. Particle Size Distribution Field Duplicates

TAPE Quality Control Samples: PSD Field Duplicates at Effluent		
Date	PSD, >63 micron (mg/L)	PSD, <63 micron (mg/L)
1/5/19	2.4	3.4
1/14/19	2.3	3.4
2/13/19	3.4	2.8

2.11.4 Oil Duplicates, Total Petroleum Hydrocarbons at Effluent

Table B-24. Oil and Grease Duplicates

TAPE Quality Control Samples: O&G Duplicates at Effluent	
Date	**O&G (1664) (mg/L)**
11/29/18	ND[U]
12/5/18	2.4[J]
1/5/19	3.4[J]
3/11/18	1.8[J]
3/20/19	ND[U]

[J] <Minimum Reporting Limit, estimated value.
[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL

Table B-25. In Situ NWTPH-Dx Duplicates

TAPE Quality Control Samples: O&G Duplicates at Effluent		
Date	**DRO (µg/L)**	**RRO (µg/L)**
2/13/19	150[J]	160[J]
5/16/19	380[Y]	370[J]

[J] <Minimum Reporting Limit, estimated value
[Y] The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.

2.11.5 Total Phosphorous Duplicates at Effluent

Table B-26. Total Phosphorous Duplicates

TAPE Quality Control Samples: Total Phosphorus Duplicates at Effluent	
Date	**TP (mg/L)**
11/29/18	0.030
12/5/18	0.024
1/5/19	0.012

2.11.6 Orthophosphate Duplicates at Effluent

Table B- 27. Orthophosphate Duplicates

TAPE Quality Control Samples: Orthophosphate Duplicates at Effluent	
Date	**Orthophosphate (mg/L)**
11/29/18	ND[U]
12/5/18	ND[U]
1/5/19	ND[U]

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL

2.11.7 Total Hardness $CaCO_3$ Duplicates at Effluent

Table B-28. Total Hardness CaCO3 Duplicates

TAPE Quality Control Samples: Total Hardness $CaCO_3$ Duplicates at Effluent	
Date	**Orthophosphate (mg/L)**
11/29/18	81.2
12/5/18	38.8
1/5/19	61.2

Table B-29. pH Duplicates at Effluent

TAPE Quality Control Samples: In Situ pH Duplicates at Effluent	
Date	**pH (S.I.)**
11/29/18	7.4
12/5/18	7.0
1/5/19	7.4
1/14/19	8.1
2/13/19	8.7
5/16/19	7.8

2.11.8 Quality Control Samples: Influent Rinsate Blanks

The required number of rinsate blanks is three for TSS, TP, Orthophosphate, Total Dissolved Copper and Zinc, and Hardness $CaCO_3$.

Table B- 30. Rinsate Blanks at Influent

TAPE Quality Control Samples: Field Rinsate Blanks at Influent			
Parameter	Date		
	29 Nov 2018	5 Dec 2018	14 Jan 2019
Total Copper (µg/L)	0.71	0.65	0.51
Dissolved Copper (µg/L)	0.36	0.37	0.31
Total Zinc (µg/L)	4.6	6.0	4.1
Dissolved Zinc (µg/L)	3.6	3.8	4.7
TSS (mg/L)	ND^U	ND^U	ND^U
TP (mg/L)	0.005^J	ND^U	ND^U
Orthophosphate (mg/L)	ND^U	ND^U	ND^U
Total Hardness $CaCO_3$ (mg/L)	0.8^J	ND^U	ND^U

^{J} <Minimum Reporting Limit, estimated value.
^{U} The analyte was analyzed for, but was not detected at or above the MRL/MDL

Appendix C: Statistics Worksheets and Results

1.0 Copper

1.1 Wilcox Signed Ranks Test

Total Copper

Storm Event	Influent	Effluent	Differences	Absolute Differences	Rank
1	98.5	1.82	-96.68	96.68	11
2	49.3	1.87	-47.43	47.43	3
3	31.8	0.95	-30.85	30.85	1
4	78.8	6.14	-72.66	72.66	8
5	64.5	3.9	-60.6	60.6	6
6	75.5	2.07	-73.43	73.43	9
7	53.8	2.31	-51.49	51.49	5
8	88.3	0.8	-87.5	87.5	10
9	35.8	2.87	-32.93	32.93	2
10	50.4	1.83	-48.57	48.57	4
11	63.7	2.9	-60.8	60.8	7
12	298	3.08	-294.92	294.92	14
13	102	2.37	-99.63	99.63	12
14	116	5.59	-110.41	110.41	13
					105

Null — **Ho: Effluent pollutant concentrations are equal to or greater than influent concentrations.**

Alternative — **Ha: Effluent concentrations are less than influent concentrations.**

N = 14

α=0.05

T (-)	**105**
T(+)	**0**
Wstat	**0**
Wcritical	**25**

From table- Critical Values of the Wilcoxon Signed Ranks test One-tailed test (per TAPE Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies)

Wstat <Wcritical

Reject the Null hypothesis
Therefore effluent concentrations are less than influent concentrations

1.1.1 **Critical Values**

n	Two-Tailed Test		One-Tailed Test	
	α = .05	α = .01	α = .05	α = .01
5	--	--	0	--
6	0	--	2	--
7	2	--	3	0
8	3	0	5	1
9	5	1	8	3
10	8	3	10	5
11	10	5	13	7
12	13	7	17	9
13	17	9	21	12
14	21	12	25	15
15	25	15	30	19
16	29	19	35	23
17	34	23	41	27
18	40	27	47	32
19	46	32	53	37
20	52	37	60	43
21	58	42	67	49
22	65	48	75	55
23	73	54	83	62
24	81	61	91	69
25	89	68	100	76
26	98	75	110	84
27	107	83	119	92
28	116	91	130	101
29	126	100	140	110
30	137	109	151	120

Total Copper (Chronological Order)

Independent Variable		Dependent Variable
INFLUENT	EFFLUENT	PERCENT REMOVAL
308	5.79	98.1
112	5.71	94.9
39.3	3.2	91.9
84.9	5.97	93.0
66.5	4.23	93.6
118	6.32	94.6
82.3	5.02	93.9
176	1.49	99.2
218	5.29	97.6
67.8	4.05	94.0
217	6.01	97.2
379	5.64	98.5
134	4.61	96.6
137	9.32	93.2

Ho (Null hypothesis) No relationship between influent concentration and removal efficiency

Ha (Alt. hypothesis) Relationship between influent concentration and removal efficiency

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.80444725
R Square	0.647135378
Adjusted R Square	0.615056776
Standard Error	1.435560306
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	41.57407472	41.57407472	20.17342834	0.000913937
Residual	11	22.6691673	2.060833391		
Total	12	64.24324202			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	92.3536554	0.756604703	122.0632849	1.39632E-18	90.68837968	94.01893112	90.68837968	94.01893112
308	0.020507655	0.004565897	4.491483979	0.000913937	0.010458182	0.030557127	0.010458182	0.030557127

Since P-value = 0.0009, and 0.0009 < 0.05 Strong evidence against this happening randomly- Reject the Null Hypothesis.

There is a relationship between influent concentration and removal efficiency

Dissolved Copper (Chronological Order)

Independent Variable		Dependent Variable
INFLUENT	EFFLUENT	PERCENT REMOVAL
98.5	1.82	98.2
49.3	1.87	96.2
31.8	0.95	97.0
78.8	6.14	92.2
64.5	3.9	94.0
75.5	2.07	97.3
53.8	2.31	95.7
88.3	0.8	99.1
35.8	2.87	92.0
50.4	1.83	96.4
63.7	2.9	95.4
298	3.08	99.0
102	2.37	97.7
116	5.59	95.2

Ho (Null hypothesis) No relationship between influent concentration and removal efficiency

Ha (Alt. hypothesis) Relationship between influent concentration and removal efficiency

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.460066226
R Square	0.211660932
Adjusted R Square	0.139993744
Standard Error	2.067880099
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12.6290606	12.6290606	2.95339	0.113676993
Residual	11	47.03740913	4.276128103		
Total	12	59.66646973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	94.65185859	0.938243839	100.8819399	1.1E-17	92.58679782	96.71691935	92.58679782	96.71691935
98.5	0.014973522	0.008712921	1.718542077	0.11368	-0.004203489	0.034150532	-0.004203489	0.034150532

Since P-value = 0.11, and 0.11 > 0.05 No evidence against this happening randomly- Accept the Null Hypothesis.

There is no relationship between influent concentration and removal efficiency

1.2 Total Copper Using TAPE Bootstrap Program: Removal Efficiency

Enabling Macros

Macros must be enabled in order for the spreadsheet to work. Consult the Help Menu in the version of Microsoft Excel you are using for instructions on enabling macros.

Macro Description

The macro uses a "bootstrapping" procedure to calculate either the one-tailed upper 95% confidence interval around the mean effluent concentration, or the one-tailed lower 95% confidence interval around the mean pollutant removal efficiency. To perform these calculations, the macro randomly resamples the original data to create 5000 datasets with the same number of values as the original data. The mean of each resampled dataset is then calculated. The 5000 means are then sorted in ascending order. The one-tailed upper 95% confidence interval around the mean effluent concentration is the mean with the rank of 4750 out of 5000. The one-tailed lower 95% confidence interval around the mean pollutant removal efficiency is the mean with the rank of 250 out of 5000. THIS MACRO SHOULD ONLY BE USED WHEN THERE ARE 10 OR MORE DATA POINTS FOR EFFLUENT CONCENTRATION OR POLLUTANT REMOVAL EFFICIENCY. See references in accompanying worksheet for more detailed information on bootstrapped confidence intervals.

1. Clear any previous effluent and remove data by clicking on the **Clear Data** button

2. Enter effluent concentration and remove efficiency data in columns K and L

3. Select which confidence limit to calculate

○ **Upper 95% confidence limit for effluent concentration**

◉ **Lower 95% confidence limit for removal efficiency**

4. Click on the calculate button **Calculate**

Lower 95% for removal efficiency (%) **94.464**

Effluent Concentration	Removal Efficiency (%)
5.79	98.1
5.71	94.9
3.2	91.9
5.97	93.0
4.23	93.6
6.32	94.6
5.02	93.9
1.49	99.2
5.29	97.6
4.05	94.0
6.01	97.2
5.64	98.5
4.61	96.6
9.32	93.2

1.3 Total Copper Using TAPE Bootstrap Program: Effluent Concentration

Enabling Macros

Macros must be enabled in order for the spreadsheet to work. Consult the Help Menu in the version of Microsoft Excel you are using for instructions on enabling macros.

Macro Description

The macro uses a "bootstrapping" procedure to calculate either the one-tailed upper 95% confidence interval around the mean effluent concentration, or the one-tailed lower 95% confidence interval around the mean pollutant removal efficiency. To perform these calculations, the macro randomly resamples the original data to create 5000 datasets with the same number of values as the original data. The mean of each resampled dataset is then calculated. The 5000 means are then sorted in ascending order. The one-tailed upper 95% confidence interval around the mean effluent concentration is the mean with the rank of 4750 out of 5000. The one-tailed lower 95% confidence interval around the mean pollutant removal efficiency is the mean with the rank of 250 out of 5000. THIS MACRO SHOULD ONLY BE USED WHEN THERE ARE 10 OR MORE DATA POINTS FOR EFFLUENT CONCENTRATION OR POLLUTANT REMOVAL EFFICIENCY. See references in accompanying worksheet for more detailed information on bootstrapped confidence intervals.

1. Clear any previous effluent and remove data by clicking on the **Clear Data** button

2. Enter effluent concentration and remove efficiency data in columns K and L

3. Select which confidence limit to calculate

   ◉ **Upper 95% confidence limit for effluent concentration**

   ○ **Lower 95% confidence limit for removal efficiency**

4. Click on the calculate button **Calculate**

Upper 95% for effluent concentration **5.938**

Effluent Concentration	Removal Efficiency (%)
5.79	98.1
5.71	94.9
3.2	91.9
5.97	93.0
4.23	93.6
6.32	94.6
5.02	93.9
1.49	99.2
5.29	97.6
4.05	94.0
6.01	97.2
5.64	98.5
4.61	96.6
9.32	93.2

1.4 Dissolved Copper Using TAPE Bootstrap Program: Removal Efficiency

Enabling Macros

Macros must be enabled in order for the spreadsheet to work. Consult the Help Menu in the version of Microsoft Excel you are using for instructions on enabling macros.

Macro Description

The macro uses a "bootstrapping" procedure to calculate either the one-tailed upper 95% confidence interval around the mean effluent concentration, or the one-tailed lower 95% confidence interval around the mean pollutant removal efficiency. To perform these calculations, the macro randomly resamples the original data to create 5000 datasets with the same number of values as the original data. The mean of each resampled dataset is then calculated. The 5000 means are then sorted in ascending order. The one-tailed upper 95% confidence interval around the mean effluent concentration is the mean with the rank of 4750 out of 5000. The one-tailed lower 95% confidence interval around the mean pollutant removal efficiency is the mean with the rank of 250 out of 5000. THIS MACRO SHOULD ONLY BE USED WHEN THERE ARE 10 OR MORE DATA POINTS FOR EFFLUENT CONCENTRATION OR POLLUTANT REMOVAL EFFICIENCY. See references in accompanying worksheet for more detailed information on bootstrapped confidence intervals.

1. Clear any previous effluent and remove data by clicking on the **Clear Data** button

2. Enter effluent concentration and remove efficiency data in columns K and L

3. Select which confidence limit to calculate

   ○ **Upper 95% confidence limit for effluent concentration**

   ◉ **Lower 95% confidence limit for removal efficiency**

4. Click on the calculate button **Calculate**

Lower 95% for removal efficiency (%) **95.138**

Effluent Concentration	Removal Efficiency (%)
1.82	98.2
1.87	96.2
0.95	97.0
6.14	92.2
3.9	94.0
2.07	97.3
2.31	95.7
0.8	99.1
2.87	92.0
1.83	96.4
2.9	95.4
3.08	99.0
2.37	97.7
5.59	95.2

1.5 Dissolved Copper Using TAPE Bootstrap Program: Effluent Concentration

Enabling Macros

Macros must be enabled in order for the spreadsheet to work. Consult the Help Menu in the version of Microsoft Excel you are using for instructions on enabling macros.

Macro Description

The macro uses a "bootstrapping" procedure to calculate either the one-tailed upper 95% confidence interval around the mean effluent concentration, or the one-tailed lower 95% confidence interval around the mean pollutant removal efficiency. To perform these calculations, the macro randomly resamples the original data to create 5000 datasets with the same number of values as the original data. The mean of each resampled dataset is then calculated. The 5000 means are then sorted in ascending order. The one-tailed upper 95% confidence interval around the mean effluent concentration is the mean with the rank of 4750 out of 5000. The one-tailed lower 95% confidence interval around the mean pollutant removal efficiency is the mean with the rank of 250 out of 5000. THIS MACRO SHOULD ONLY BE USED WHEN THERE ARE 10 OR MORE DATA POINTS FOR EFFLUENT CONCENTRATION OR POLLUTANT REMOVAL EFFICIENCY. See references in accompanying worksheet for more detailed information on bootstrapped confidence intervals.

1. Clear any previous effluent and remove data by clicking on the **Clear Data** button

2. Enter effluent concentration and remove efficiency data in columns K and L

3. Select which confidence limit to calculate

   ◉ **Upper 95% confidence limit for effluent concentration**

   ○ **Lower 95% confidence limit for removal efficiency**

4. Click on the calculate button **Calculate**

Upper 95% for effluent concentration **3.458**

Effluent Concentration	Removal Efficiency (%)
1.82	98.2
1.87	96.2
0.95	97.0
6.14	92.2
3.9	94.0
2.07	97.3
2.31	95.7
0.8	99.1
2.87	92.0
1.83	96.4
2.9	95.4
3.08	99.0
2.37	97.7
5.59	95.2

This Page Intentionally Blank

Appendix D: Cost Model

Site Cost Model Spreadsheet			
Site Information	Watershed Runoff Area (acres)	1	Determined from site drawings
	Watershed Runoff Area (acres, rounded up)	1	
	Hydraulic Surface Coefficient	0.95	Typically .85 or higher for industrial areas
	Regional Labor Cost Factor (high 1, med 0.9, low 0 .8)	1	Estimate
	Available Hydraulic Head (ft)	4.5	Top surface to invert (catch basin flow line)
Design Constraint	Hydraulic Head (ft)	4.5	Must be equal or greater than 4.5 feet
Regulatory Requirements	Design flow rate (gpm)	86.0	Using NPDES Permit formula to determine design flo
Hydraulic Data	Annual Rainfall (in/year)	10.34	From San Diego County Water Authority
	Design Rainfall Intensity (in/hr)	0.2	From NPDES Permit design formula
	Average 24 hour rain event from Isopluvial chart (in)	0.5	From 85% Isopluvials Charts
	Storm Water Volume generated per ave. year (gallons)	266,718	Total volume of stormwater per year
	Average Number of Storms per Year	16	Historical data from NOAA website
Calculations	Volume of water for pump and treat (gallons)	108,610	Capture first 0.25"
	Square footage needed for installation (ft^2)	345	Minimum area needed
	Tank size (0.25") for capture and dispose (gallons)	6,788	Tank size
	Cost of pump skid for capture and dispose ($)	$ 4,000.00	Estimate
LID/BMP Design Criteria	LID infiltration rate (inches/hour)	100	Per manufacturers data on new material
	Size of LID based on infiltration rate and watershed (ft^2)	136	Calculated based on 100 in/hr infiltration rate
	LID Area (ft^2 per acre)	200	Use this value per acre to adjust for clogging
	Area of LID needed (ft^2)	200	Includes a Safety Factor of 2.0
	Flow rate through single dual media vault (gpm)	86.0	Standard Vault (16' x 8.5' x 5'-9")
	BMP Length (ft)	16	Outer dimension
	BMP Width (ft)	8.5	Outer dimension
	Required Dual Media Filter contact time (minutes)	8	Reference EXWC Study
	Number of Vaults needed	1	
Economic Criteria	Electrical cost (Per kW-hr)	$0.1653	January 2020, U.S. Energy Information Administratio
	Life cycle (years)	20	
	Cost to dispose ($/gallon)	$0.10	Based on NRRC data
	Unit cost of holding tank ($5-10 per gallon)	$6.00	
	Cost of holding tank ($5-10 per gallon)	$ 40,729	
	Cost to operate pump (assume 1.5 HP pump)	$ 120	Negligible
	Cost of pump skid 1-2 HP motor 50 gpm	$ 4,000	Estimated
Hybrid LID/BMP System Cost Data			
Design	Utilities Survey	$ 650.00	
	Elevation Survey	$ 2,000.00	
	Design	$ 800.00	
Media Filter	FS-50	$ 1.14	Unit Cost per lb (Axens North America)
	Amount of FS-50 needed per vault (lbs)	4,000	
	Cost of FS-50 for site	$ 4,560.00	Total Cost (2.2 cubic yards per vault, 9" deep)
	Bone Char	$ 2.00	Unit Cost per lb (Procured by contractor)
	Amount of Bone Char needed per vault (lbs)	1,635	
	Cost of Bone Char for site	$ 3,270.00	Total Cost (1.5 cubic yards per vault, 6" deep)
	Vault	$ 15,340.00	Made by Jensen Precast
	Miscellaneous	$ 5,390.00	
	Vault and Media Cost	$ 28,560.00	
Biofilter	Unit Cost for LID Biofilter Materials	$ 235.00	Unit Cost includes water harvest tank modules, gabion, hard wood mulch, engineered soil matrix, miscellaneous plumbing and irrigation
	LID Biofilter (SF)	200	
	Cost of Biofilter Material for site	$ 47,000.00	
Installation	Shipping	$ 8,000.00	
	Cost of System Installation	$ 70,000.00	$70,000 per acre
Total Capital Cost		**$ 157,010.00**	
Hybrid LID/BMP System - Total Lifecycle Cost (20 years)			
Hybrid LID/BMP System	**Capital Cost**	**$ 157,010.00**	
	Annual Maintenance Cost (@ $2500/yr)	**$ 50,000.00**	Total cost for entire lifecycle (Cell D30)
	Periodic Maintenance	**$ 10,030.00**	Replacement of media
Total Cost		**$ 217,040.00**	
Capture and Dispose Alternative - Total Lifecycle Cost (20 years)			
Capture and Dispose	Capital Cost	**$ 44,728.60**	
	Annual Maintenance Cost ($1,000 per acre)	**$ 20,000.00**	
	Disposal Cost (20 years)	**$ 217,219.20**	
Total Cost		**$ 281,947.80**	

Appendix E: Sampling Data & Mass Balance

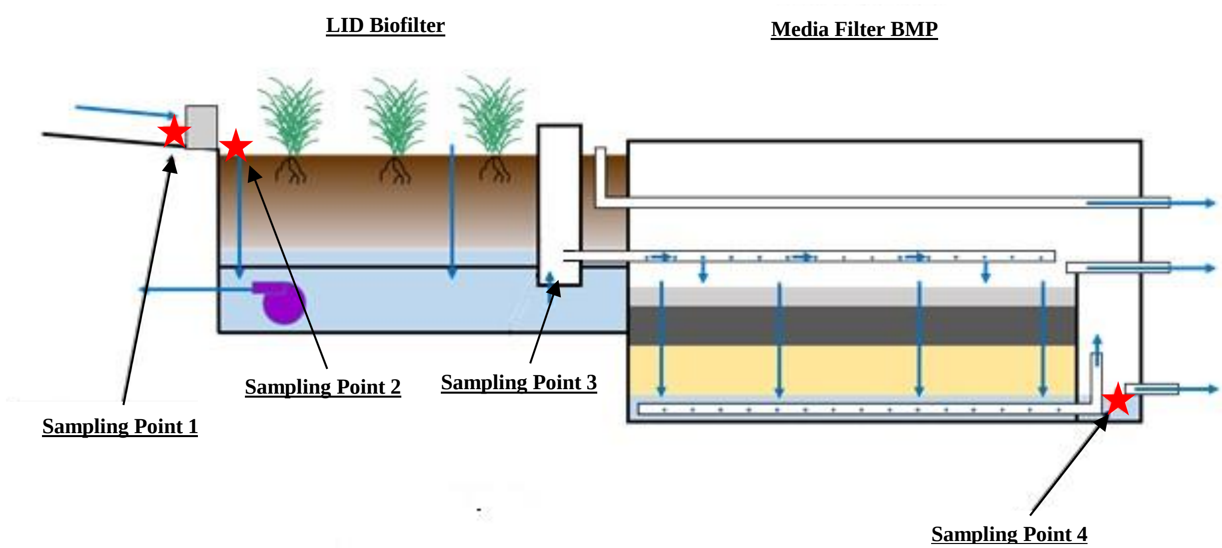


Figure E-1. Sampling Points on System

Table E- 1. Sampling Data From All Rain Events Across the Hybrid LID/BMP System

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	27 Feb 2018*	10 Mar 2018*	29 Nov 2018+	27 Feb 2018*	10 Mar 2018*	29 Nov 2018+	
Gabion (SP1)							
Total Copper	210	122	308	600	182	252	µg/L
Dissolved Copper	12	51.3	98.5	3.6	164	31.1	µg/L
Total Zinc	470	359	769	890	249	919	µg/L
Dissolved Zinc	150	212	433	100	231	708	µg/L
TSS	220	15.7	280	19	8.2	23.9	mg/L
Total Phosphorous	0.21	0.199	0.356	NA	NA	0.719	mg/L
Total Hardness (CaCO3)	NA	NA	24.8	NA	NA	NA	mg/L
Orthophosphate	NA	NA	0.110	NA	NA	NA	mg/L
Total O&G (1664A)	NA	NA	ND^{U}	NA	NA	NA	mg/L
Diesel Range Organics (DRO)	NA	NA	430^{J}	NA	NA	NA	mg/L
Residual Range Organics (RRO)	NA	NA	950^{J}	NA	NA	NA	mg/L
pH	6.6 ^{HF}	6.53 ^{HF}	6.3	6.8 ^{HF}	6.48 ^{HF}	NA	S.U.
LID							
Total Copper	600	182	252	26	60.6	168	µg/L
Dissolved Copper	3.6	164	31.1	19	54.6	152	µg/L

Total Zinc	890	249	919	33	37.6	213	mg/L
Dissolved Zinc	100	231	708	22	25.4	186	mg/L
TSS	19	8.2	23.9	6.1	5.2	41.7	mg/L
Total Phosphorous	NA	NA	0.719	NA	NA	0.116	mg/L
DRO	NA	NA	NA	NA	NA	580[H]	µg/L
RRO	NA	NA	NA	NA	NA	1300[O]	µg/L
pH	6.8[HF]	6.48[HF]	NA	7.8[HF]	7.4[HF]	6.2	S.U.
BMP (SP2)							
Total Copper	26	60.6	168	2.2	3.42	5.79	µg/L
Dissolved Copper	19	54.6	152	1.0	0.79	1.82	µg/L
Total Zinc	33	37.6	213	7.3	9.0	8.5	µg/L
Dissolved Zinc	22	25.4	186	2.4[J]	4.8	4.8	µg/L
TSS	6.1	5.2	41.7	1.4	7.3	6.4	mg/L
Total Phosphorous	NA	NA	0.116	<0.025	0.30	0.021	mg/L
Total Hardness (CaCO3)	NA	NA	NA	NA	NA	90.0	mg/L
DRO	NA	NA	580[H]	NA	NA	320[J]	µg/L
RRO	NA	NA	1300[O]	NA	NA	380[J]	µg/L
Total O&G (1664A)	NA	NA	NA	NA	NA	ND[U]	mg/L
pH	7.8 [HF]	7.4 [HF]	6.2	7.0 [HF]	6.97 [HF]	6.5	S.U.
Hybrid LID/BMP							
Total Copper	210	122	308	2.2	3.42	5.79	µg/L
Dissolved Copper	12	51.3	98.5	1.0	0.79	1.82	µg/L
Total Zinc	470	359	769	7.3	9.0	8.5	µg/L
Dissolved Zinc	150	212	433	2.4 [J]	4.8	4.8	µg/L
TSS	220	15.7	280	1.4	7.3	6.4	mg/L
Total Phosphorous	0.21	0.199	0.356	<0.025	0.30	0.021	mg/L
Total Hardness (CaCO3)	NA	NA	24.8	NA	NA	90	mg/L
Orthophosphate	NA	NA	0.110	NA	NA	ND	mg/L
DRO	NA	NA	580[H]	NA	NA	320[J]	µg/L
RRO	NA	NA	1300[O]	NA	NA	380[J]	µg/L
Total O&G (1664A)	NA	NA	ND[U]	NA	NA	ND[U]	mg/L
pH	6.6 [HF]	6.53 [HF]	6.3	7.0 [HF]	6.97 [HF]	6.5	S.U.

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	5 Dec 2018+	5 Jan 2019	12 Jan 2019	5 Dec 2018+	5 Jan 2019	12 Jan 2019	
Gabion (SP1)							
Total Copper	112	39.3	84.9	41.6	47.3	33.7	µg/L
Dissolved Copper	49.3	31.8	78.8	37.4	21	33.8	µg/L
Total Zinc	320	156	246	123	125	80.2	µg/L
Dissolved Zinc	223	140	242	115	80.2	86.3	µg/L
TSS	82.6	7.4	25	10.7	8.1	15.9	mg/L
Particle Size Distribution (PSD), < 63 micron	NA	7.9	21.7	NA	5.9	NA	mg/L
PSD, > 63 micron	NA	3.8	1.9	NA	3.6	NA	mg/L
Total Phosphorous	0.145	0.043	0.125	0.218	0.198	0.153	mg/L
Total Hardness (CaCO3)	7.6	5.2	8	NA	NA	NA	mg/L
Orthophosphate	0.044^{J}	ND	0.059	NA	NA	NA	mg/L
Total O&G (1664A)	2.7^{J}	3.6^{J}	3.7^{J}	NA	NA	NA	mg/L
pH	NA	NA	NA	NA	NA	NA	S.U.
LID							
Total Copper	41.6	47.3	33.7	55	21.6	24.8	µg/L
Dissolved Copper	37.4	21	33.8	49.2	16.5	23.5	µg/L
Total Zinc	123	125	80.2	52.7	37.8	30	mg/L
Dissolved Zinc	115	80.2	86.3	44.4	33.0	32.4	mg/L
PSD, < 63 micron	NA	5.9	21.7	NA	3.0	2.7	mg/L
PSD, > 63 micron	NA	3.6	1.9	NA	2.0	1.3	mg/L
TSS	10.7	8.1	15.9	4.8	3	3	mg/L
Total Phosphorous	0.218	0.198	0.153	0.046	0.040	0.034	mg/L
DRO	NA	NA	NA	NA	NA	NA	µg/L
RRO	NA	NA	NA	NA	NA	NA	µg/L
pH	NA	NA	NA	NA	NA	NA	S.U.
BMP (SP2)							
Total Copper	55	21.6	24.8	5.71	3.2	5.97	µg/L
Dissolved Copper	49.2	16.5	23.5	1.87	0.95	6.14	µg/L
Total Zinc	52.7	37.8	30	10	4.5	5.3	µg/L
Dissolved Zinc	44.4	33.0	32.4	6.1	2.5	9.2	µg/L
PSD, < 63 microns	NA	3.0	2.7	NA	3.6	3.7	mg/L
PSD, > 63 microns	NA	2.0	1.3	NA	2.0	1.2	mg/L
TSS	4.8	3	3	5.2	2.4	2.5	mg/L
Total Phosphorous	0.046	0.040	0.034	0.019	0.011	0.064	mg/L
Total Hardness (CaCO3)	NA	NA	NA	39.2	67.2	52.4	mg/L

Orthophosphate	NA	NA	NA	ND	ND	0.070	mg/L
Total O&G (1664A)	NA	NA	NA	1.8[J]	3.7[J]	2.8[J]	mg/L
DRO	NA	NA	NA	NA	NA	NA	µg/L
RRO	NA	NA	NA	NA	NA	NA	µg/L
pH	NA	NA	NA	NA	NA	NA	S.U.
Hybrid LID/BMP							
Total Copper	112	39.3	84.9	5.71	3.2	5.97	µg/L
Dissolved Copper	49.3	31.8	78.8	1.87	0.95	6.14	µg/L
Total Zinc	320	156	246	10	4.5	5.3	µg/L
Dissolved Zinc	223	140	242	6.1	2.5	9.2	µg/L
PSD, < 63 microns	NA	7.9	21.7	NA	3.6	3.7	mg/L
PSD, > 63 microns	NA	3.8	1.9	NA	2.0	1.2	mg/L
TSS	82.6	7.4	25	5.2	2.4	2.5	mg/L
Total Phosphorous	0.145	0.043	0.125	0.019	0.011	0.064	mg/L
Total Hardness (CaCO3)	7.6	5.2	8	39.2	67.2	52.4	mg/L
Orthophosphate	0.044[J]	ND	0.059	ND	ND	0.070	mg/L
Total O&G (1664A)	2.7[J]	3.6[J]	3.7[J]	1.8[J]	3.7[J]	2.8[J]	mg/L
DRO	NA	NA	NA	NA	NA	NA	µg/L
RRO	NA	NA	NA	NA	NA	NA	µg/L
pH	NA	NA	NA	NA	NA	NA	S.U.

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	14 Jan 2019	31 Jan 2019	13 Feb 2019	14 Jan 2019	31 Jan 2019	13 Feb 2019	
Gabion (SP1)							
Total Copper	66.5	118	82.3	19.5	22.1	137	µg/L
Dissolved Copper	64.5	75.5	53.8	18.7	16.0	102	µg/L
Total Zinc	204	473	241	47.9	57.9	204	µg/L
Dissolved Zinc	203	404	207	49.9	53.3	173	µg/L
TSS	26.5	30.7	15.3	14.4	12.9	294	mg/L
PSD, < 63 micron	24	31.7	13	NA	11.4	325	mg/L
PSD, > 63 micron	2.9	30.6	6.3	NA	7.8	53.8	mg/L
Total Phosphorous	0.084	0.072	0.044	0.080	0.106	5.98	mg/L
Total Hardness (CaCO3)	10.8	14.4	NA	NA	NA	NA	mg/L
Orthophosphate	0.030[J]	ND[U]	NA	NA	NA	NA	mg/L
Total O&G (1664A)	3.3[J]	3.6[J]	NA	NA	NA	NA	mg/L
pH	NA	NA	7.72	NA	NA	7.72	S.U.
LID							
Total Copper	19.5	22.1	82.3	33.9	19.8	57.8	µg/L
Dissolved Copper	18.7	16.0	53.8	32.4	14.3	43.0	µg/L
Total Zinc	47.9	57.9	241	31.6	46.2	62.3	mg/L
Dissolved Zinc	49.9	53.3	207	33.5	38.3	38.3	mg/L
PSD, < 63 micron	24	11.4	325	12	2.6	1.1	mg/L
PSD, > 63 micron	2.9	7.8	53.8	2.4	3.0	43.3	mg/L
TSS	14.4	12.9	15.3	8.8	3.2	1.3	mg/L
Total Phosphorous	0.080	0.106	0.044	0.056	0.045	0.040	mg/L
DRO	NA	NA	430[Y]	NA	NA	240[J]	µg/L
RRO	NA	NA	1000[O]	NA	NA	410[J]	µg/L
pH	NA	NA	7.72	NA	NA	7.12	S.U.
BMP (SP2)							
Total Copper	33.9	19.8	57.8	4.23	6.32	5.02	µg/L
Dissolved Copper	32.4	14.3	43.0	3.90	2.07	2.31	µg/L
Total Zinc	31.6	46.2	62.3	13.2	7.1	6.2	µg/L
Dissolved Zinc	33.5	38.3	38.3	14.7	4.2	5.0	µg/L
PSD, < 63 microns	12	2.6	1.1	5.8	3.5	3.4	mg/L
PSD, > 63 microns	2.4	3.0	43.3	2.5	3.2	2.6	mg/L
TSS	8.8	3.2	1.3	2.2	4.2	3.5	mg/L
Total Phosphorous	0.056	0.045	0.040	0.032	0.015	0.025	mg/L
Total Hardness (CaCO3)	NA	NA	NA	34.8	34.4	NA	mg/L
Total O&G	NA	NA	NA	2.8[J]	2.1[J]	NA	mg/L
DRO	NA	NA	240[J]	NA	NA	180[J]	µg/L

RRO	NA	NA	410[J]	NA	NA	190[J]	µg/L
pH	NA	NA	7.12	NA	NA	7.03	S.U.
Hybrid LID/BMP							
Total Copper	66.5	118	82.3	4.23	6.32	5.02	µg/L
Dissolved Copper	64.5	75.5	53.8	3.90	2.07	2.31	µg/L
Total Zinc	204	473	241	13.2	7.1	6.2	µg/L
Dissolved Zinc	203	404	207	14.7	4.2	5.0	µg/L
PSD, < 63 microns	24	31.7	13	5.8	3.5	3.4	mg/L
PSD, > 63 microns	2.9	30.6	6.3	2.5	3.2	2.6	mg/L
TSS	26.5	30.7	15.3	2.2	4.2	3.5	mg/L
Total Phosphorous	0.084	0.072	0.044	0.032	0.015	0.025	mg/L
Total Hardness (CaCO3)	10.8	14.4	NA	34.8	34.4	NA	mg/L
Orthophosphate	0.030J	ND[U]	NA	ND[U]	ND[U]	NA	mg/L
Total O&G (1664A)	3.3[J]	3.6[J]	NA	2.8[J]	2.1[J]	NA	mg/L
DRO	NA	NA	430[Y]	NA	NA	180[J]	µg/L
RRO	NA	NA	1000[O]	NA	NA	190[J]	µg/L
pH	NA	NA	7.72	NA	NA	7.03	S.U.

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	20 Feb 2019+	2 Mar 2019	11 Mar 2019	20 Feb 2019+	2 Mar 2019	11 Mar 2019	
Gabion (SP1)							
Total Copper	176	218	67.8	NA	149	34.1	µg/L
Dissolved Copper	88.3	35.8	50.4	NA	131	29.1	µg/L
Total Zinc	702	424	240	NA	256	48.4	µg/L
Dissolved Zinc	625	94.5	204	NA	234	44.4	µg/L
TSS	58.0	16.8	4	NA	100	11.2	mg/L
Total Phosphorous	0.102	0.095	NA	NA	0.827	NA	mg/L
Total O&G (1664A)	NA	NA	1.7^{J}	NA	NA	NA	mg/L
LID							
Total Copper	176	149	34.1	27.7	40.6	38.2	µg/L
Dissolved Copper	88.3	131	29.1	25.8	186	32.8	µg/L
Total Zinc	702	256	48.4	118	100.3	76.7	mg/L
Dissolved Zinc	625	234	44.4	116	387	61.5	mg/L
TSS	58.0	100	11.2	2.9	2.5	2.6	mg/L
Total Phosphorous	0.102	0.827	NA	0.017	0.026	NA	mg/L
Total O&G (1664A)	NA	NA	NA	NA	NA	2.5^{J}	mg/L
BMP (SP2)							
Total Copper	27.7	40.6	38.2	1.49	5.29	4.05	µg/L
Dissolved Copper	25.8	186	32.8	0.80	2.87	1.83	µg/L
Total Zinc	118	100.3	76.7	2.5	3.2	4.3	µg/L
Dissolved Zinc	116	387	61.5	1.9^{J}	4.4	2.1	µg/L
TSS	2.9	2.5	2.6	1.2	ND^{U}	1.2	mg/L
Total Phosphorous	0.017	0.026	NA	0.010^{J}	0.008^{J}	NA	mg/L
Total O&G (1664A)	NA	NA	2.5^{J}	NA	NA	2.3^{J}	mg/L
Hybrid LID/BMP							
Total Copper	176	218	67.8	1.49	5.29	4.05	µg/L
Dissolved Copper	88.3	35.8	50.4	0.80	2.87	1.83	µg/L
Total Zinc	702	424	240	2.5	3.2	4.3	µg/L
Dissolved Zinc	625	94.5	204	1.9	4.4	2.1	µg/L
TSS	58.0	16.8	4	1.2	ND^{U}	1.2	mg/L
Total Phosphorous	0.102	0.095	NA	0.010^{J}	0.008^{J}	NA	mg/L
Total O&G (1664A)	NA	NA	1.7^{J}	NA	NA	2.3^{J}	mg/L

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	20 and 21 Mar 2019	29 April 2019	10 May 2019	20 and 21 Mar 2019	29 April 2019	10 May 2019	
Gabion (SP1)							
Total Copper	217	379	134	129	1290	272	µg/L
Dissolved Copper	63.7	298	102	104	444	225	µg/L
Total Zinc	379	599	217	418	1520	267	µg/L
Dissolved Zinc	291	539	181	396	908	222	µg/L
TSS	99.6	33.6	16.5	12.1	675	74.3	mg/L
Total O&G (1664A)	3.9[J]	NA	NA	NA	NA	NA	mg/L
LID							
Total Copper	129	1290	272	NA	111	46.4	µg/L
Dissolved Copper	104	444	225	NA	106	43.4	µg/L
Total Zinc	418	1520	267	NA	201	53.9	mg/L
Dissolved Zinc	396	908	222	NA	193	48.1	mg/L
TSS	12.1	74.3	74.3	NA	2.3	ND[U]	mg/L
BMP (SP2)							
Total Copper	NA	111	46.4	6.01	5.64	4.61	µg/L
Dissolved Copper	NA	106	43.4	2.90	3.08	2.37	µg/L
Total Zinc	NA	201	53.9	4.2	7.5	6.1	µg/L
Dissolved Zinc	NA	193	48.1	2.2	5.9	4.7	µg/L
TSS	NA	2.3	ND[U]	2.7	2.2	ND[U]	mg/L
Total O&G (1664A)	NA	NA	NA	1.6[J]	NA	NA	mg/L
Hybrid LID/BMP							
Total Copper	217	379	134	6.01	5.64	4.61	µg/L
Dissolved Copper	63.7	298	102	2.90	3.08	2.37	µg/L
Total Zinc	379	599	217	4.2	7.5	6.1	µg/L
Dissolved Zinc	291	539	181	2.2	5.9	4.7	µg/L
TSS	99.6	33.6	16.5	2.7	2.2	ND[U]	mg/L
Total O&G (1664A)	3.9[J]	NA	NA	1.6[J]	NA	NA	mg/L

Pollutant	NBPL Rain Event Analytical Results Summary						Units
	Influent			Effluent			
	16 May 2019	19 May 2019		16 May 2019	19 May 2019		
Gabion (SP1)							
Total Copper	NA	137	NA	NA	NA	NA	µg/L
Dissolved Copper	NA	116	NA	NA	NA	NA	µg/L
Total Zinc	NA	265	NA	NA	NA	NA	µg/L
Dissolved Zinc	NA	239	NA	NA	NA	NA	µg/L
TSS	NA	9.0	NA	NA	NA	NA	mg/L
DRO	2200[Y]	NA	NA	380[Y]	NA	NA	mg/L
RRO	1900[L]	NA	NA	550[J]	NA	NA	mg/L
pH	7.3	NA	NA	7.3	NA	NA	S.U.
LID							
Total Copper	NA	NA	NA	NA	NA	NA	µg/L
Dissolved Copper	NA	NA	NA	NA	NA	NA	µg/L
Total Zinc	NA	NA	NA	NA	NA	NA	mg/L
Dissolved Zinc	NA	NA	NA	NA	NA	NA	mg/L
TSS	NA	NA	NA	NA	NA	NA	mg/L
DRO	380[Y]	NA	NA	NA	NA	NA	µg/L
RRO	550[J]	NA	NA	NA	NA	NA	µg/L
pH	7.3	NA	NA	7.2	NA	NA	S.U.
BMP (SP2)							
Total Copper	NA	NA	NA	NA	9.32	NA	µg/L
Dissolved Copper	NA	NA	NA	NA	5.59	NA	µg/L
Total Zinc	NA	NA	NA	NA	9.2	NA	µg/L
Dissolved Zinc	NA	NA	NA	NA	7.2	NA	µg/L
TSS	NA	NA	NA	NA	1.2	NA	mg/L
DRO	NA	NA	NA	550[Z]	NA	NA	µg/L
RRO	NA	NA	NA	580[L]	NA	NA	µg/L
pH	7.2	NA	NA	8.0	NA	NA	S.U.
Hybrid LID/BMP							
Total Copper	NA	137	NA	NA	9.32	NA	µg/L
Dissolved Copper	NA	116	NA	NA	5.59	NA	µg/L
Total Zinc	NA	265	NA	NA	9.2	NA	µg/L
Dissolved Zinc	NA	239	NA	NA	7.2	NA	µg/L
TSS	NA	9.0	NA	NA	1.2	NA	mg/L
DRO	2200[Y]	NA	NA	550[Z]	NA	NA	µg/L
RRO	1900[L]	NA	NA	580[L]	NA	NA	µg/L
pH	7.3	NA	NA	8.0	NA	NA	S.U.

LEGEND:

* TAPE qualifying rain event requirements not met. Data will not be included in TAPE application. Gabion influent and effluent sample collection location not adjacent to one another.

\+ Rain event has time period greater than 6 hours without 0.04 inch rain. Data will be included in TAPE application.

J < Minimum Reporting Limit, estimated value.

H The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard.

O The chromatographic fingerprint of the sample resembles an oil, but does not match the calibration standard.

Y The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.

U The analyte was analyzed for, but was not detected at or above the MRL/MDL

Z The chromatographic fingerprint does not resemble a petroleum product

L The chromatographic fingerprint of the sample resembles a petroleum product, but the elution pattern indicates the presence of a greater amount of lighter molecular weight constituents than the calibration standard

ND Non Detect

HF Non in situ analysis

Red values denote increased values across stages, or if dissolved metals are greater than total metals. In the majority of instances, the different values are from using different sampling techniques (grab vs. composite sample). Also, sampling inlet trays may contain residual material as it is not cleaned after each event. Small lab result differences also play a factor, but they are in the acceptable error range for ppb concentration analysis.

This Page Intentionally Blank

Table E-2. Total Suspended Solids Mass Balance Across System

TSS Removal (mg/L)															
Storm	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**	**Average Without Suspected Sampler Difference Errors**
Date	29-Nov	5-Dec	5-Jan	12-Jan	14-Jan	30-Jan	13-Feb	20-Feb	2-Mar	11-Mar	20-Mar	29-Apr	10-May		
Gabion	280 23.9 91%	82.6 10.7 87%	7.4 8.1 -9%	25 15.9 36%	26.5 14.4 46%	30.7 12.9 58%	15.3 15.3 0%	58 58 0%	16.8 100 -495%	4 11.2 -180%	99.6 12.1 88%	33.6 675 -1909%	16.5 74.3 -350%	**-195%**	**22%**
LID	23.9 41.7 -74%	10.7 4.8 55%	8.1 3 63%	15.9 3 81%	14.4 8.8 39%	12.9 3.2 75%	15.3 1.3 92%	58 2.9 95%	100 2.5 98%	11.2 2.6 77%	12.1 ND 92%	74.3 2.3 97%	74.3 ND 99%	**68%**	**68%**
BMP	41.7 6.4 85%	4.8 5.2 -8%	3 2.4 20%	3 2.5 17%	8.8 2.2 75%	3.2 4.2 -31%	1.3 3.5 -169%	2.9 1.2 59%	2.5 1 60%	2.6 1.2 54%	ND 2.7 -170%	2.3 2.2 4%	ND ND -	**0%**	**15%**
Total	280 6.4 98%	82.6 5.2 94%	7.4 2.4 68%	25 2.5 90%	26.5 2.2 92%	30.7 4.2 86%	15.3 3.5 77%	58 1.2 98%	16.8 1 94%	4 1.2 70%	99.6 2.7 97%	33.6 2.2 93%	16.5 ND 94%	**89%**	**89%**

Table E-3. Total Copper Mass Balance Across System

Total Copper Removal (ug/L)															
Storm	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Average**	**Average Without Suspected Sampler Difference Errors**
Date	29-Nov	5-Dec	5-Jan	12-Jan	14-Jan	30-Jan	13-Feb	20-Feb	2-Mar	11-Mar	20-Mar	29-Apr	10-May		
Gabion	308 252 18%	112 41.6 63%	39.3 47.3 -20%	84.9 33.7 60%	66.5 19.5 71%	118 22.1 81%	82.3 82.3 0%	176 176 0%	218 149 32%	67.8 34.1 50%	217 129 41%	379 1290 -240%	134 272 -103%	**4%**	**36%**
LID	252 168 33%	41.6 55 -32%	47.3 21.6 54%	33.7 24.8 26%	19.5 33.9 -74%	22.1 19.8 10%	82.3 57.8 30%	176 27.7 84%	149 40.6 73%	34.1 38.2 -12%	129 NA -	1290 111 91%	272 46.4 83%	**31%**	**31%**
BMP	168 5.79 97%	55 5.71 90%	21.6 3.2 85%	24.8 5.97 76%	33.9 4.23 88%	19.8 6.32 68%	57.8 5.02 91%	27.7 1.49 95%	40.6 5.29 87%	38.2 4.05 89%	NA 6.01 -	111 5.64 95%	46.4 4.61 90%	**88%**	**88%**
Total	308 5.79 98%	112 5.71 95%	39.3 3.2 92%	84.9 5.97 93%	66.5 4.23 94%	118 6.32 95%	82.3 5.02 94%	176 1.49 99%	218 5.29 98%	67.8 4.05 94%	217 6.01 97%	379 5.64 99%	134 4.61 97%	**96%**	**96%**

Table E-4. Total Zinc Mass Balance Across System

Total Zinc Removal (ug/L)															
Storm	1	2	3	4	5	6	7	8	9	10	11	12	13	Average	Average Without Suspected Sampler Difference Errors
Date	29-Nov	5-Dec	5-Jan	12-Jan	14-Jan	30-Jan	13-Feb	20-Feb	2-Mar	11-Mar	20-Mar	29-Apr	10-May		
Gabion	769 919 -20%	320 123 62%	156 125 20%	246 80.2 67%	204 47.9 77%	473 57.9 88%	241 204 15%	702 702 0%	424 256 40%	240 48.4 80%	379 418 -10%	599 1520 -154%	217 267 -23%	19%	33%
LID	919 213 77%	123 52.7 57%	125 37.8 70%	80.2 30 63%	47.9 31.6 34%	57.9 46.2 20%	241 62.3 74%	702 118 83%	256 100.3 61%	48.4 76.7 -58%	418 NA -	1520 201 87%	267 53.9 80%	54%	54%
BMP	213 8.5 96%	52.7 10 81%	37.8 4.5 88%	30 5.3 82%	31.6 13.2 58%	46.2 7.1 85%	62.3 6.2 90%	118 2.5 98%	100.3 3.2 97%	76.7 4.3 94%	NA 4.2 -	201 7.5 96%	53.9 6.1 89%	88%	88%
Total	769 8.5 99%	320 10 97%	156 4.5 97%	246 5.3 98%	204 13.2 94%	473 7.1 98%	241 6.2 97%	702 2.5 100%	424 3.2 99%	240 4.3 98%	379 4.2 99%	599 7.5 99%	217 6.1 97%	98%	98%

This Page Intentionally Blank

Appendix F: Diffusive Gradient in Thin Film (DGT)

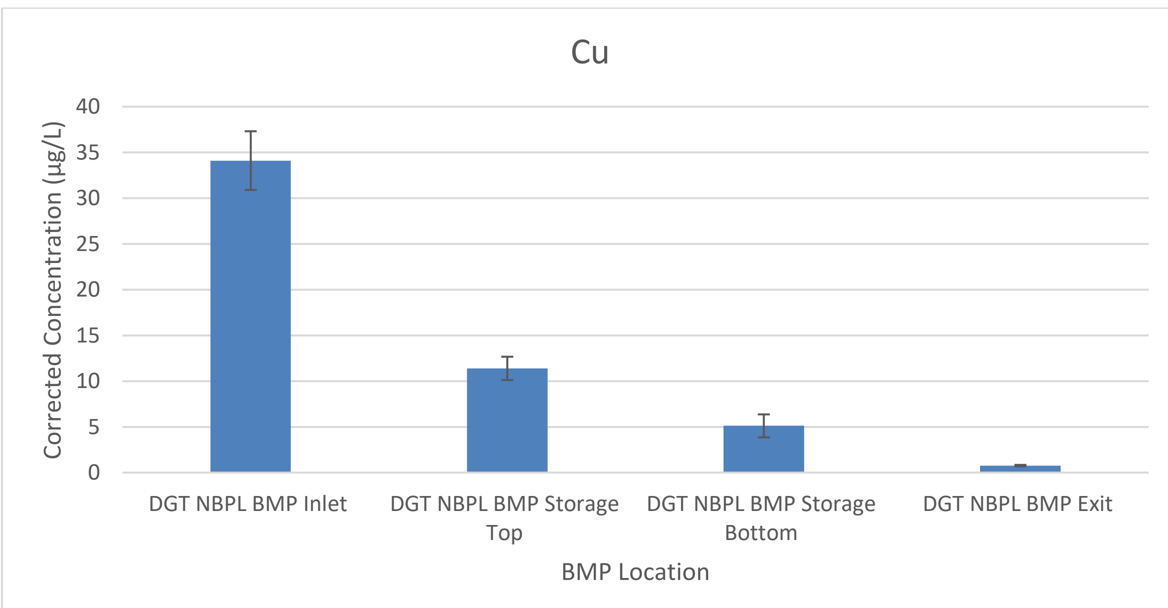
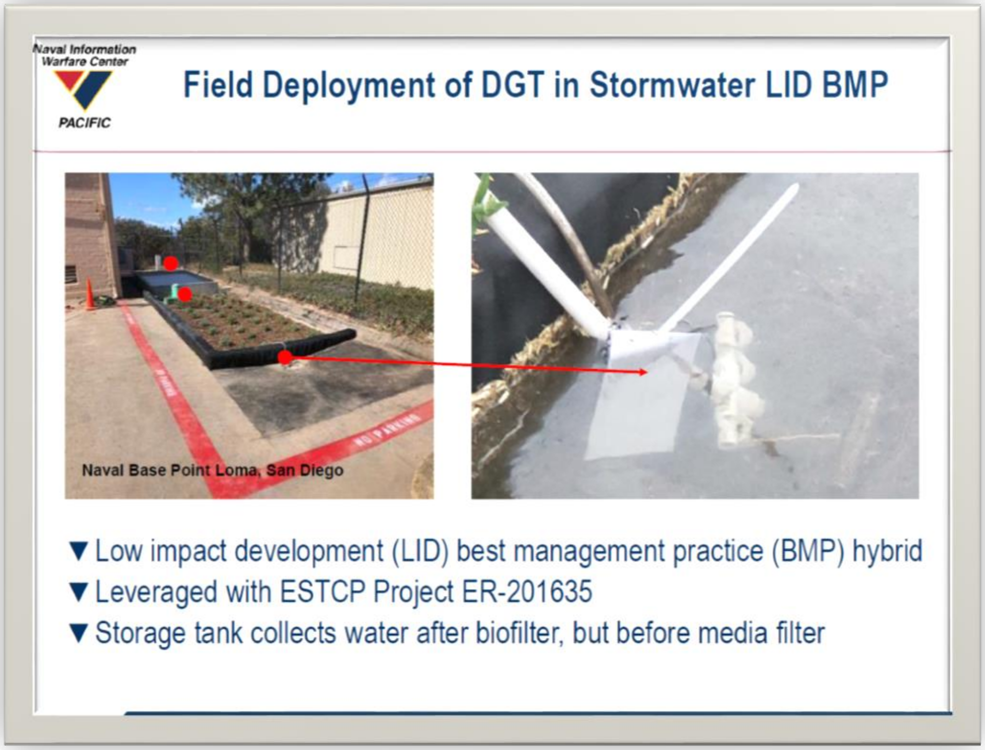
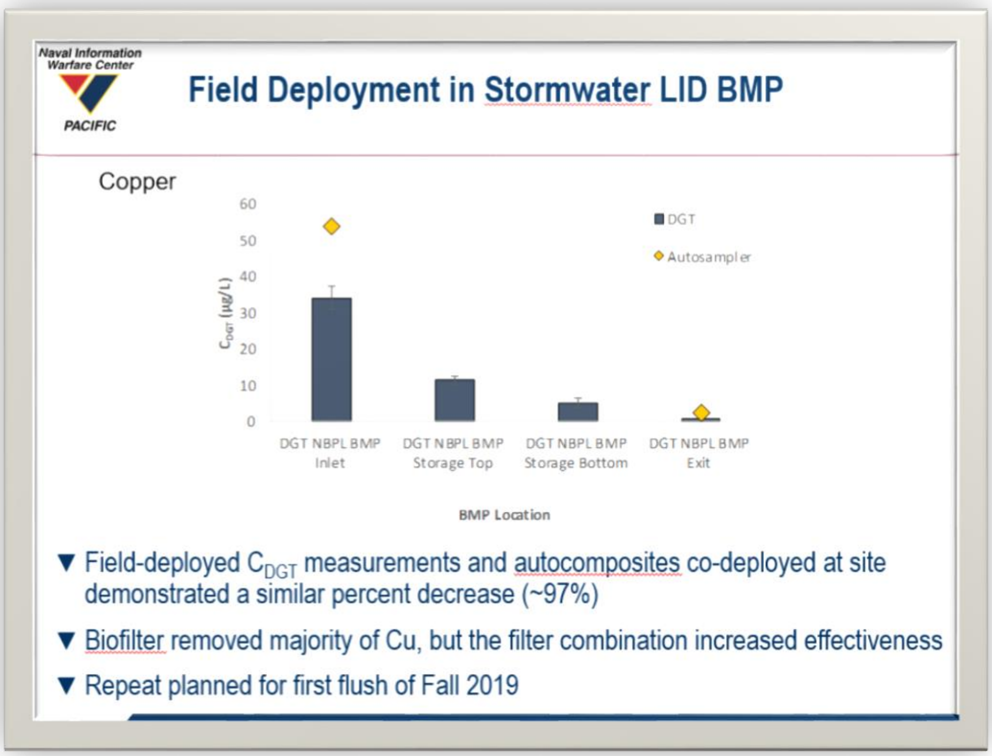


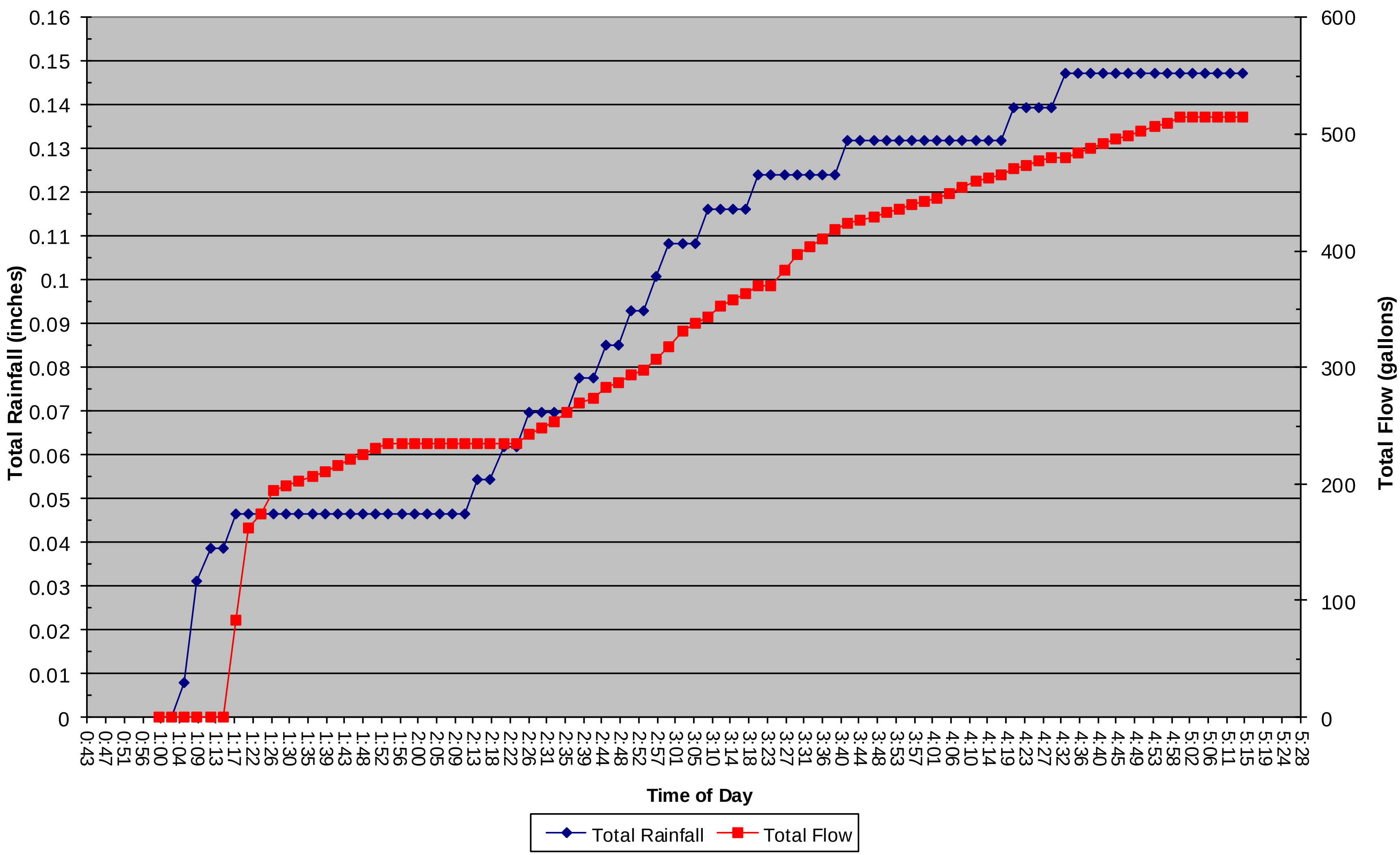
Figure F-1. SPAWAR Pacific DGT Sampling Results


Naval Information Warfare Center PACIFIC
Field Deployment of DGT in Stormwater LID BMP
Naval Base Point Loma, San Diego
▼ Low impact development (LID) best management practice (BMP) hybrid
▼ Leveraged with ESTCP Project ER-201635
▼ Storage tank collects water after biofilter, but before media filter

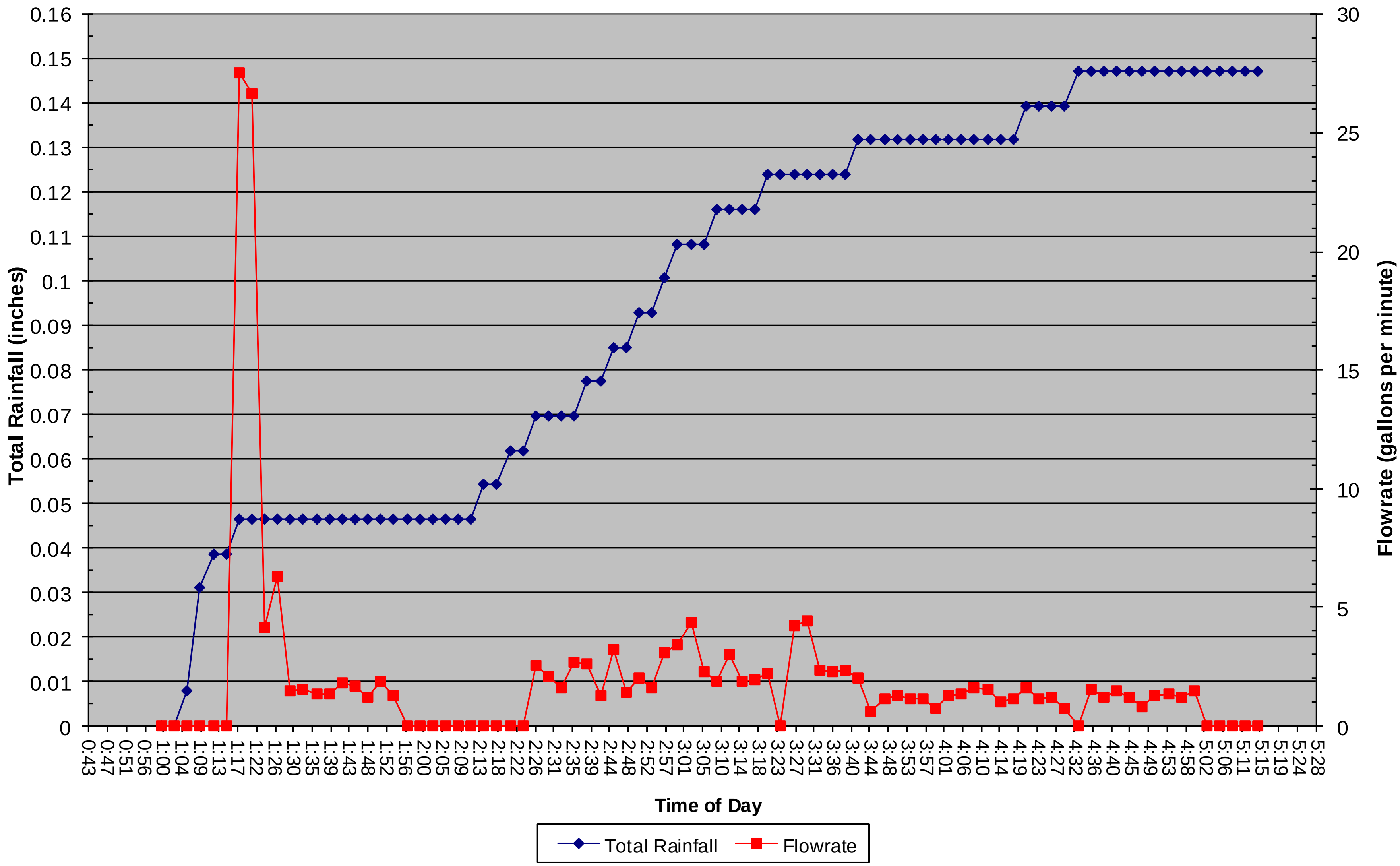

Naval Information Warfare Center PACIFIC
Field Deployment in Stormwater LID BMP
Copper
60
50
40
30
20
10
0
C_DGT (µg/L)
DGT
Autosampler
DGT NBPL BMP Inlet
DGT NBPL BMP Storage Top
DGT NBPL BMP Storage Bottom
DGT NBPL BMP Exit
BMP Location
▼ Field-deployed C_{DGT} measurements and autocomposites co-deployed at site demonstrated a similar percent decrease (~97%)
▼ Biofilter removed majority of Cu, but the filter combination increased effectiveness
▼ Repeat planned for first flush of Fall 2019

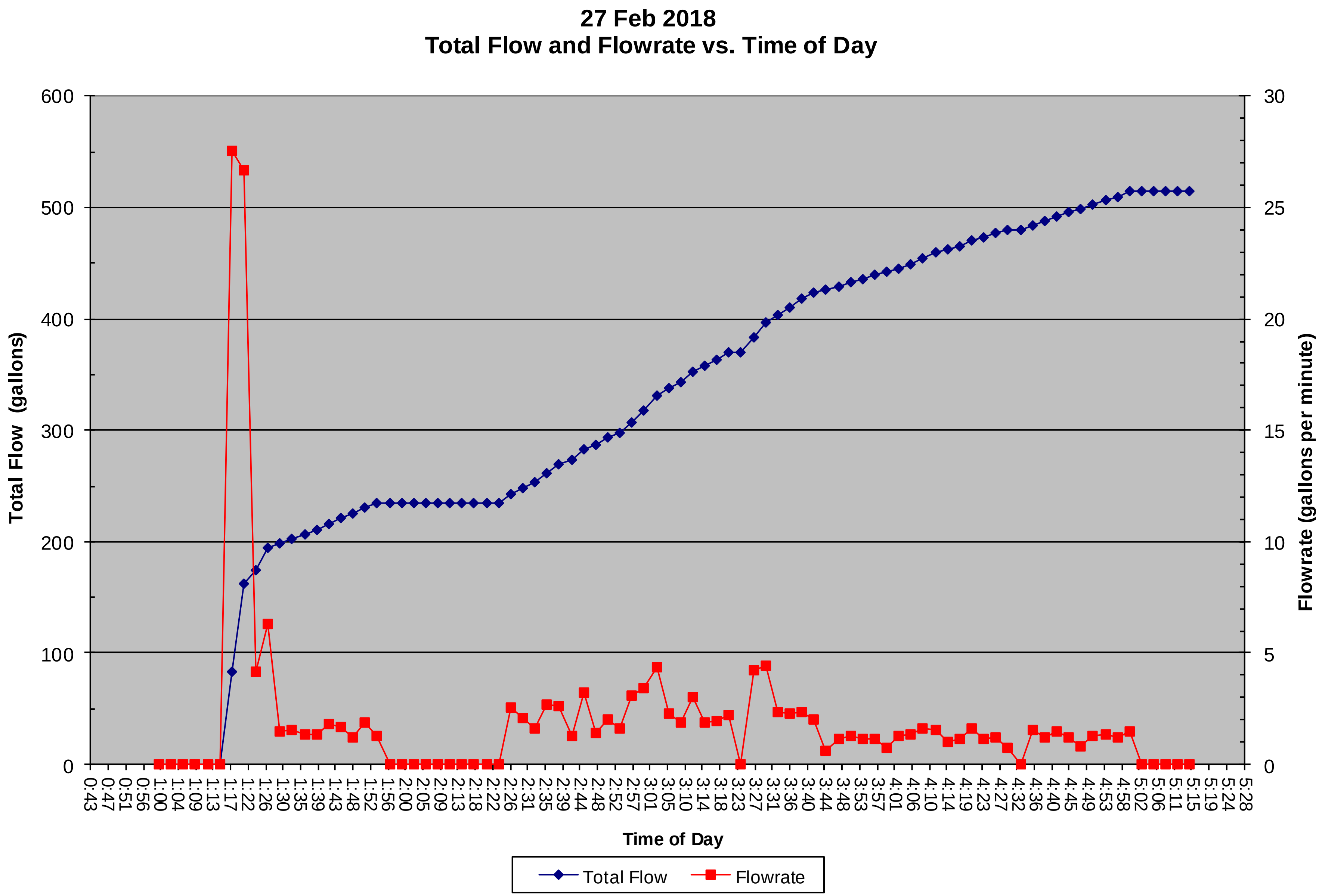
APPENDIX G: Storm Event Flow Graphs

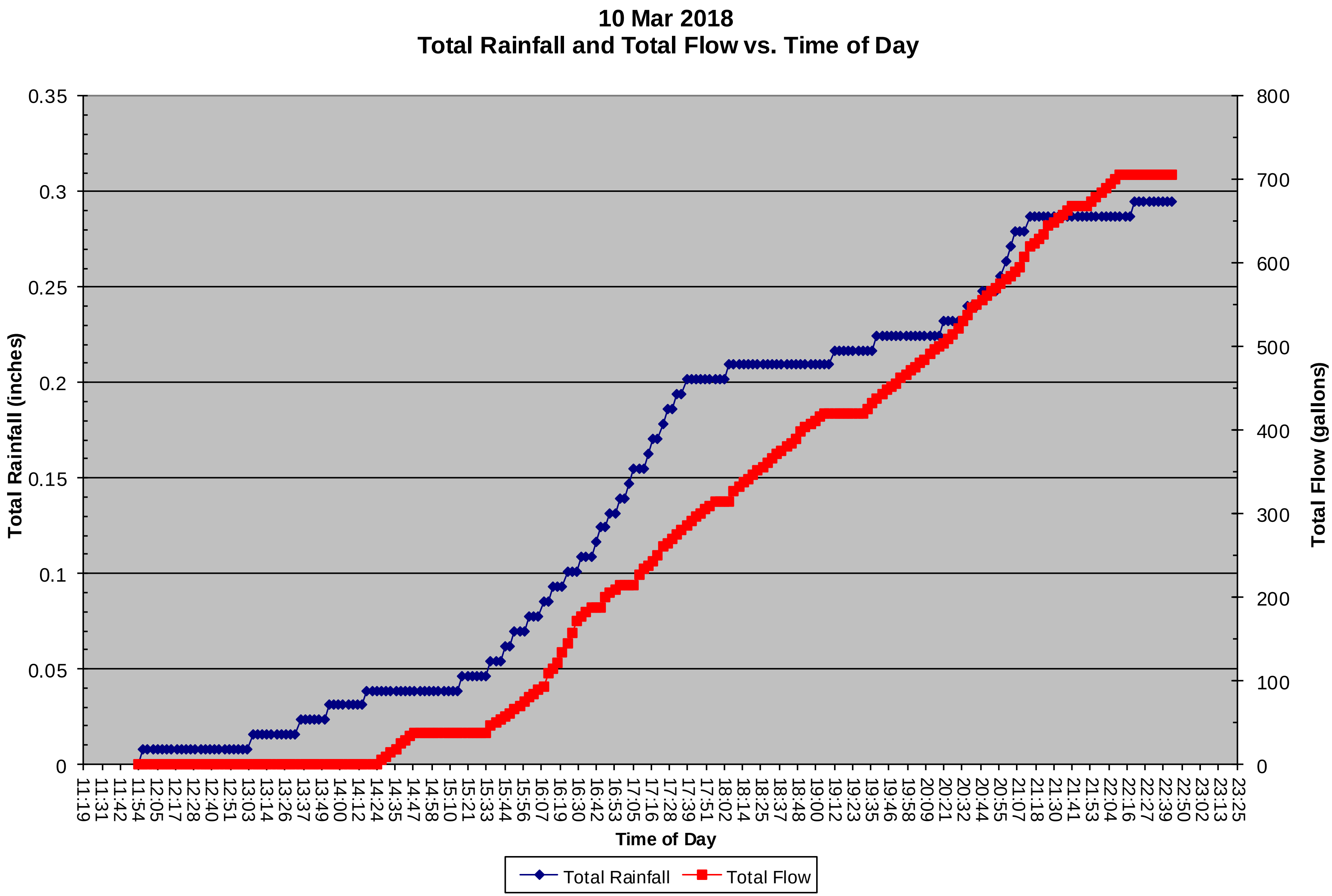
27 Feb 2018
Total Rainfall and Total Flow vs. Time of Day



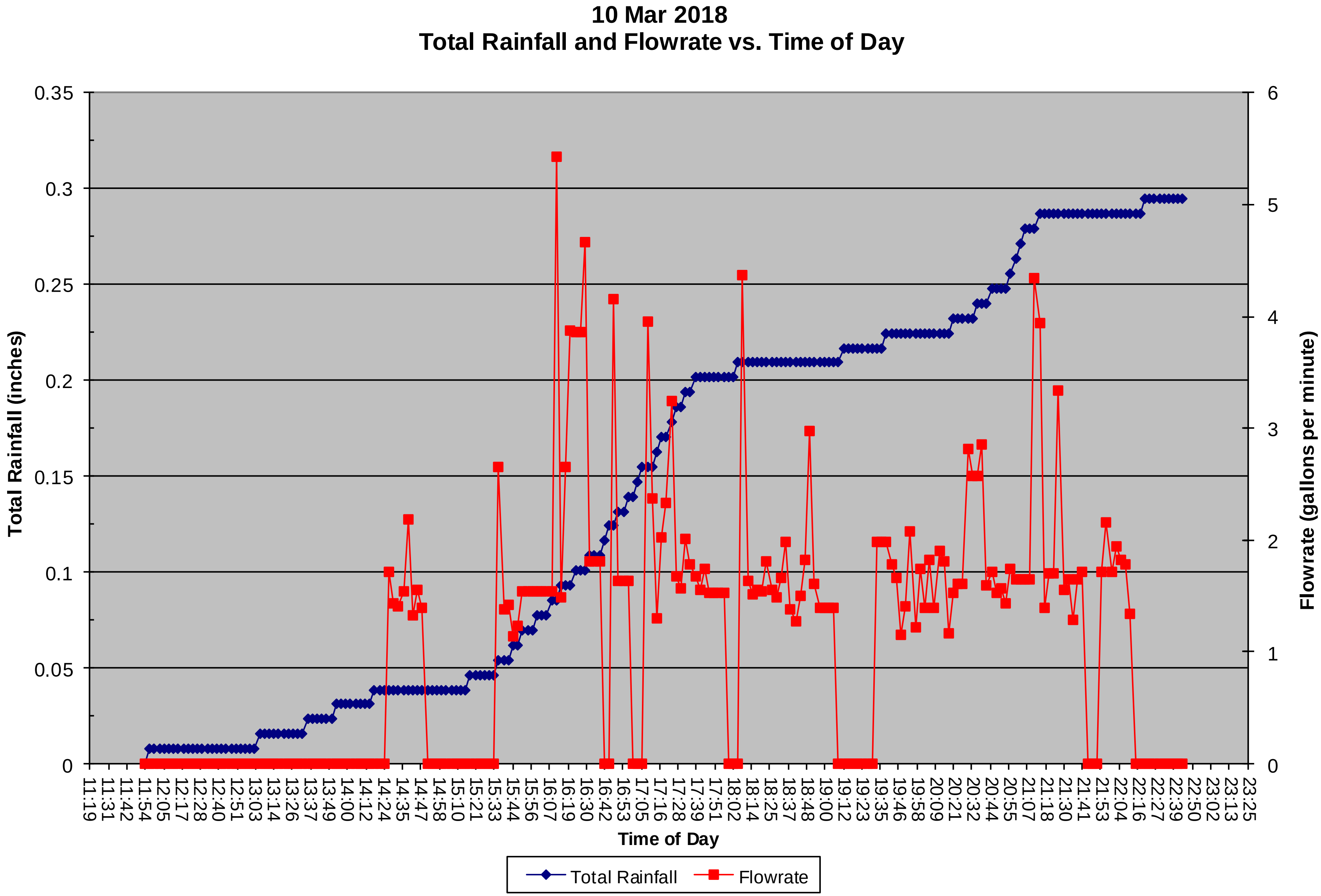
27 Feb 2018
Total Rainfall and Flowrate vs. Time of Day



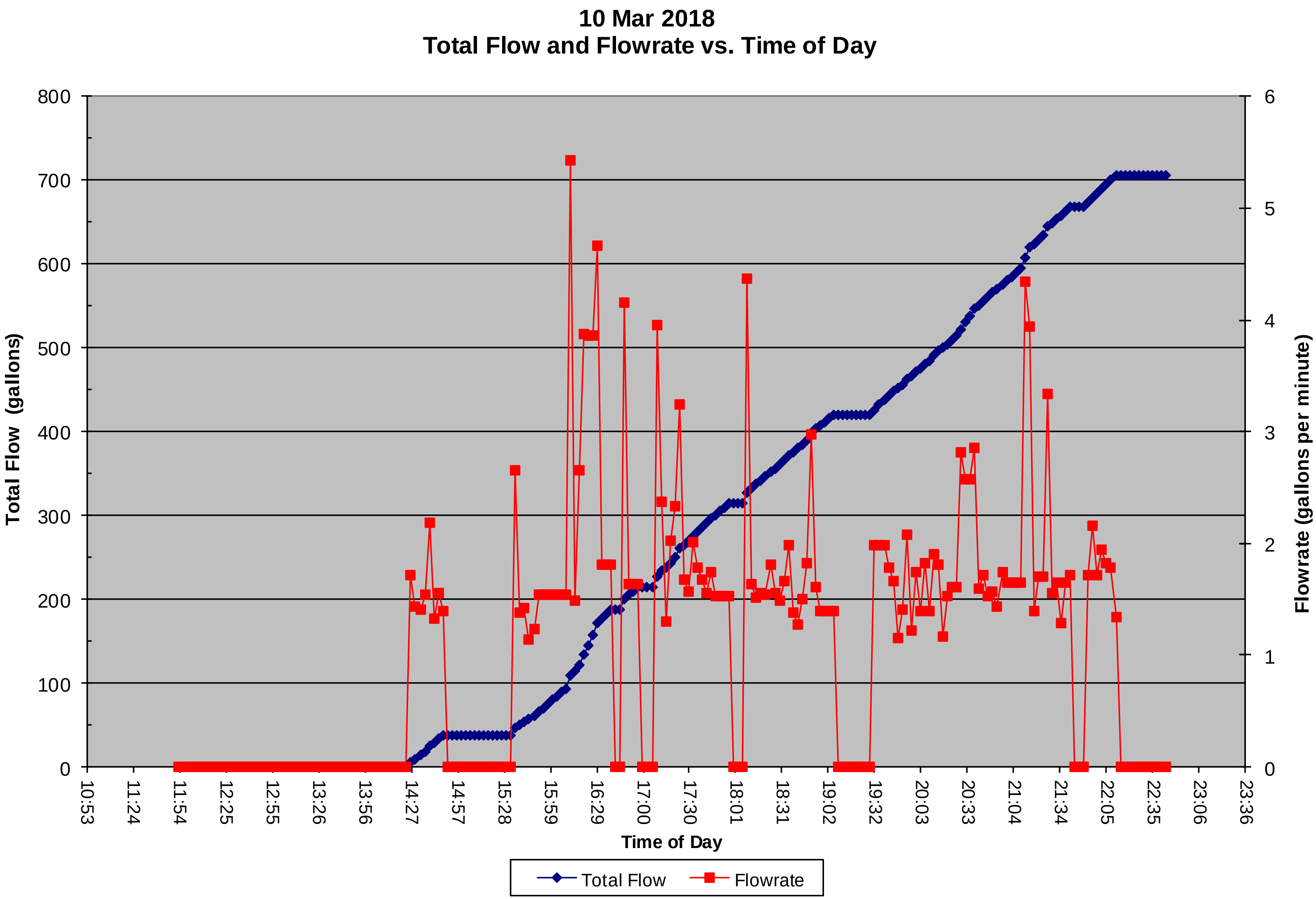

27 Feb 2018
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate
600
500
400
300
200
100
0
30
25
20
15
10
5
0

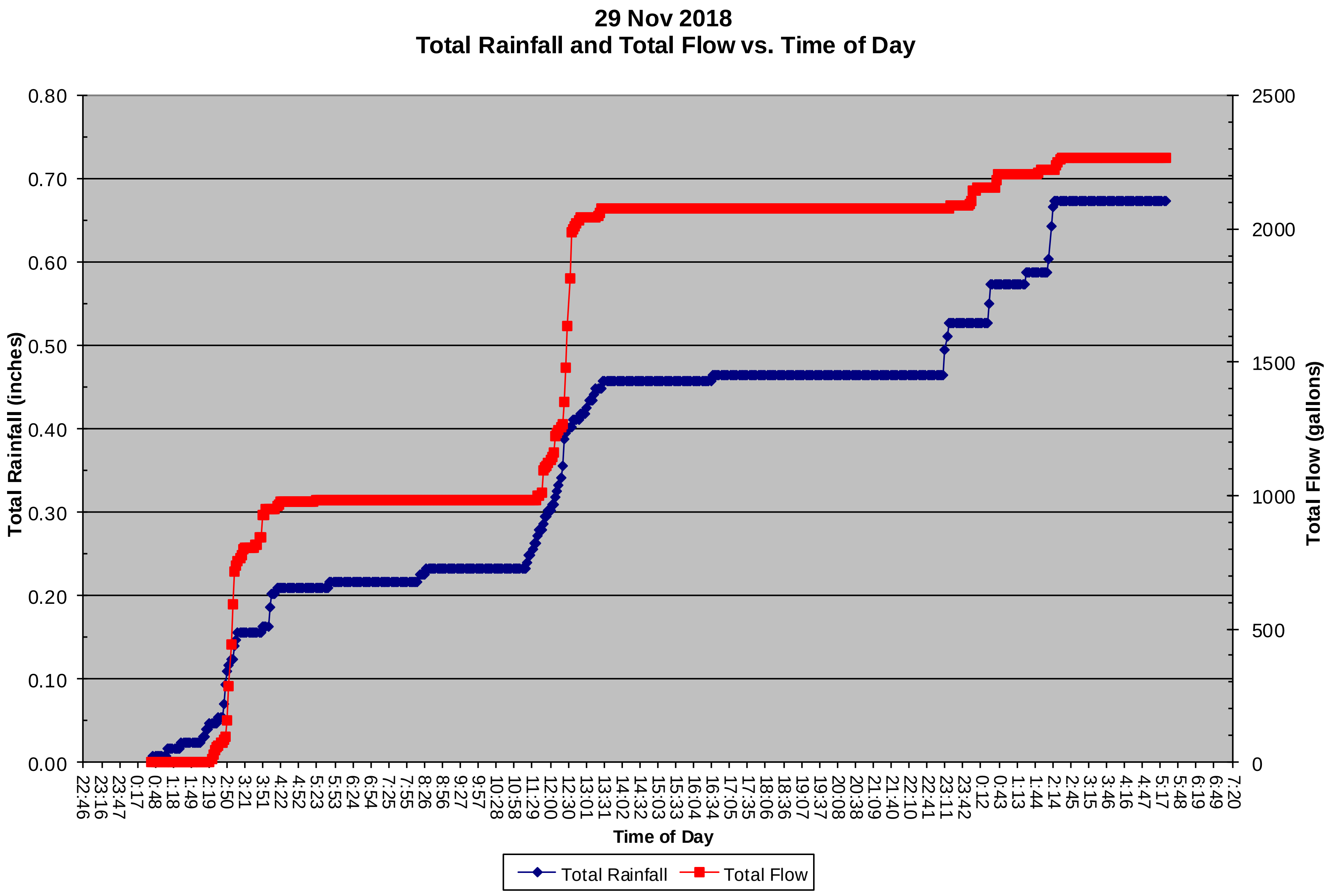


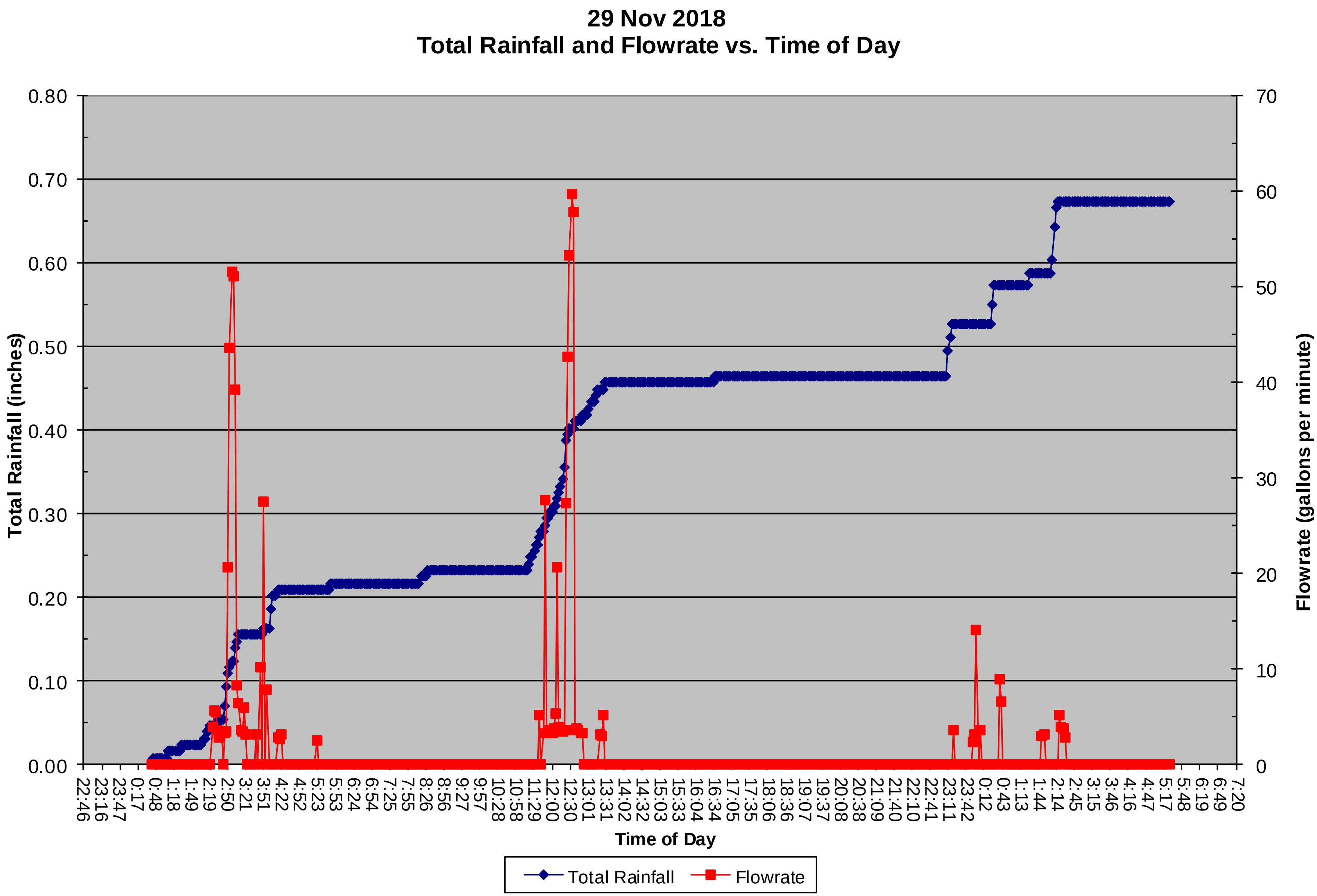
10 Mar 2018
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
800
700
600
500
400
300
200
100
0
Total Rainfall
Total Flow

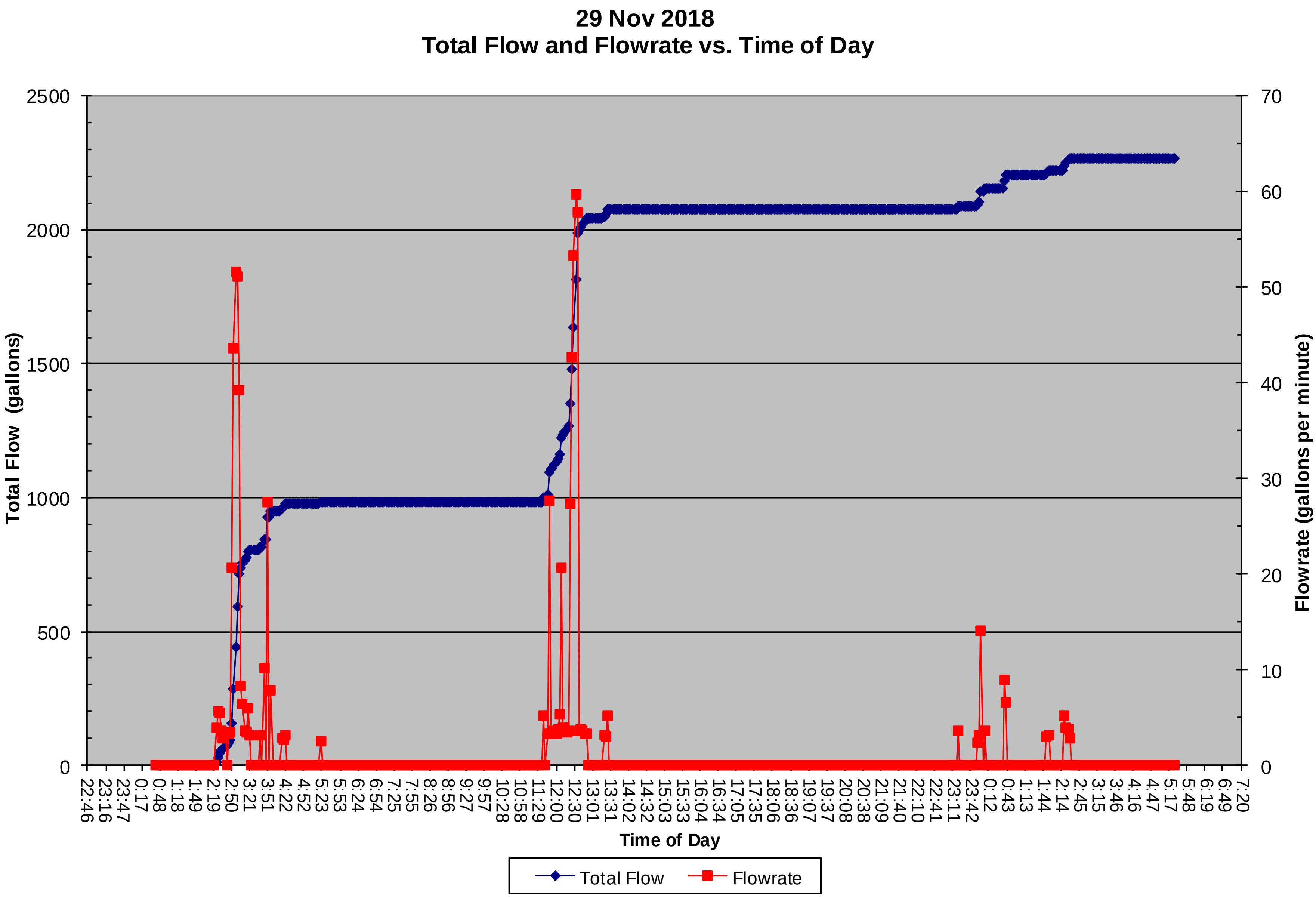


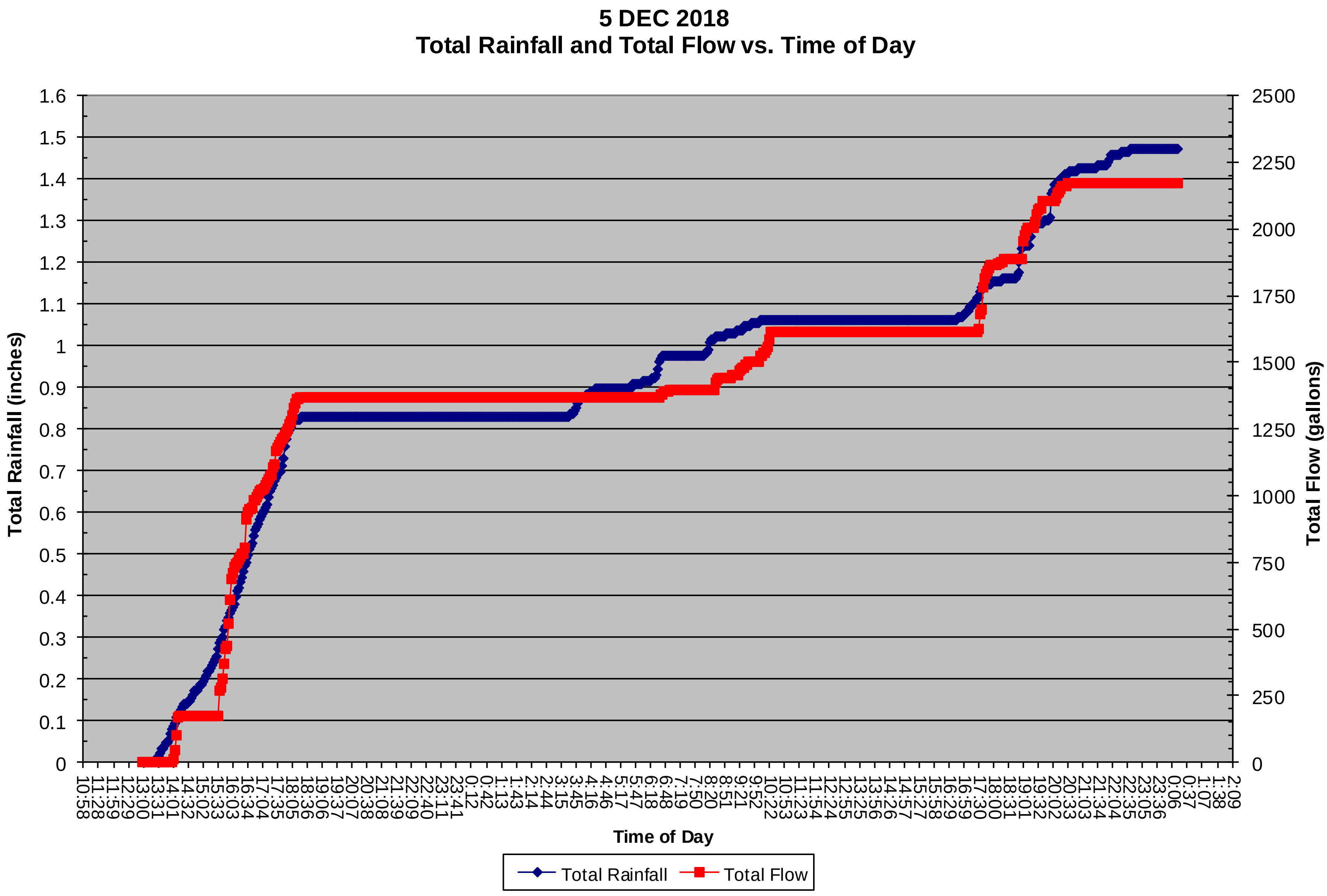
10 Mar 2018
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate


10 Mar 2018
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
0
100
200
300
400
500
600
700
800
0
1
2
3
4
5
6
10:53
11:24
11:54
12:25
12:55
13:26
13:56
14:27
14:57
15:28
15:59
16:29
17:00
17:30
18:01
18:31
19:02
19:32
20:03
20:33
21:04
21:34
22:05
22:35
23:06
23:36
Total Flow
Flowrate

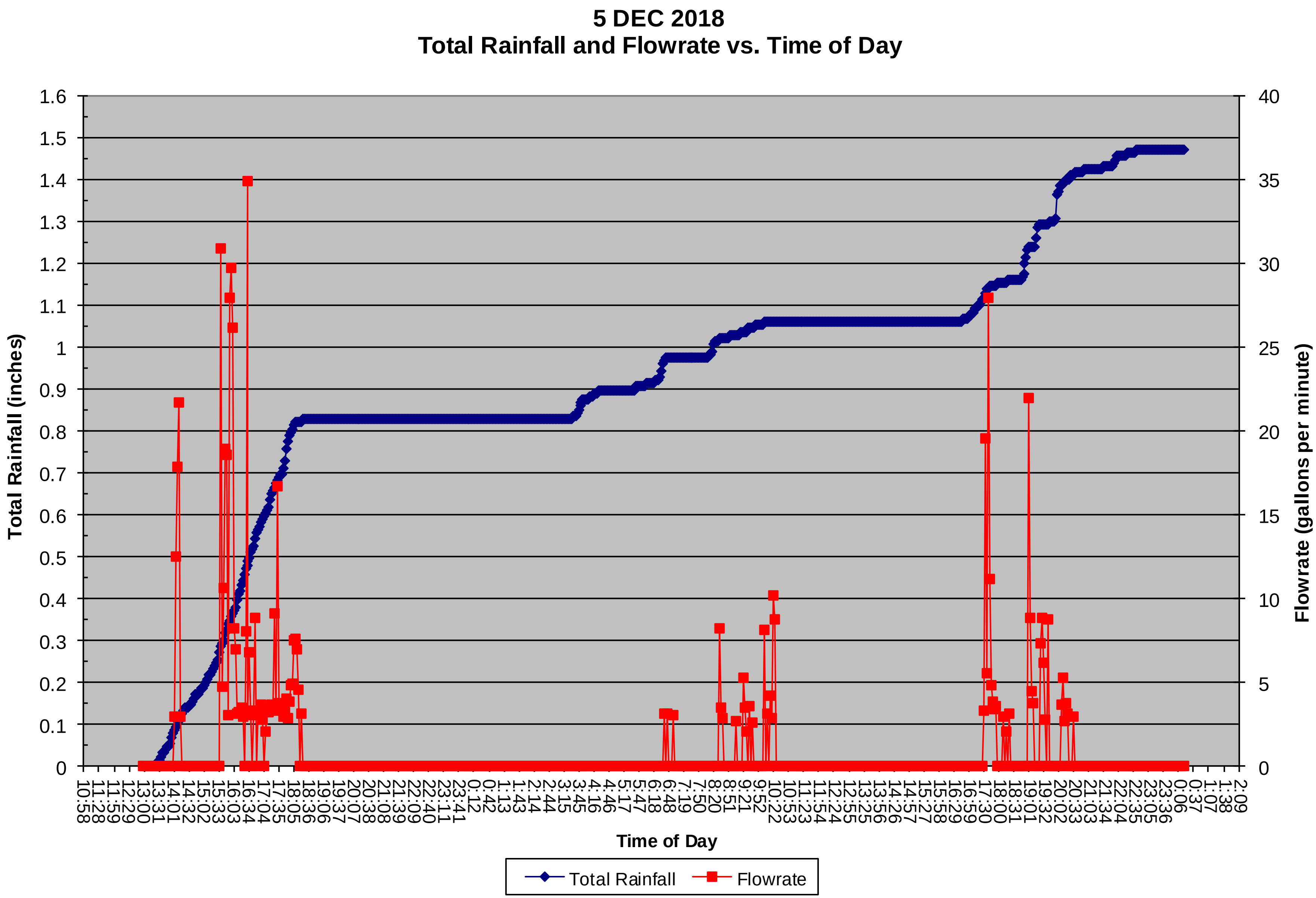

29 Nov 2018
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow


29 Nov 2018
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

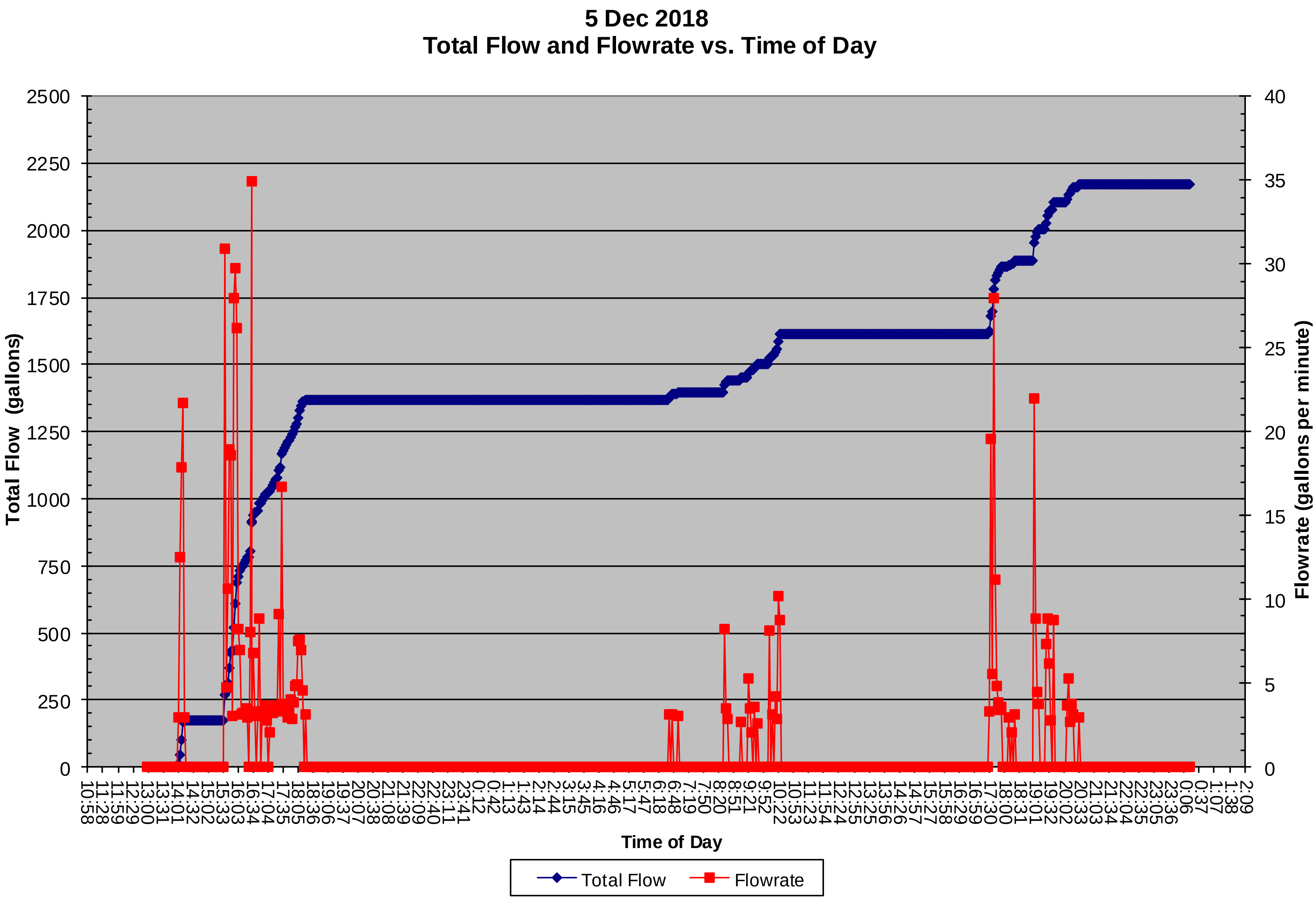

29 Nov 2018
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
70
22:46
23:16
23:47
0:17
0:48
1:18
1:49
2:19
2:50
3:21
3:51
4:22
4:52
5:23
5:53
6:24
6:54
7:25
7:55
8:26
8:56
9:27
9:57
10:28
10:58
11:29
12:00
12:30
13:01
13:31
14:02
14:32
15:03
15:33
16:04
16:34
17:05
17:35
18:06
18:36
19:07
19:37
20:08
20:38
21:09
21:40
22:10
22:41
23:11
23:42
0:12
0:43
1:13
1:44
2:14
2:45
3:15
3:46
4:16
4:47
5:17
5:48
6:19
6:49
7:20
Total Flow
Flowrate

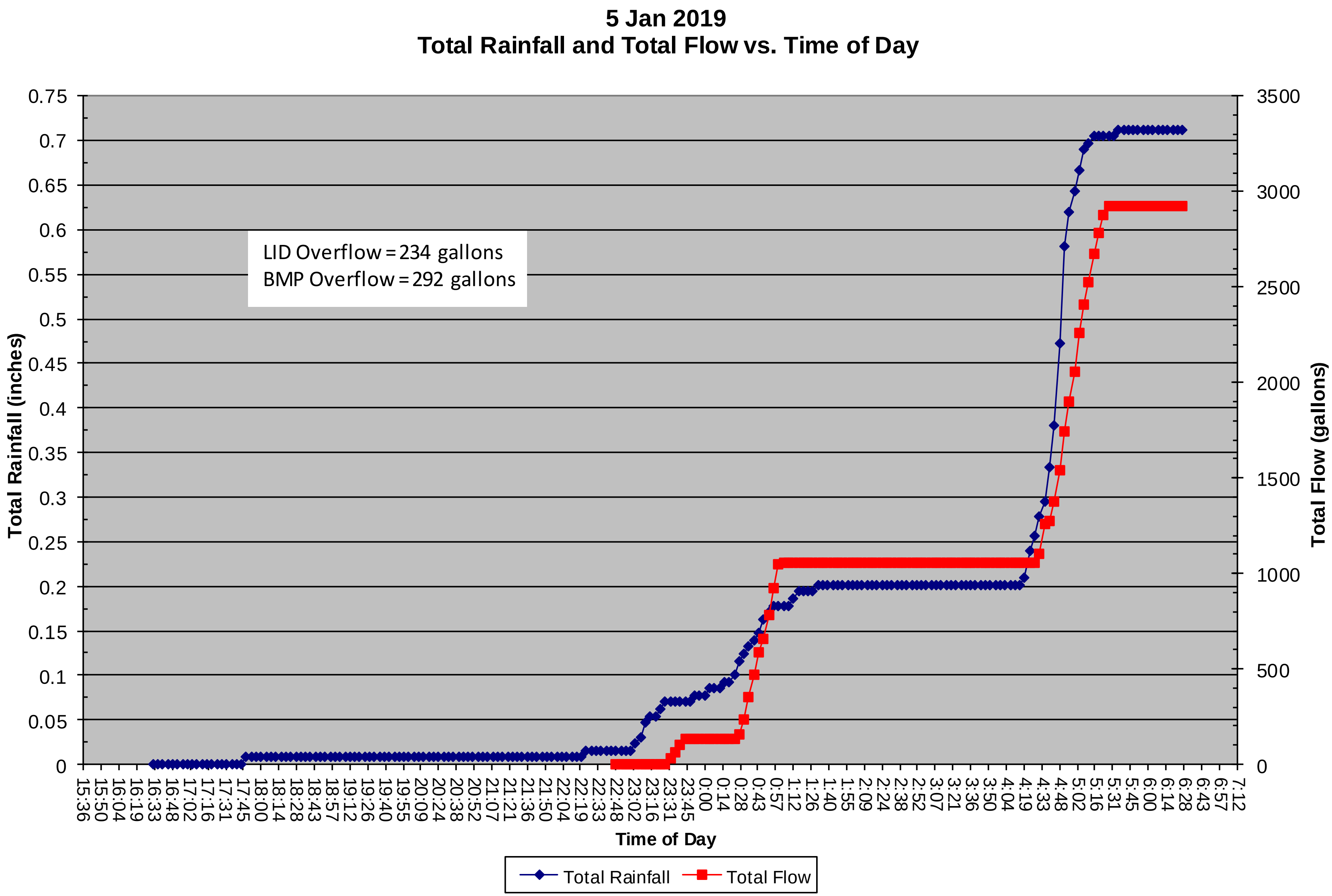


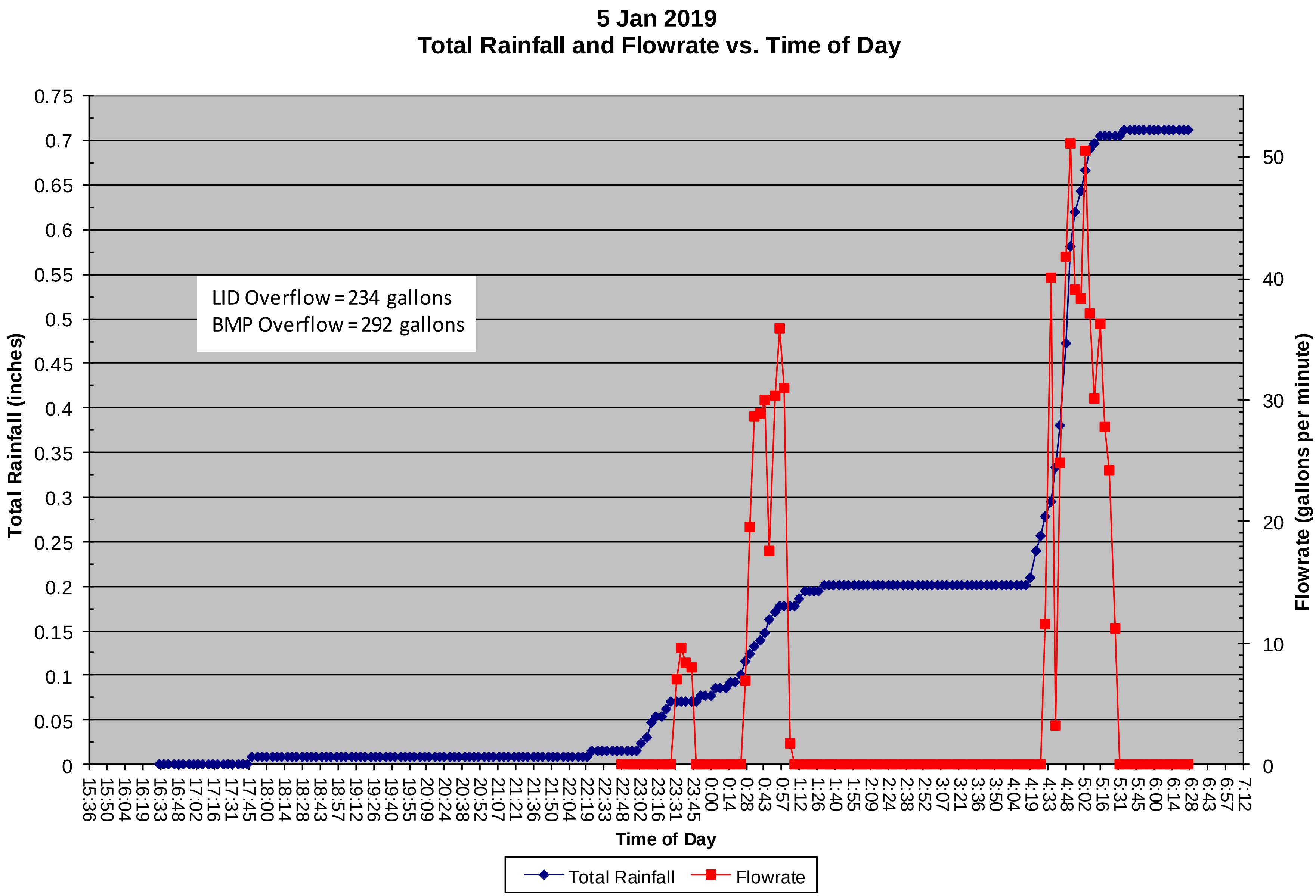
5 DEC 2018
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

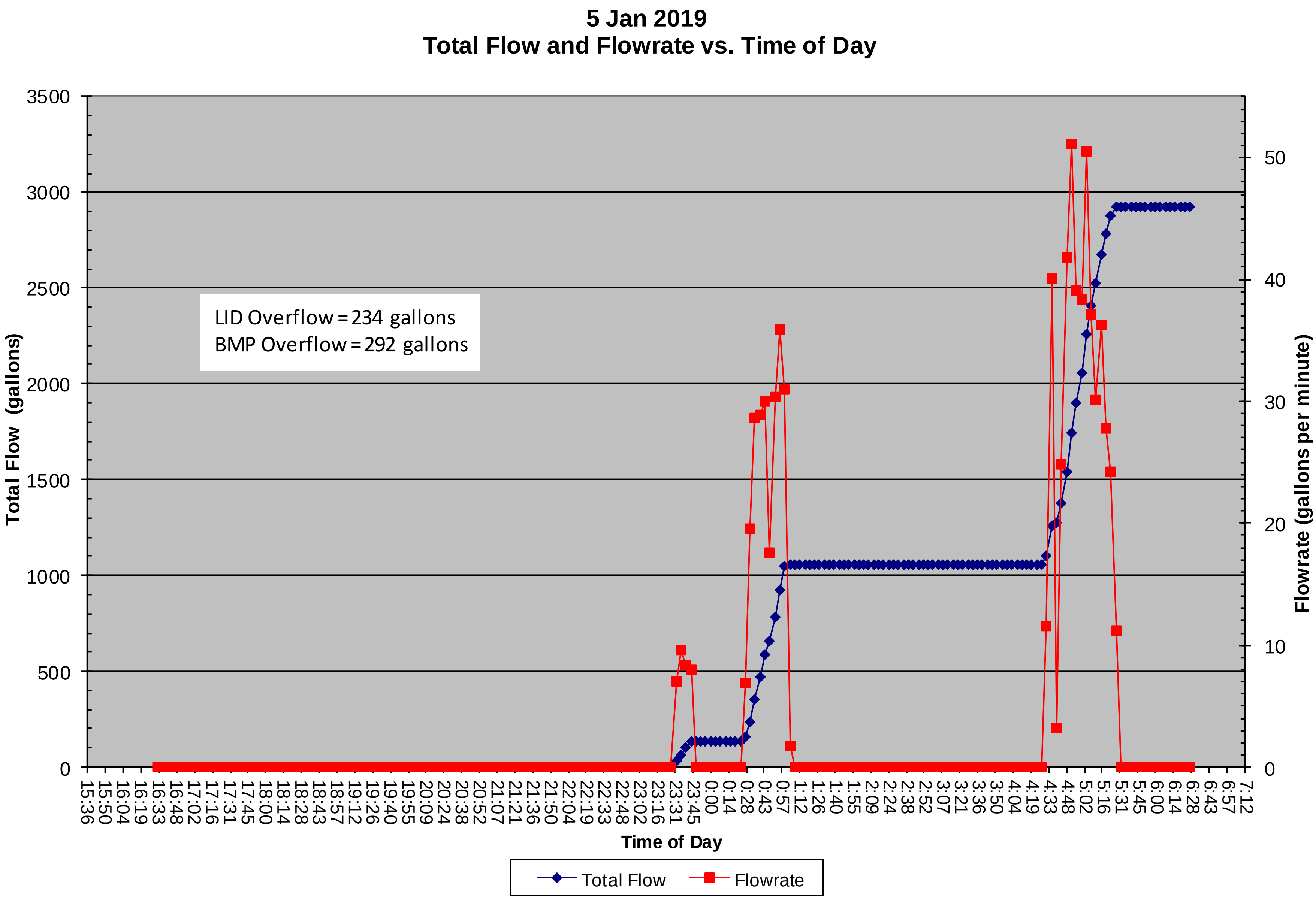


5 DEC 2018
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

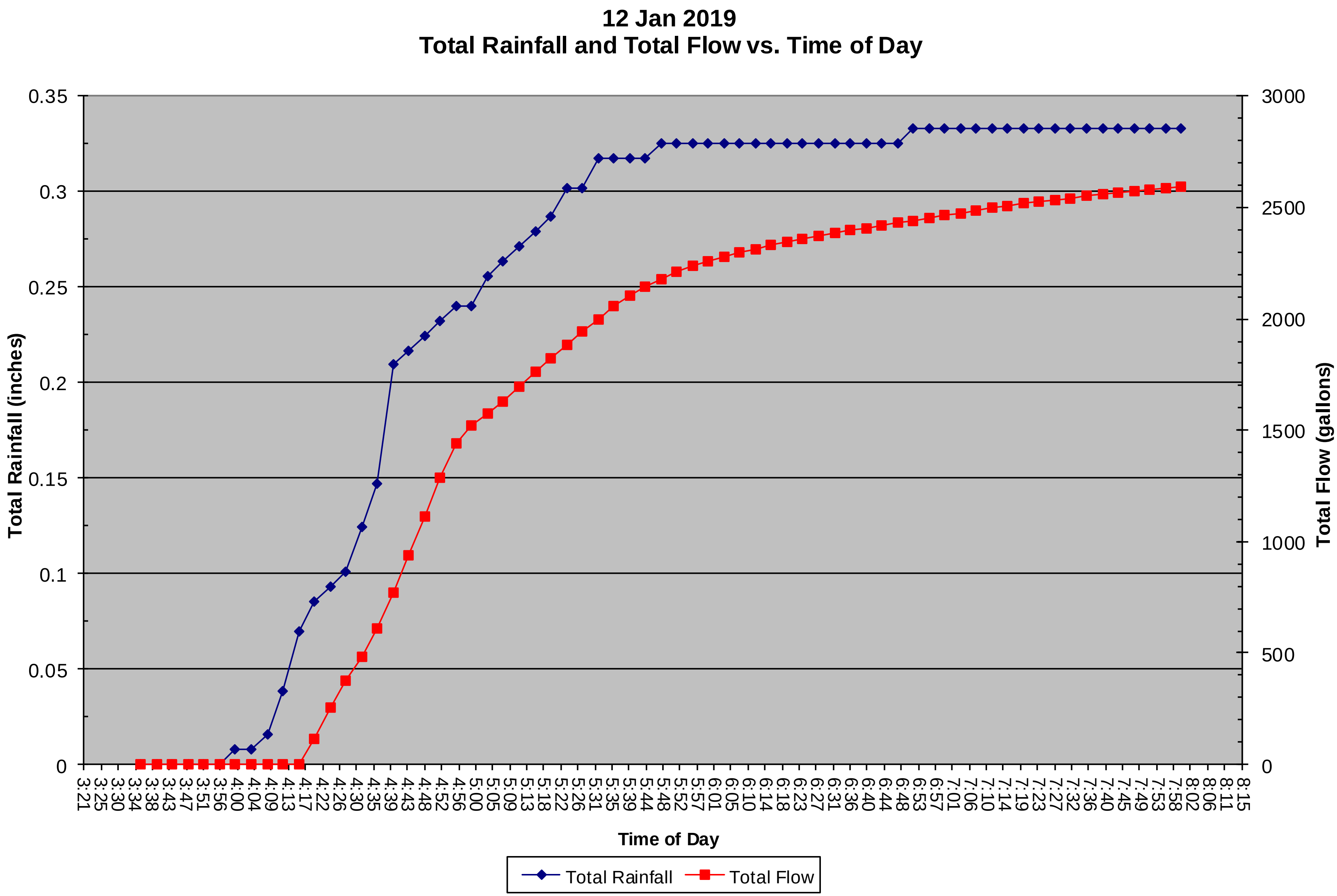

5 Dec 2018
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

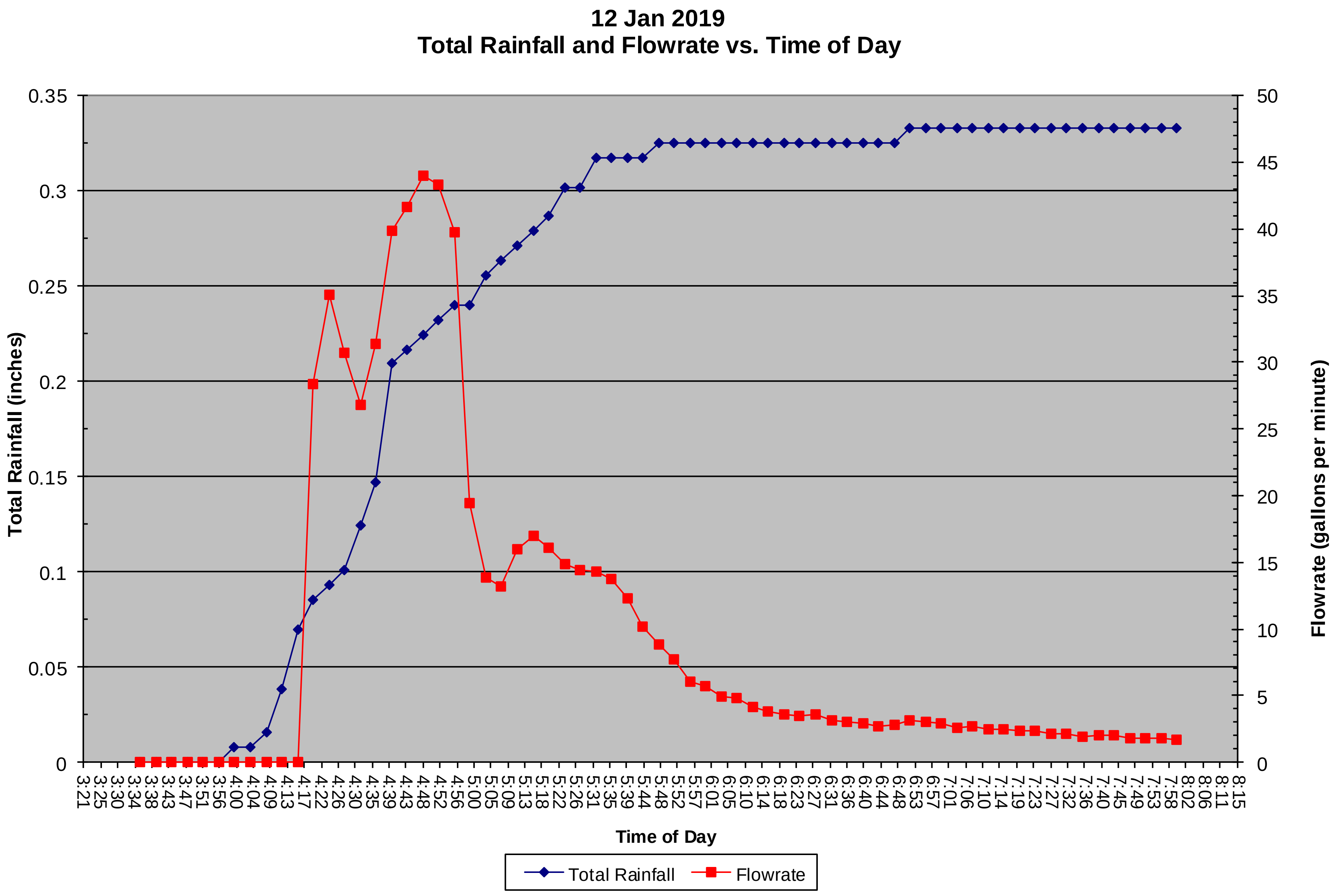

5 Jan 2019
Total Rainfall and Total Flow vs. Time of Day
LID Overflow = 234 gallons
BMP Overflow = 292 gallons
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

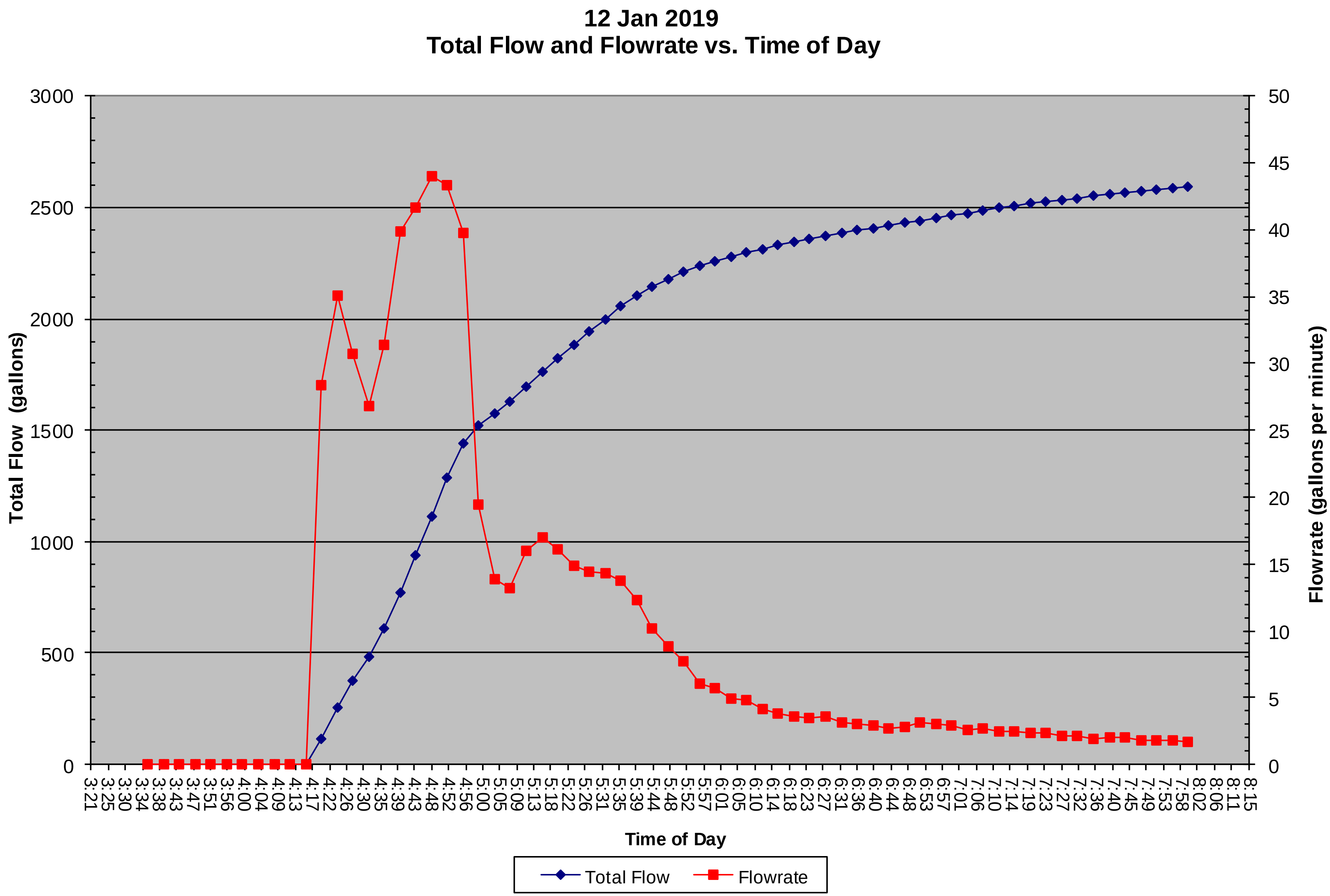

5 Jan 2019
Total Rainfall and Flowrate vs. Time of Day
LID Overflow = 234 gallons
BMP Overflow = 292 gallons
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

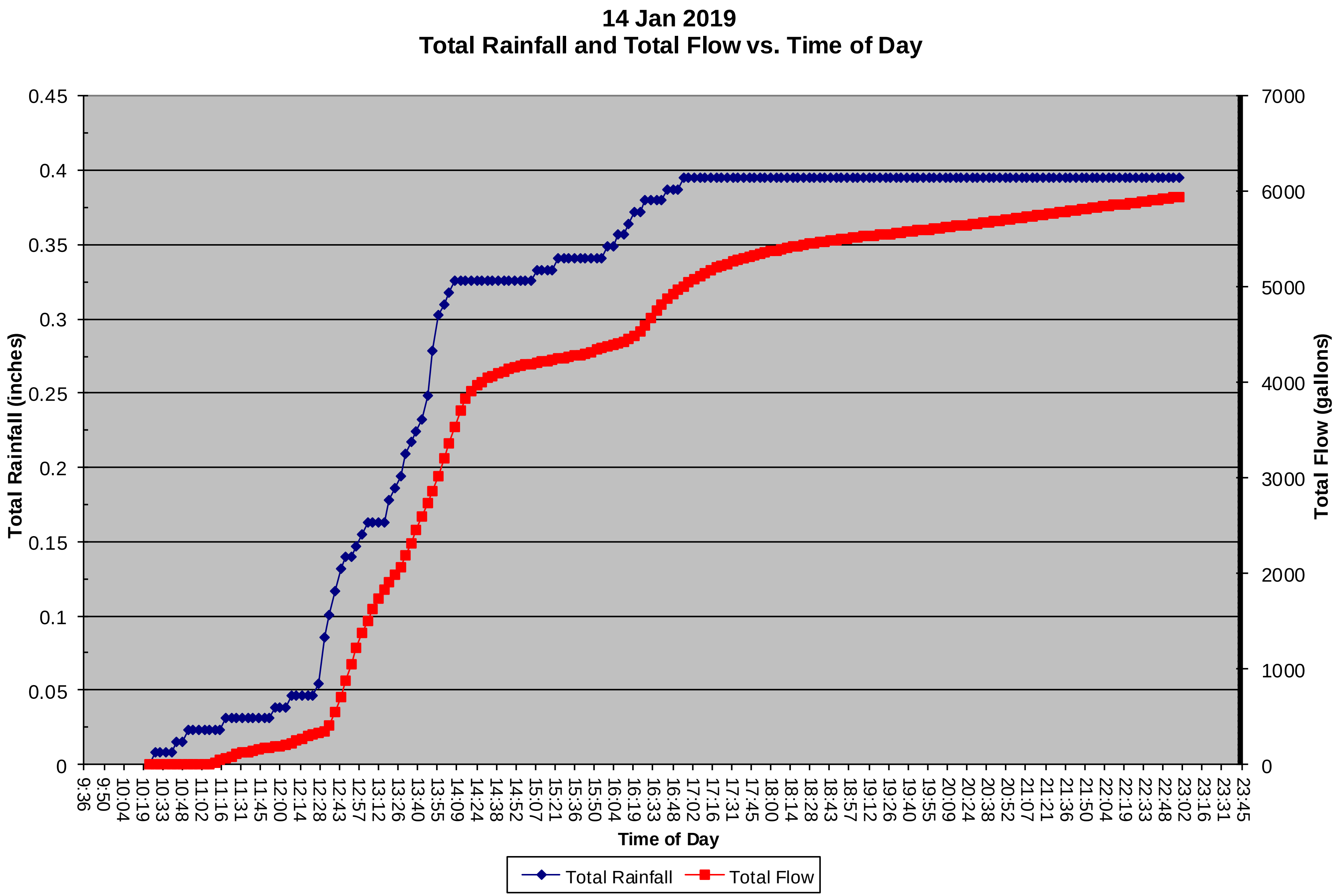


5 Jan 2019
Total Flow and Flowrate vs. Time of Day
LID Overflow = 234 gallons
BMP Overflow = 292 gallons
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

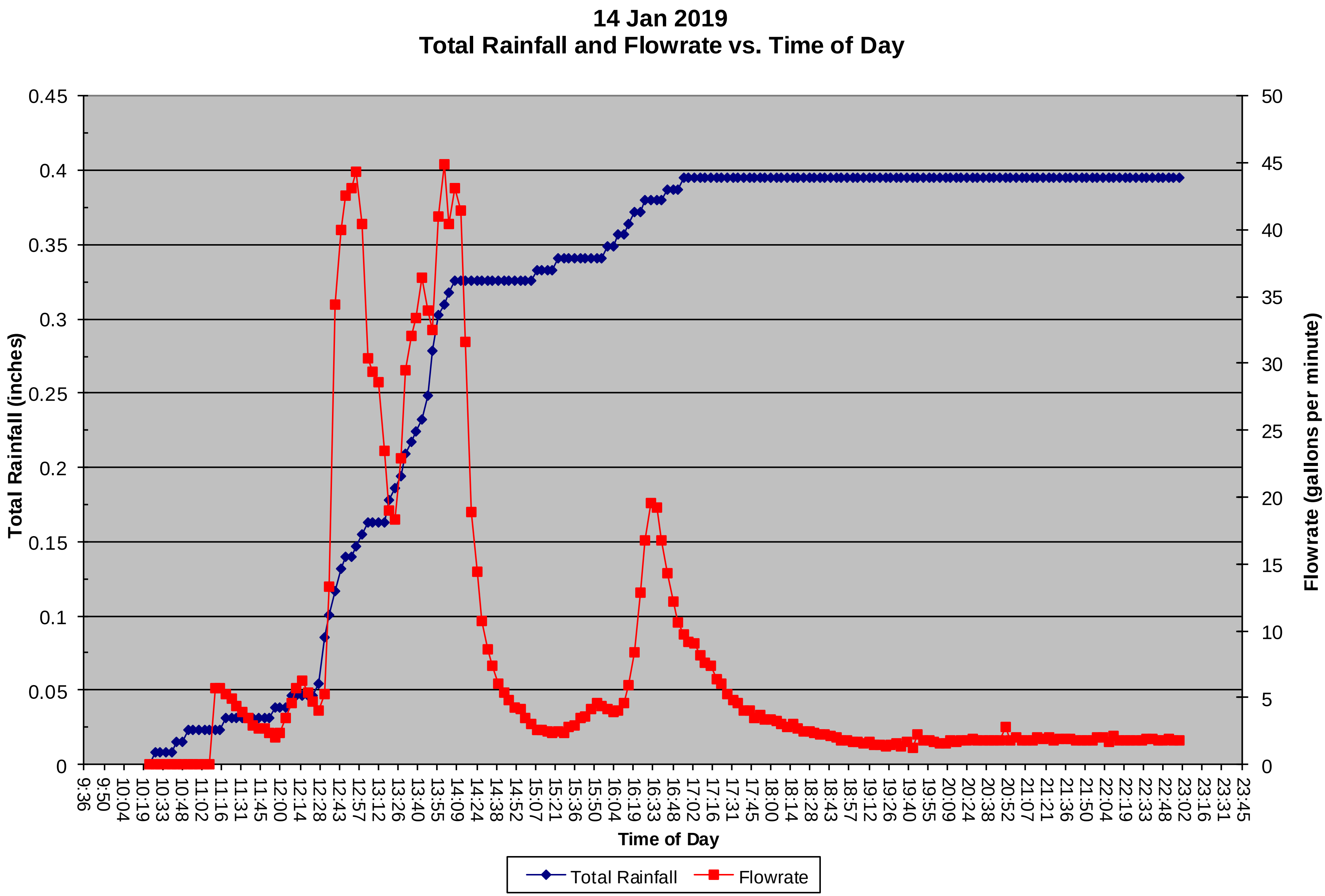

12 Jan 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow


12 Jan 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

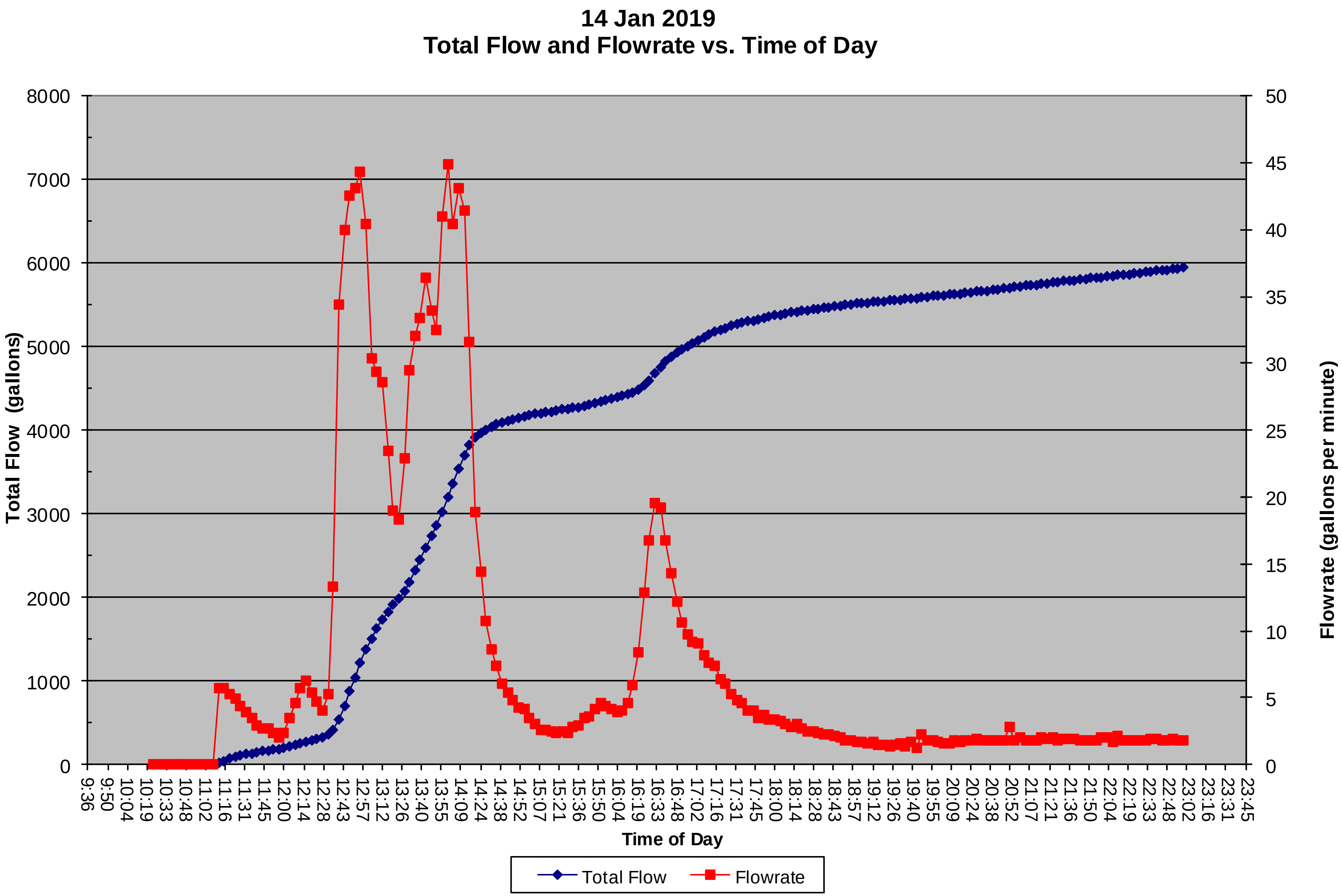

12 Jan 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate
0
500
1000
1500
2000
2500
3000
0
5
10
15
20
25
30
35
40
45
50
3:21
3:25
3:30
3:34
3:38
3:43
3:47
3:51
3:56
4:00
4:04
4:09
4:13
4:17
4:22
4:26
4:30
4:35
4:39
4:43
4:48
4:52
4:56
5:00
5:05
5:09
5:13
5:18
5:22
5:26
5:31
5:35
5:39
5:44
5:48
5:52
5:57
6:01
6:05
6:10
6:14
6:18
6:23
6:27
6:31
6:36
6:40
6:44
6:48
6:53
6:57
7:01
7:06
7:10
7:14
7:19
7:23
7:27
7:32
7:36
7:40
7:45
7:49
7:53
7:58
8:02
8:06
8:11
8:15



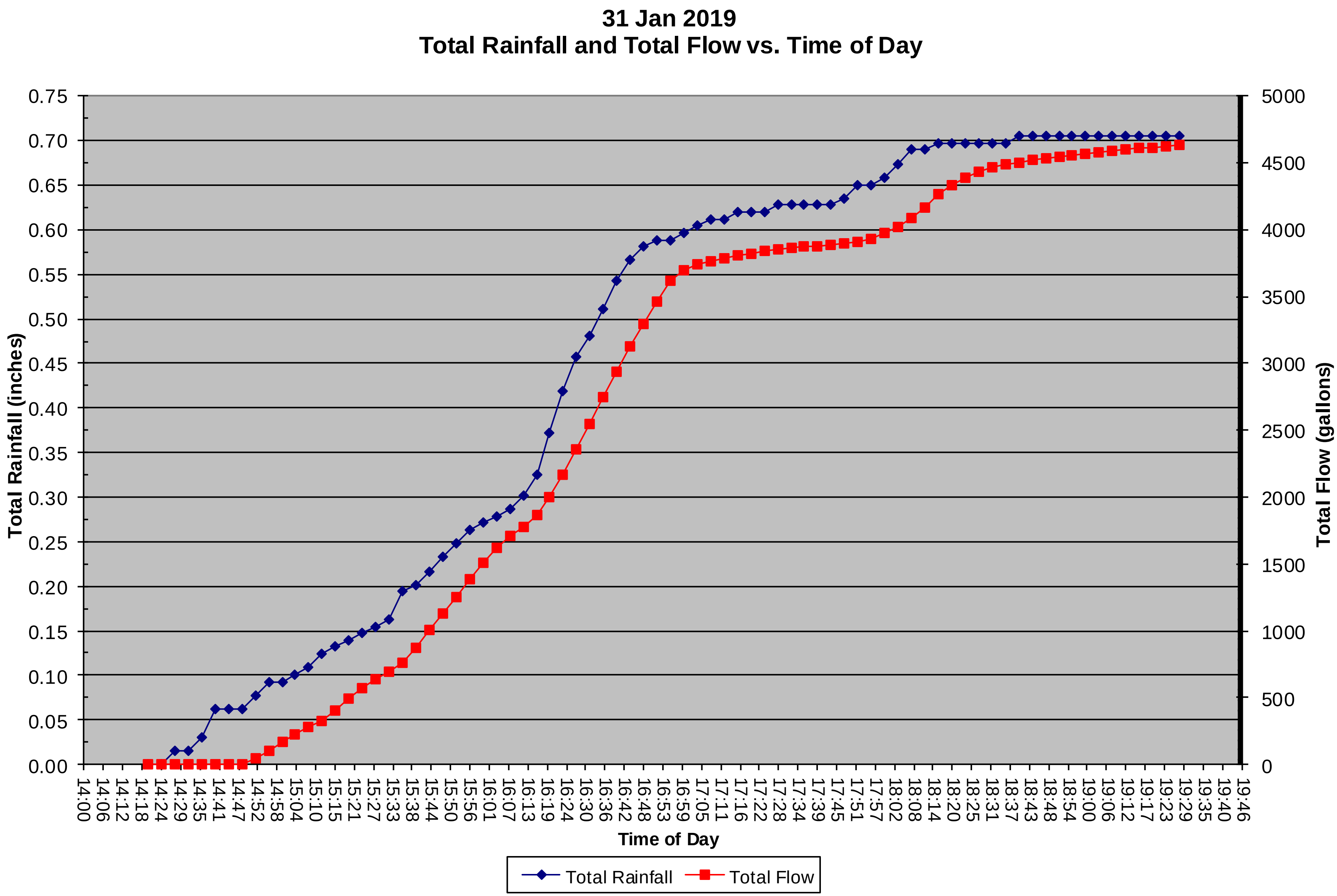
14 Jan 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7000
6000
5000
4000
3000
2000
1000
0
9:36
9:50
10:04
10:19
10:33
10:48
11:02
11:16
11:31
11:45
12:00
12:14
12:28
12:43
12:57
13:12
13:26
13:40
13:55
14:09
14:24
14:38
14:52
15:07
15:21
15:36
15:50
16:04
16:19
16:33
16:48
17:02
17:16
17:31
17:45
18:00
18:14
18:28
18:43
18:57
19:12
19:26
19:40
19:55
20:09
20:24
20:38
20:52
21:07
21:21
21:36
21:50
22:04
22:19
22:33
22:48
23:02
23:16
23:31
23:45
Total Rainfall
Total Flow

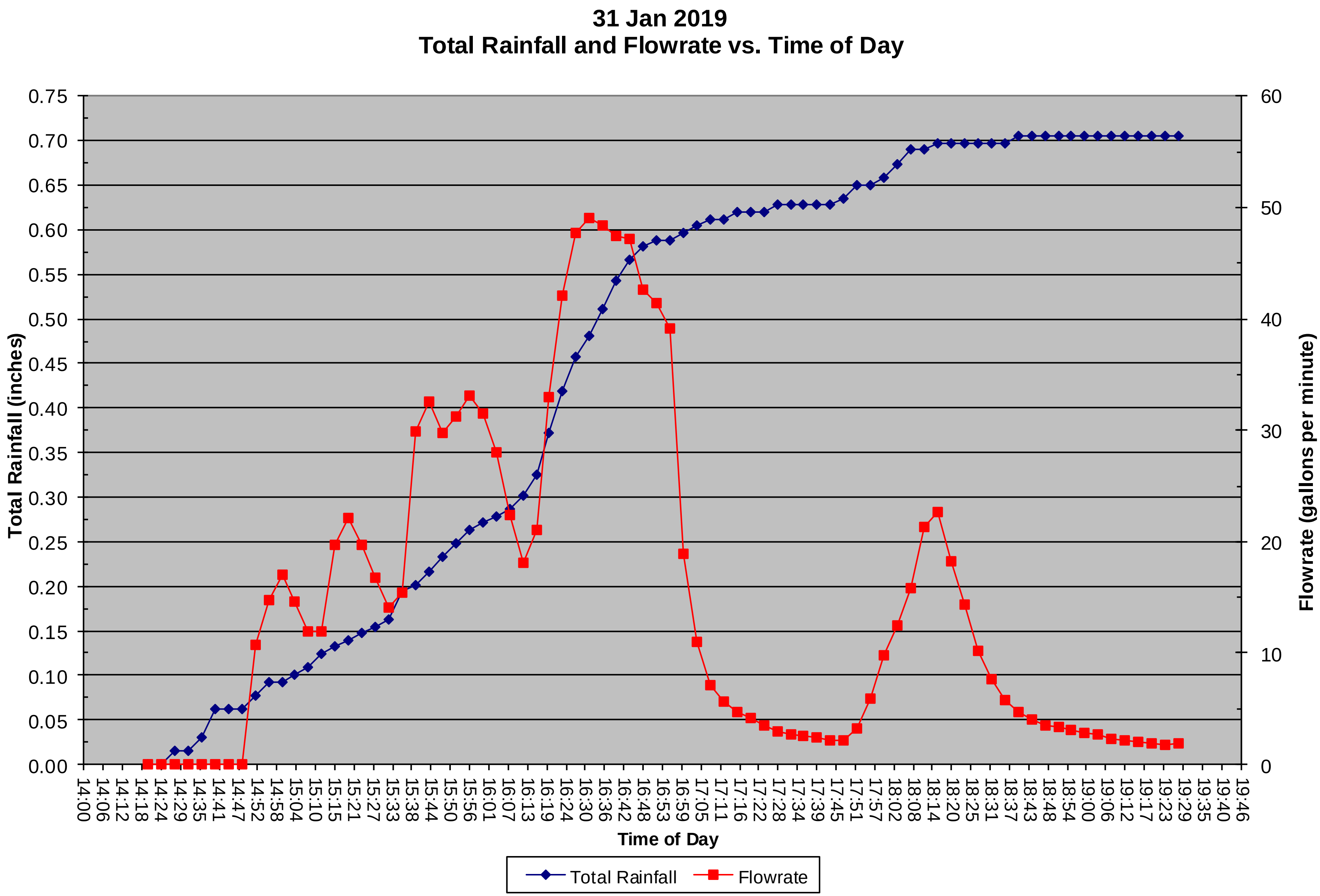


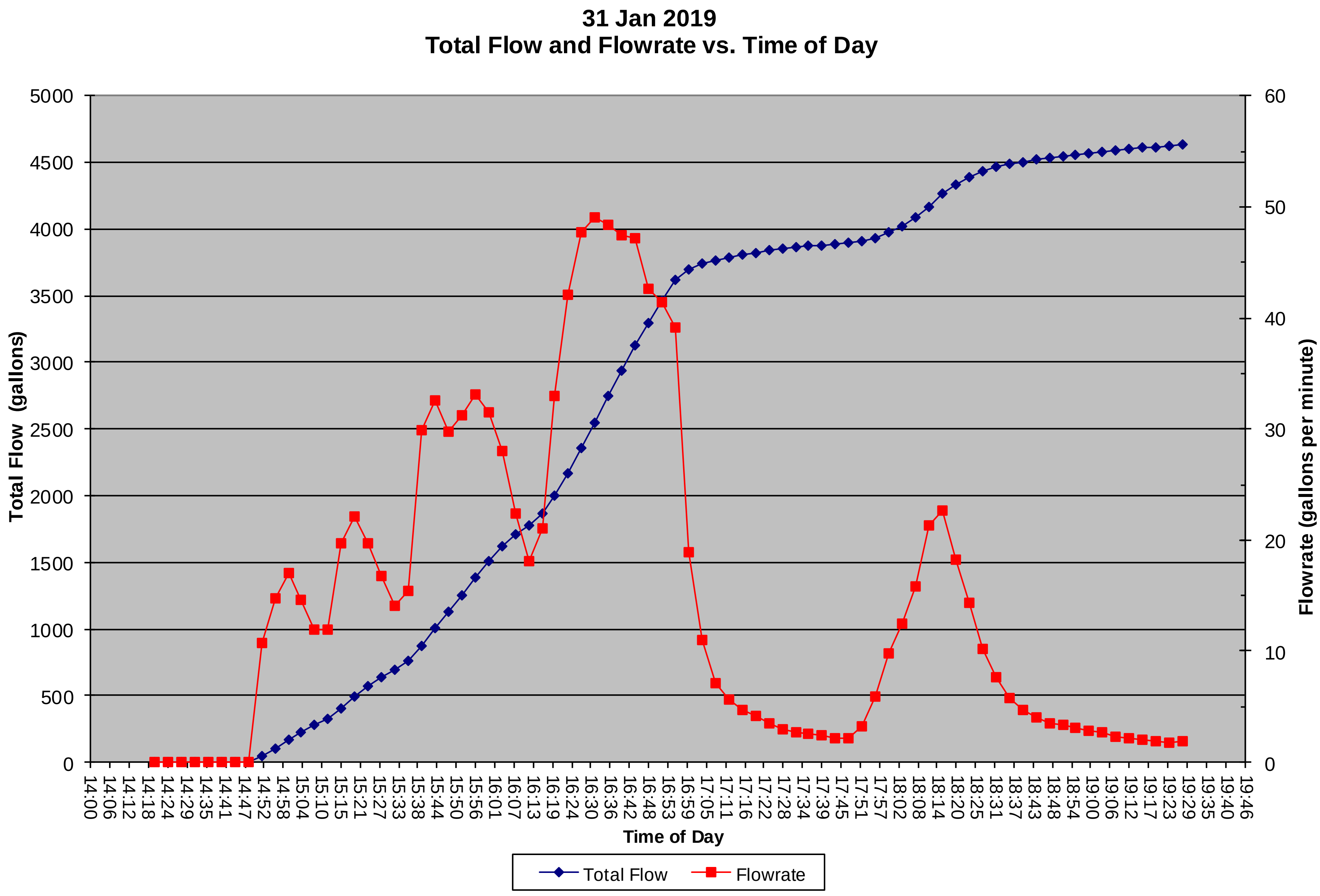
14 Jan 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

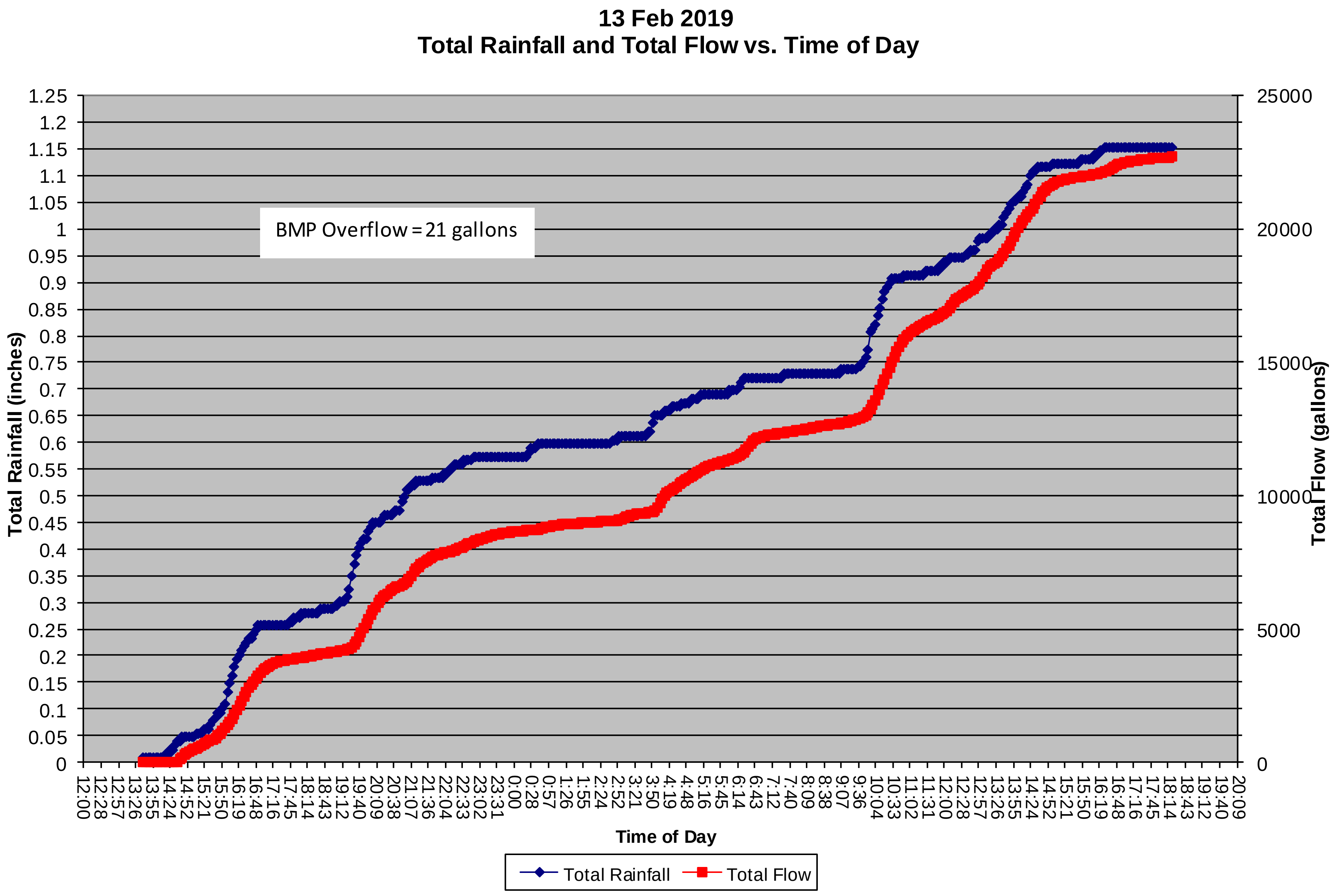

14 Jan 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

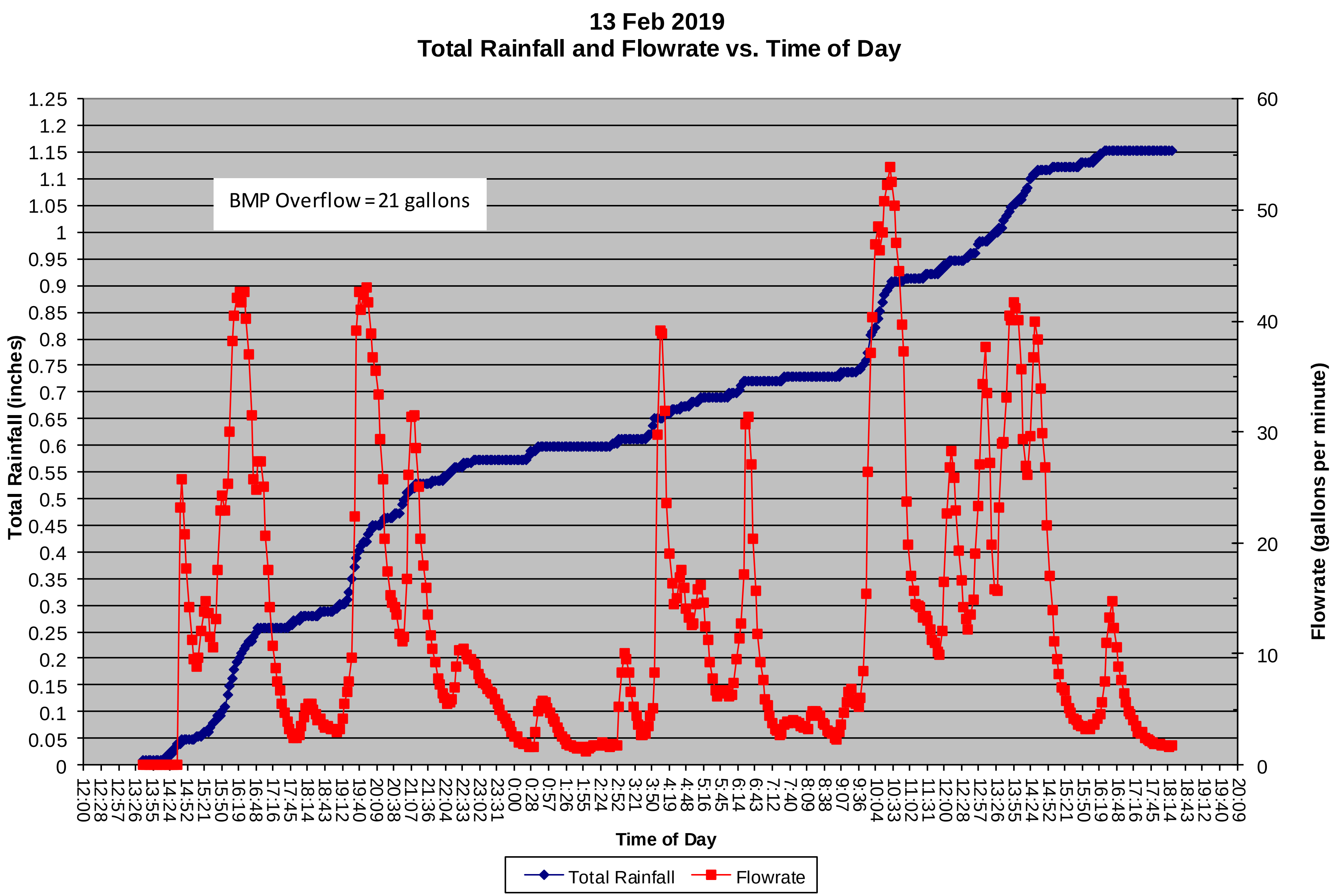
G-22


31 Jan 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
14:00 14:06 14:12 14:18 14:24 14:29 14:35 14:41 14:47 14:52 14:58 15:04 15:10 15:15 15:21 15:27 15:33 15:38 15:44 15:50 15:56 16:01 16:07 16:13 16:19 16:24 16:30 16:36 16:42 16:48 16:53 16:59 17:05 17:11 17:16 17:22 17:28 17:34 17:39 17:45 17:51 17:57 18:02 18:08 18:14 18:20 18:25 18:31 18:37 18:43 18:48 18:54 19:00 19:06 19:12 19:17 19:23 19:29 19:35 19:40 19:46
Total Rainfall
Total Flow

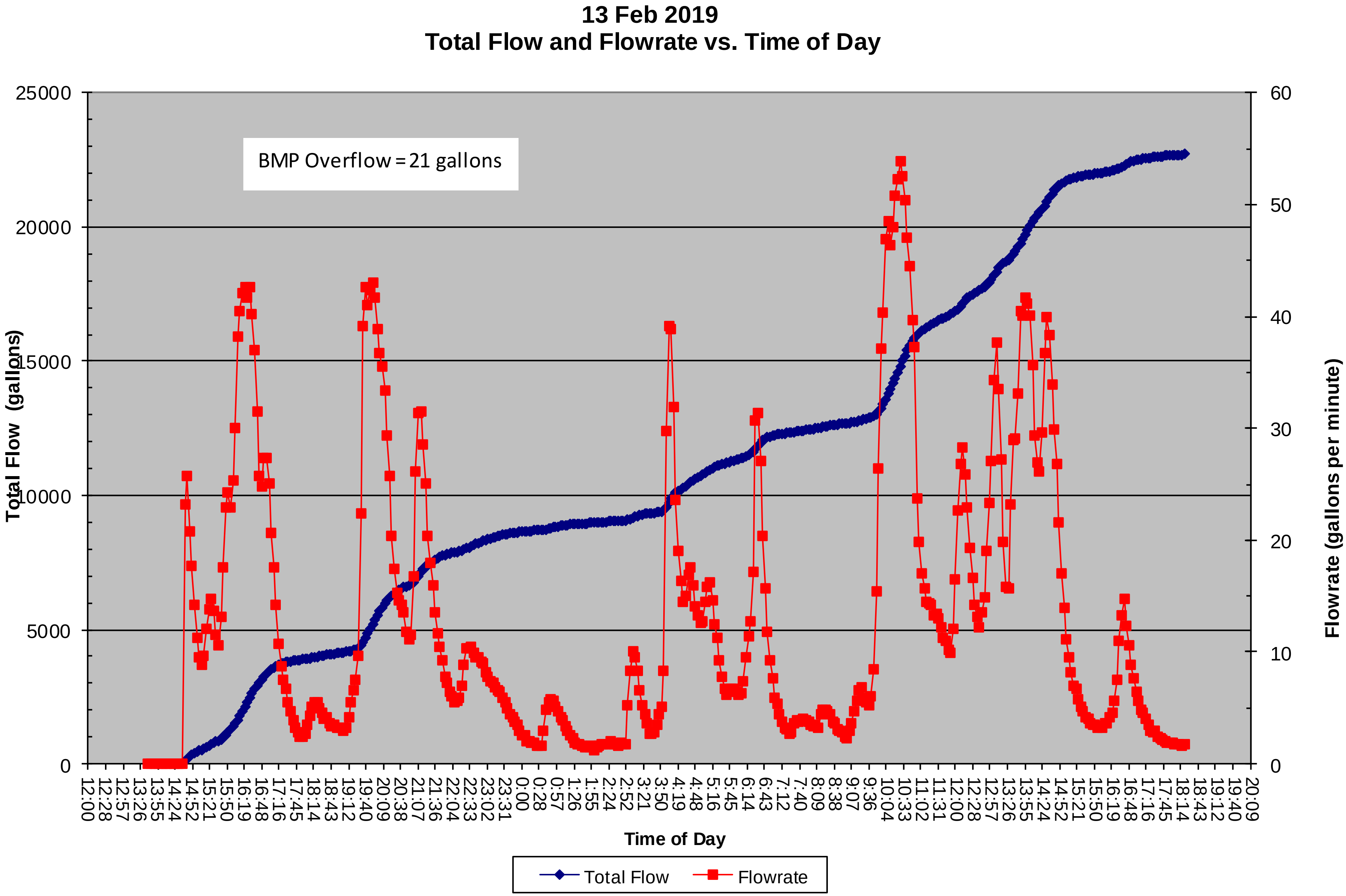

31 Jan 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
60
50
40
30
20
10
0
14:00 14:06 14:12 14:18 14:24 14:29 14:35 14:41 14:47 14:52 14:58 15:04 15:10 15:15 15:21 15:27 15:33 15:38 15:44 15:50 15:56 16:01 16:07 16:13 16:19 16:24 16:30 16:36 16:42 16:48 16:53 16:59 17:05 17:11 17:16 17:22 17:28 17:34 17:39 17:45 17:51 17:57 18:02 18:08 18:14 18:20 18:25 18:31 18:37 18:43 18:48 18:54 19:00 19:06 19:12 19:17 19:23 19:29 19:35 19:40 19:46

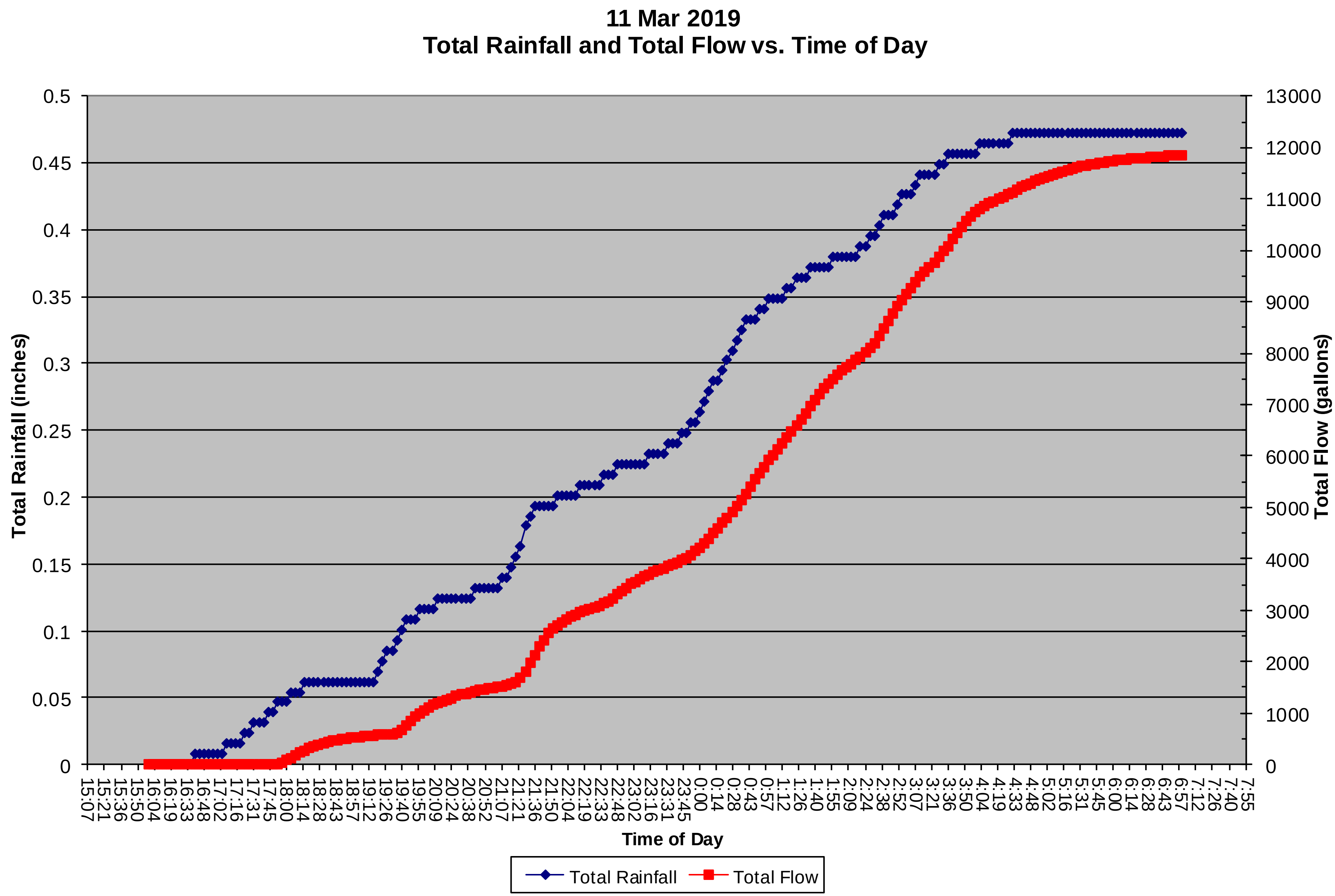

31 Jan 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

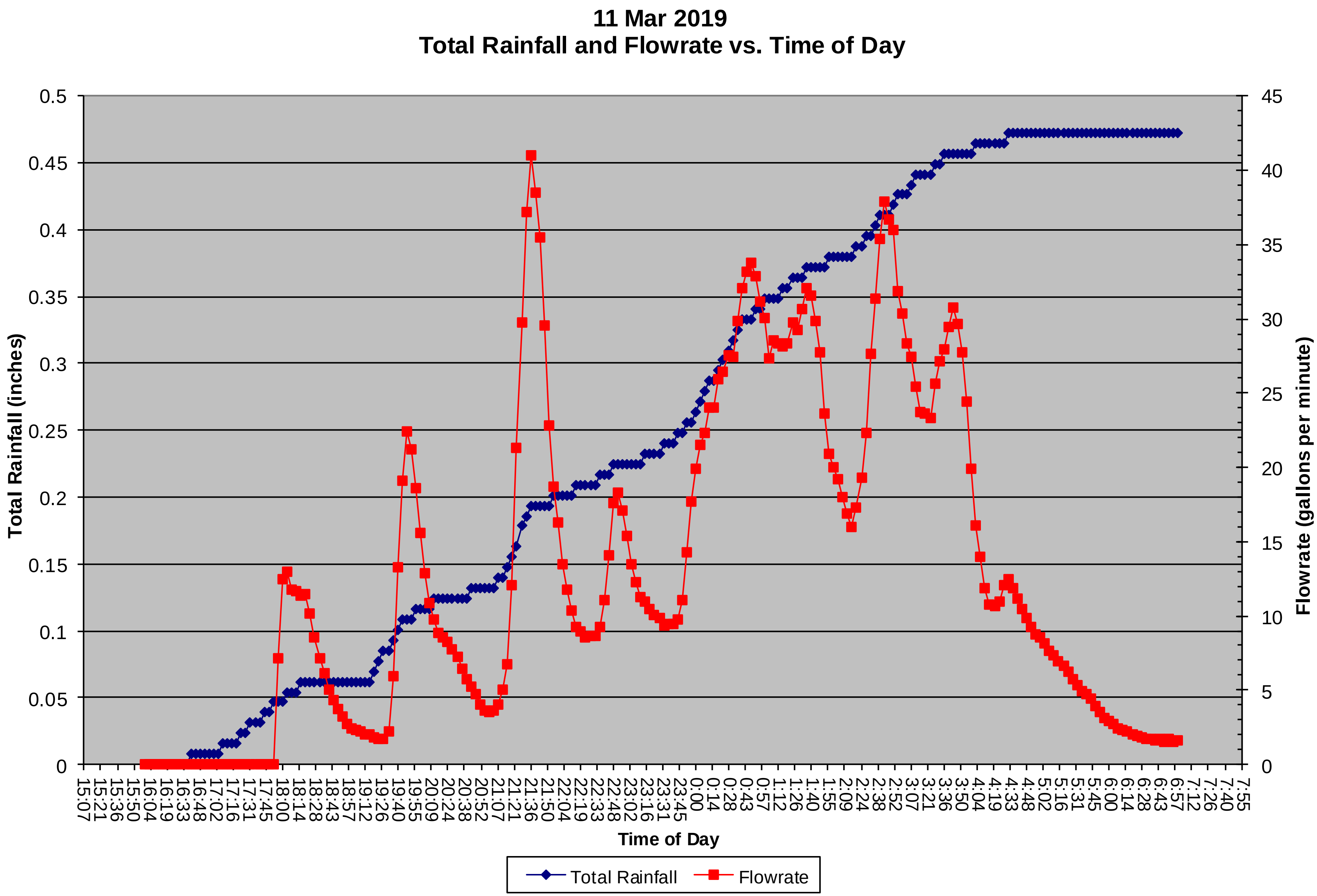

13 Feb 2019
Total Rainfall and Total Flow vs. Time of Day
BMP Overflow = 21 gallons
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

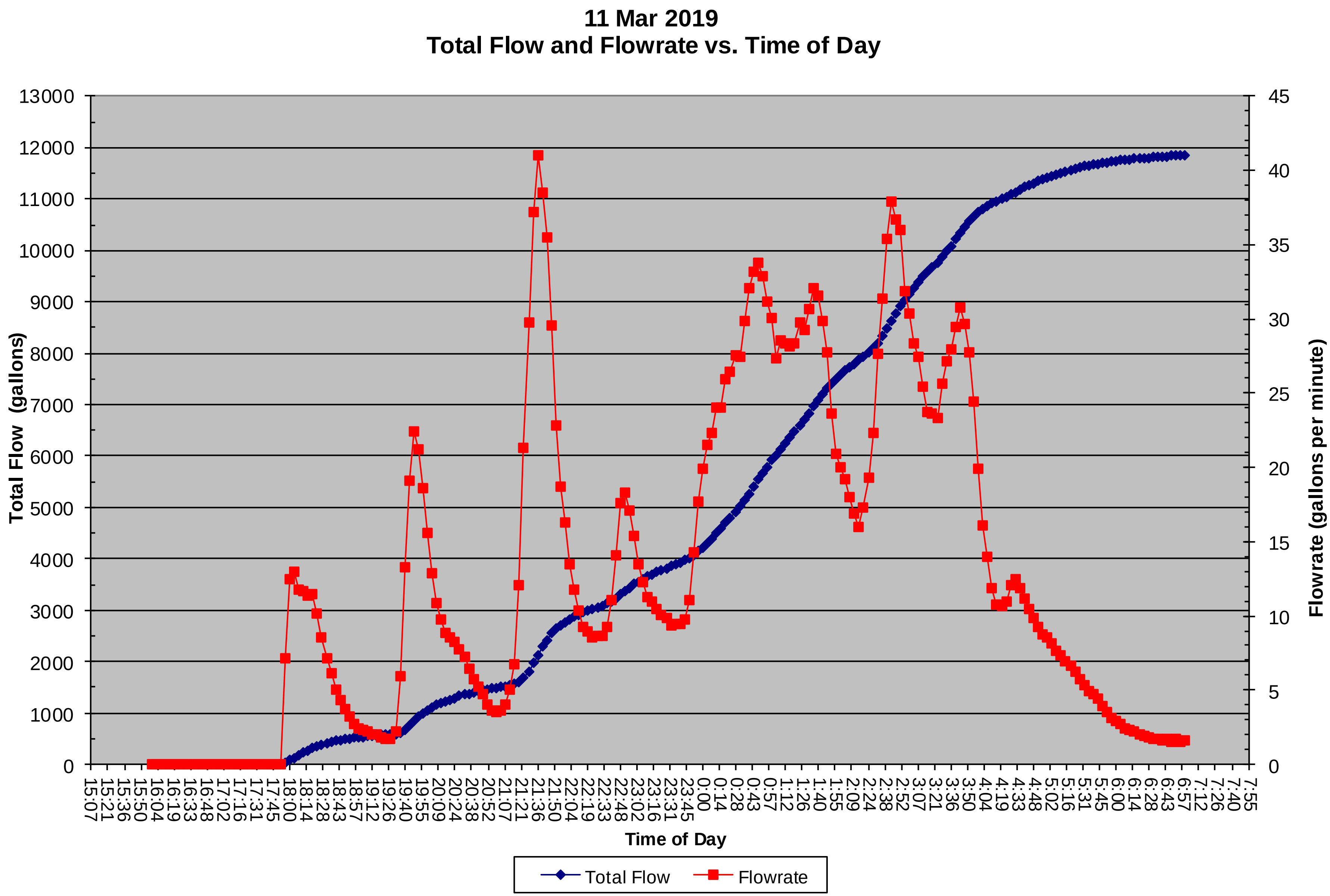


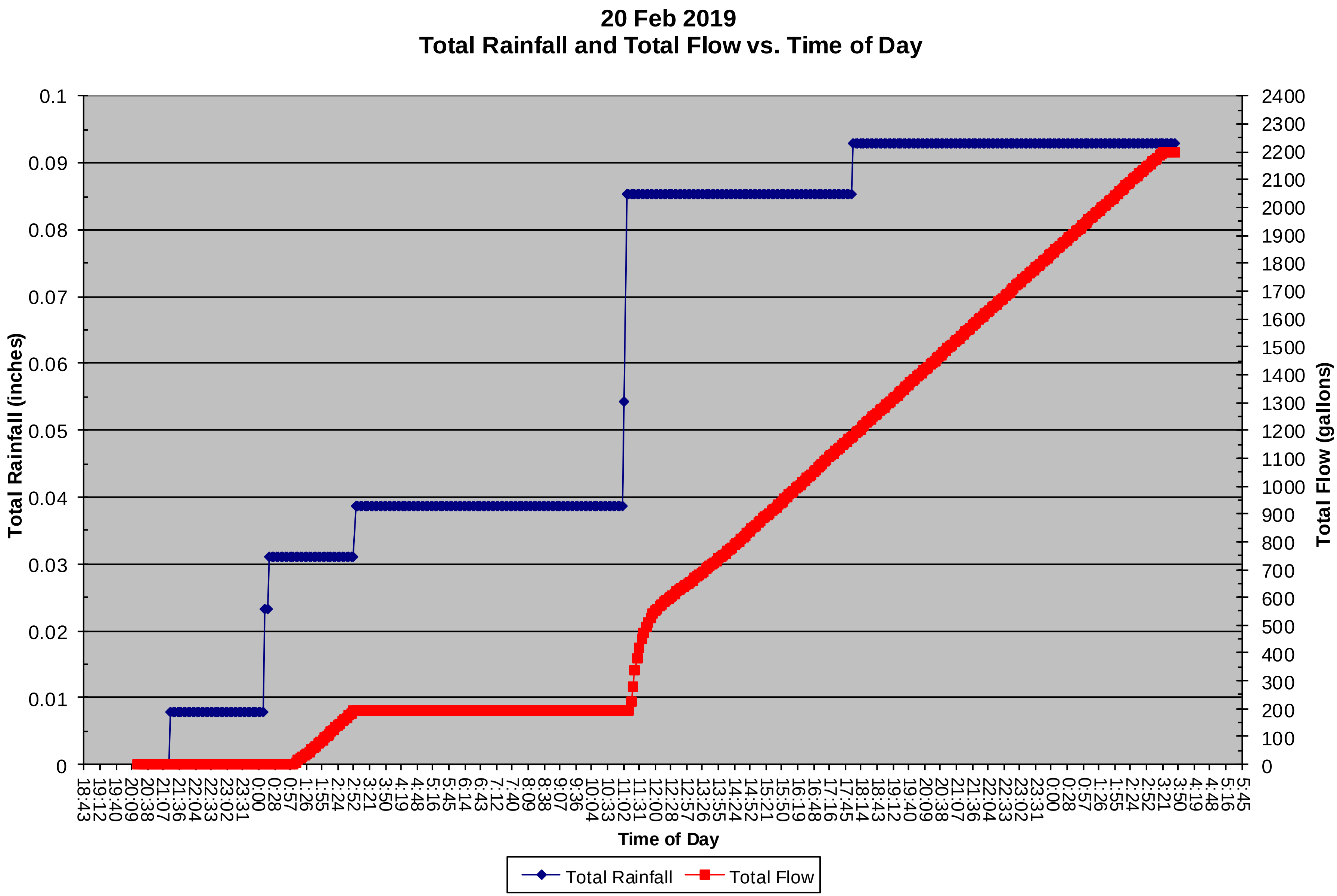
13 Feb 2019
Total Rainfall and Flowrate vs. Time of Day
BMP Overflow = 21 gallons
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

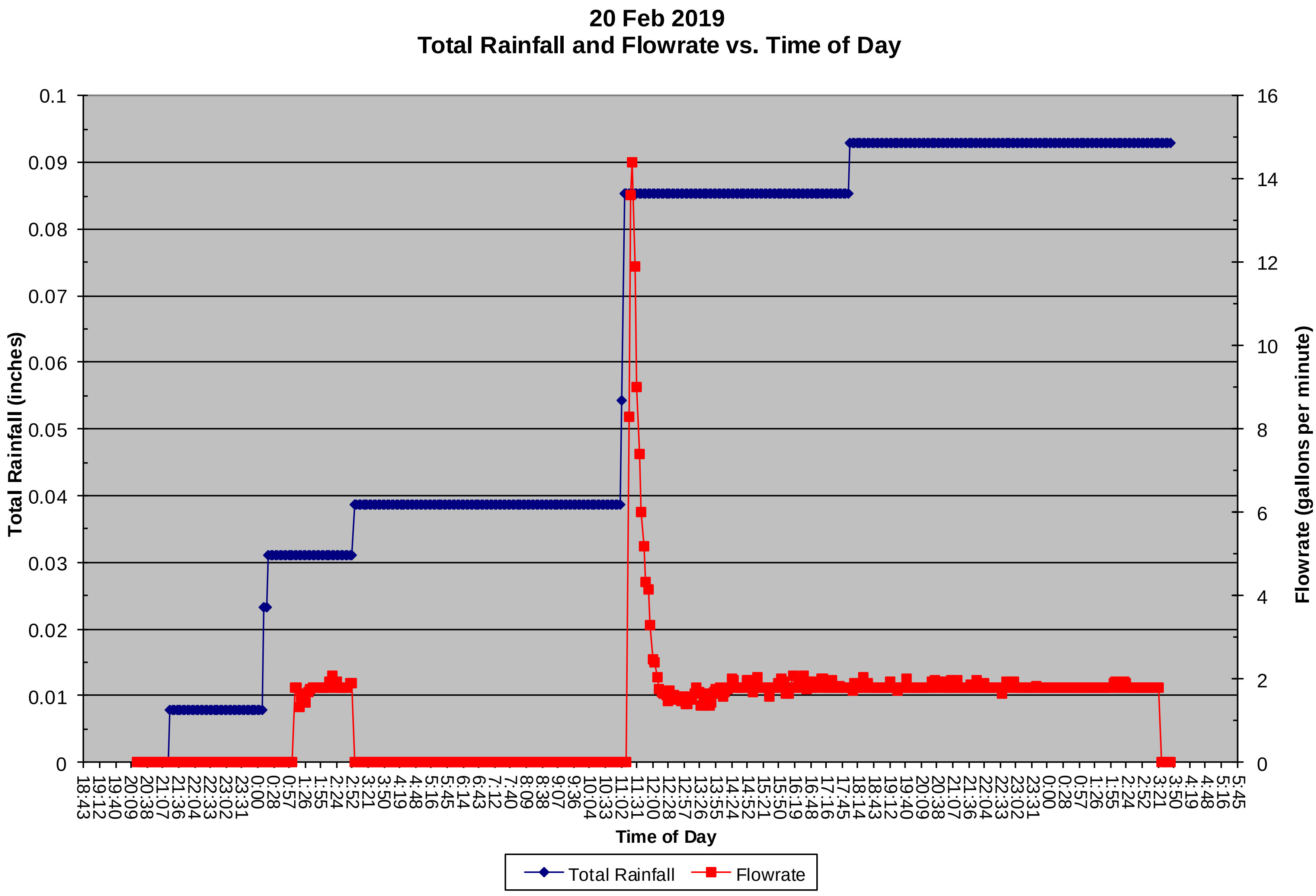

13 Feb 2019
Total Flow and Flowrate vs. Time of Day
BMP Overflow = 21 gallons
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate
25000
20000
15000
10000
5000
0
60
50
40
30
20
10
0
12:00
12:28
12:57
13:26
13:55
14:24
14:52
15:21
15:50
16:19
16:48
17:16
17:45
18:14
18:43
19:12
19:40
20:09
20:38
21:07
21:36
22:04
22:33
23:02
23:31
0:00
0:28
0:57
1:26
1:55
2:24
2:52
3:21
3:50
4:19
4:48
5:16
5:45
6:14
6:43
7:12
7:40
8:09
8:38
9:07
9:36
10:04
10:33
11:02
11:31
12:00
12:28
12:57
13:26
13:55
14:24
14:52
15:21
15:50
16:19
16:48
17:16
17:45
18:14
18:43
19:12
19:40
20:09


11 Mar 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

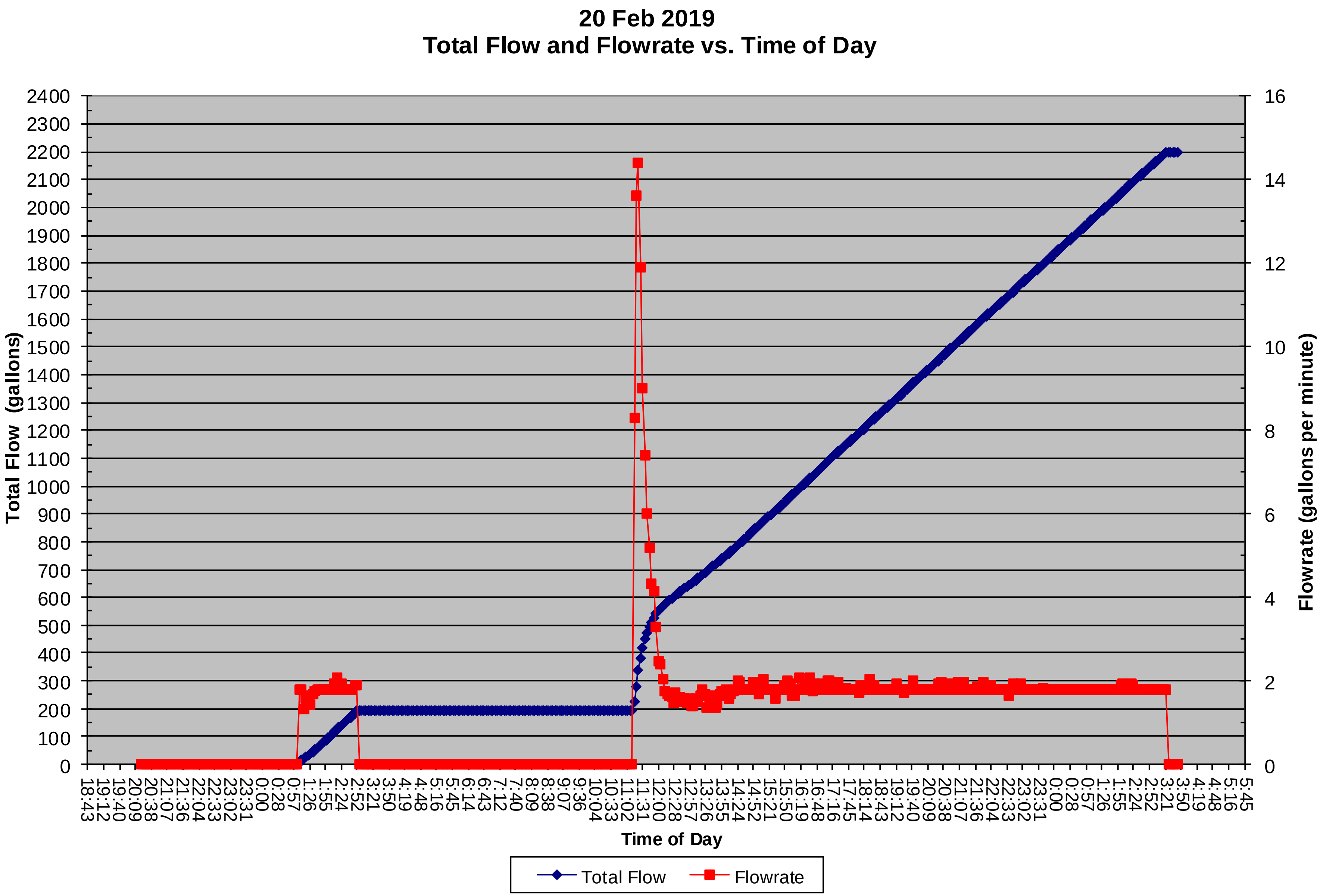

11 Mar 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

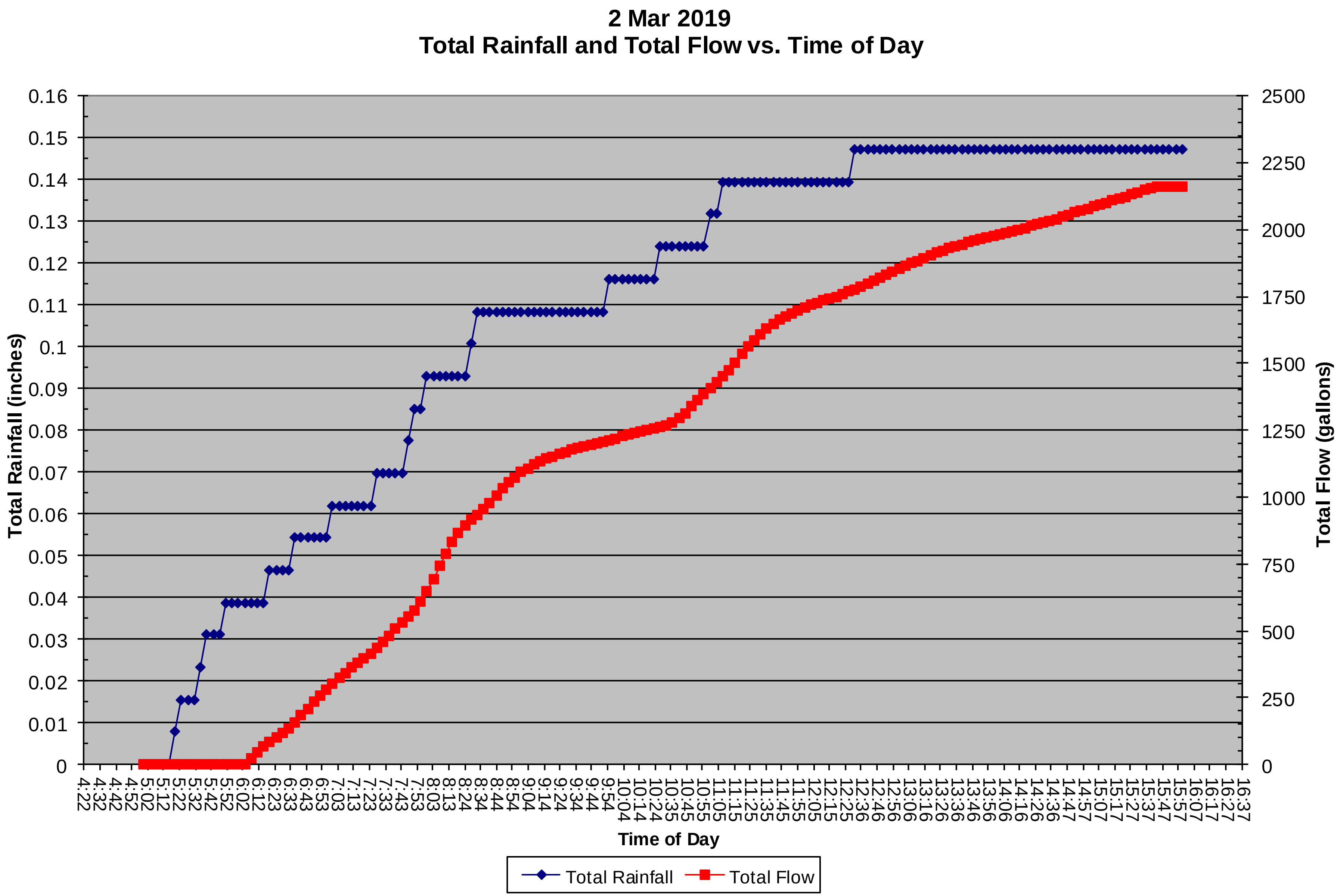

11 Mar 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
0
5
10
15
20
25
30
35
40
45
15:07
15:21
15:36
15:50
16:04
16:19
16:33
16:48
17:02
17:16
17:31
17:45
18:00
18:14
18:28
18:43
18:57
19:12
19:26
19:40
19:55
20:09
20:24
20:38
20:52
21:07
21:21
21:36
21:50
22:04
22:19
22:33
22:48
23:02
23:16
23:31
23:45
0:00
0:14
0:28
0:43
0:57
1:12
1:26
1:40
1:55
2:09
2:24
2:38
2:52
3:07
3:21
3:36
3:50
4:04
4:19
4:33
4:48
5:02
5:16
5:31
5:45
6:00
6:14
6:28
6:43
6:57
7:12
7:26
7:40
7:55


20 Feb 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

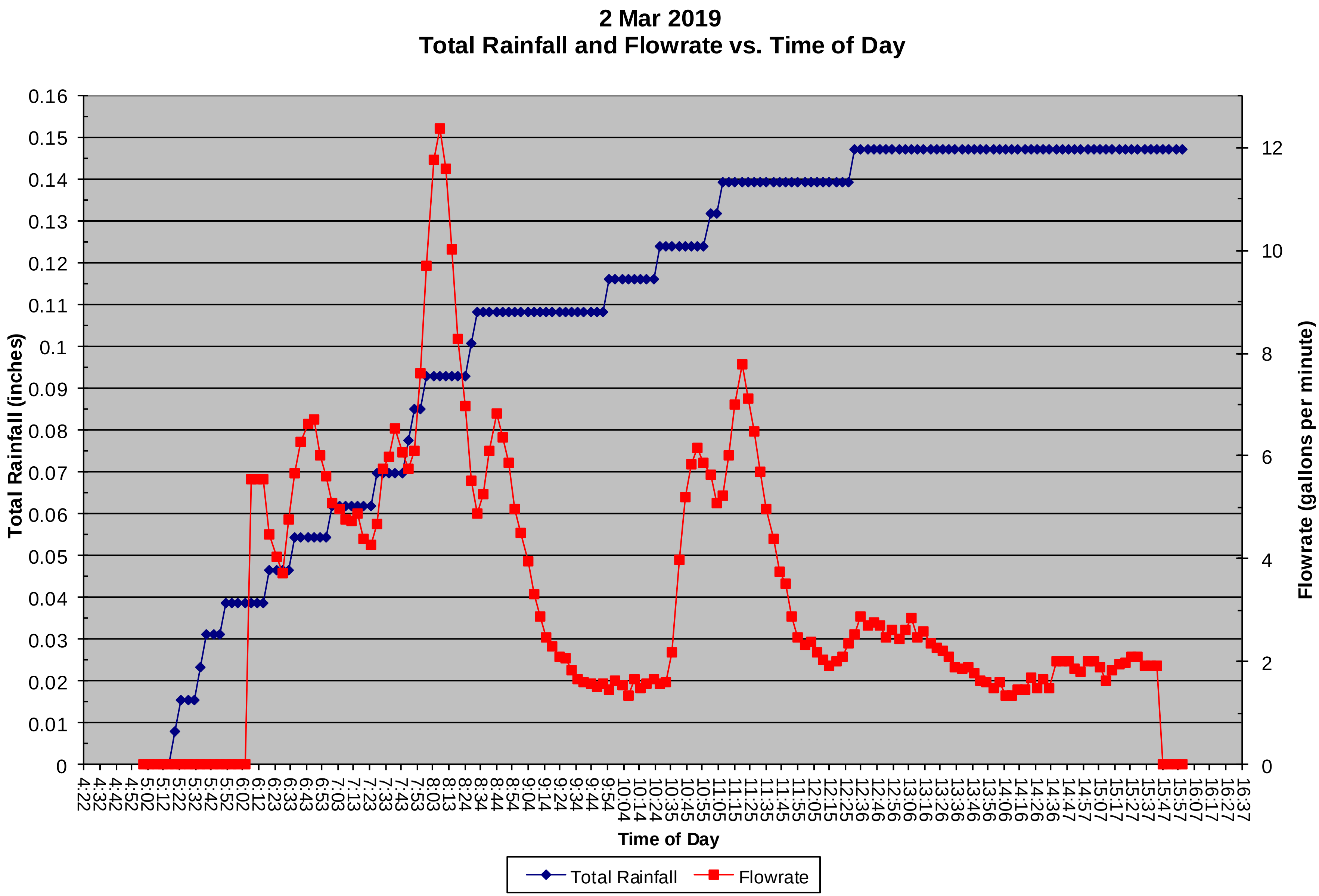


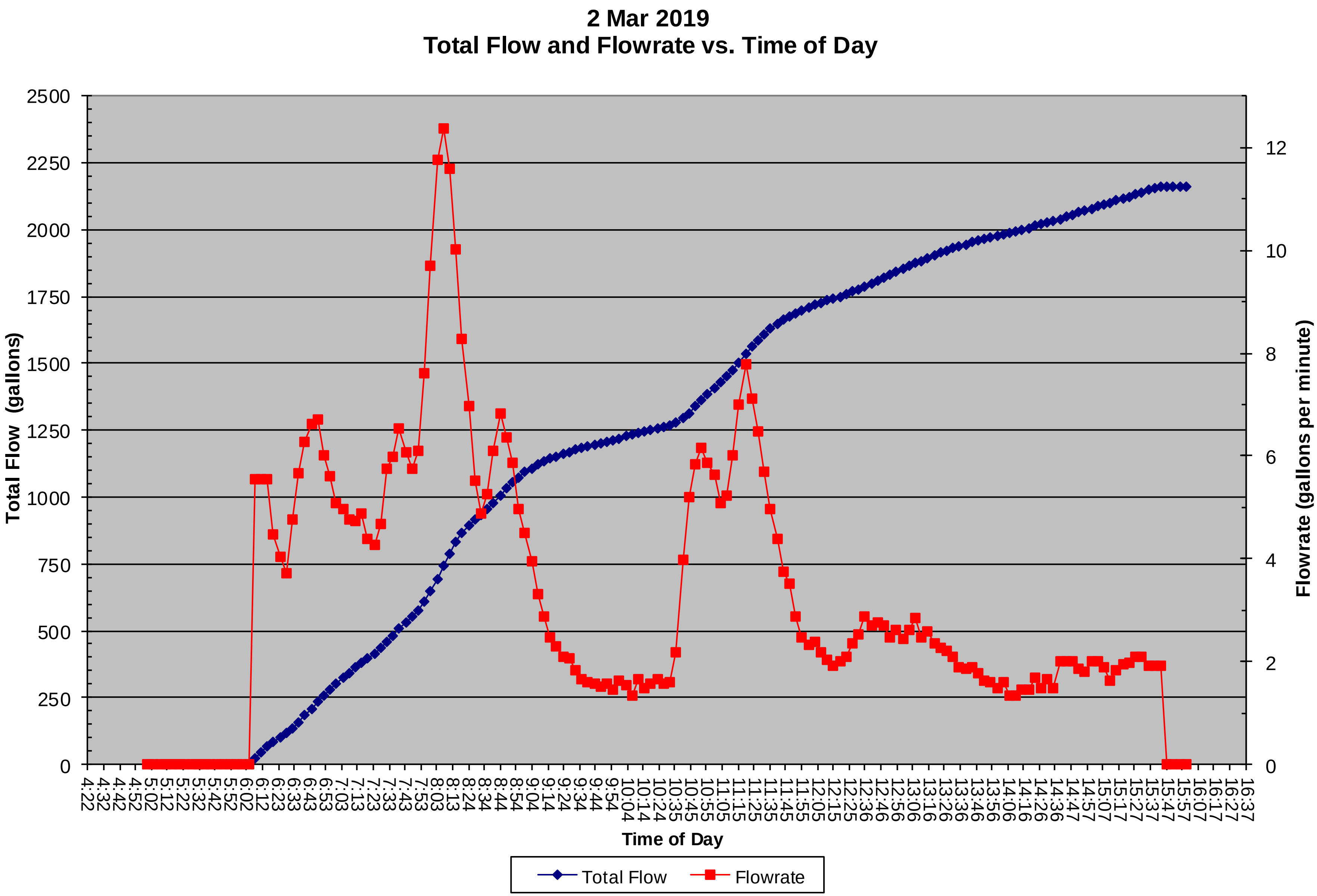
20 Feb 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate


20 Feb 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
0
2
4
6
8
10
12
14
16

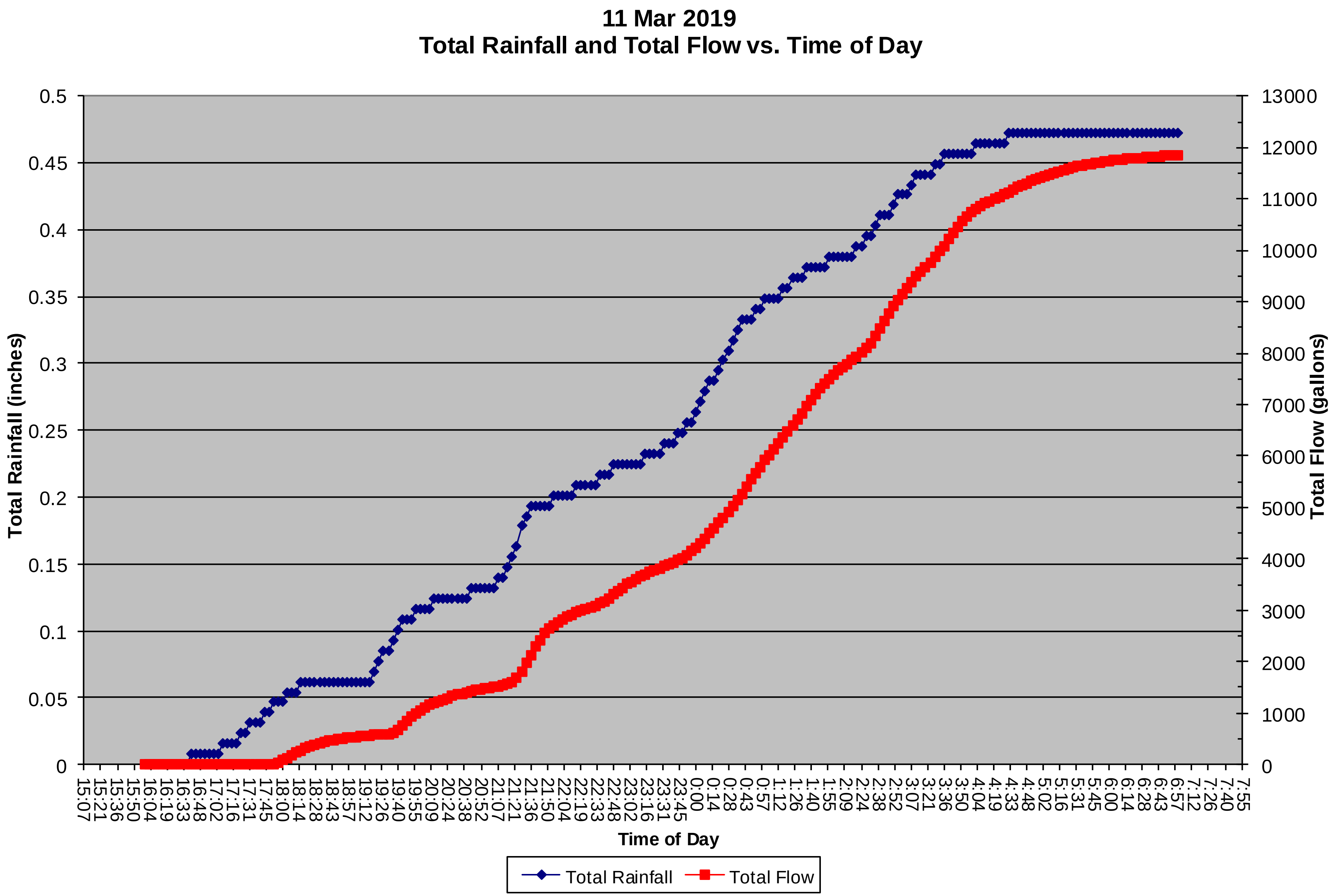


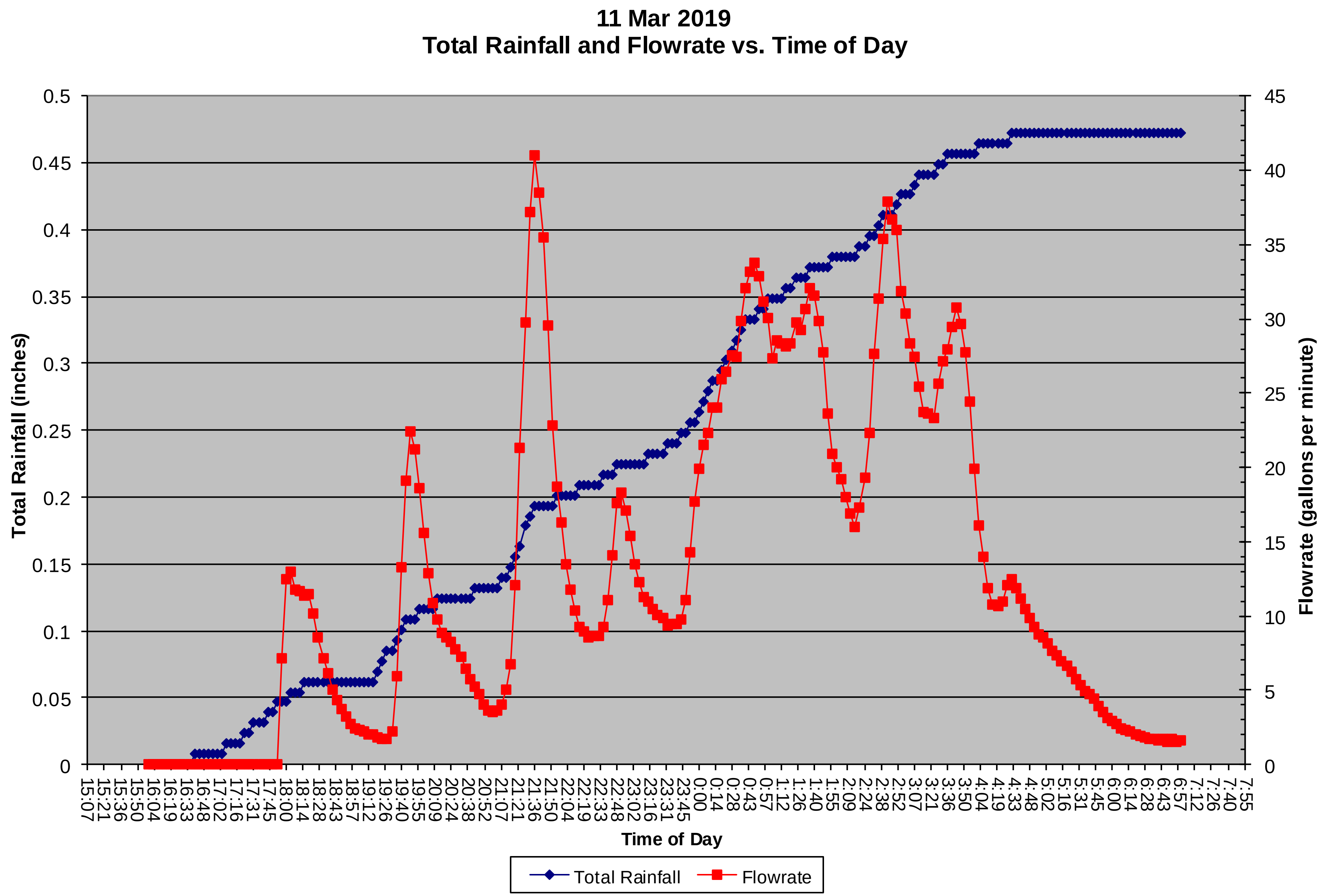
2 Mar 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

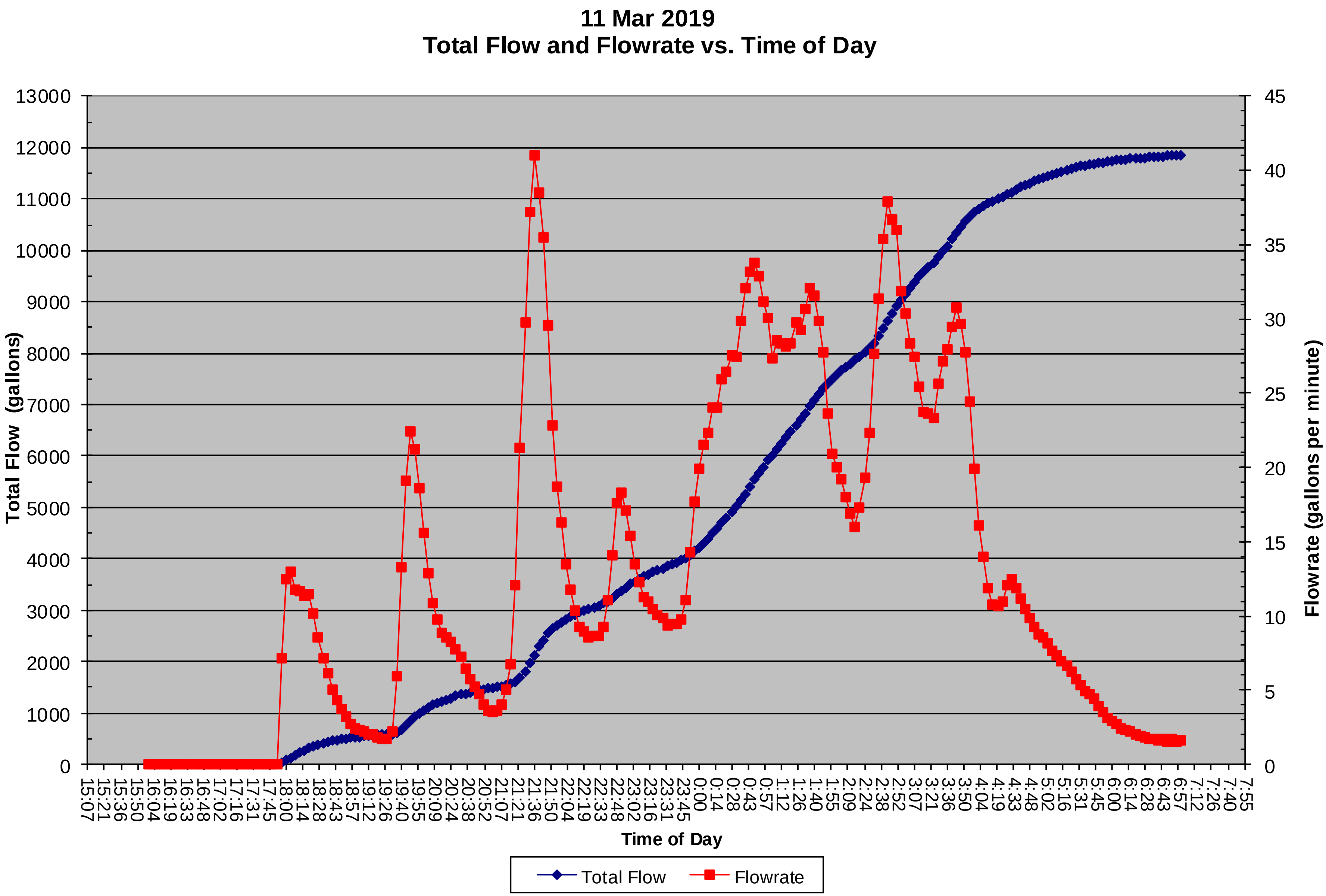

2 Mar 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate



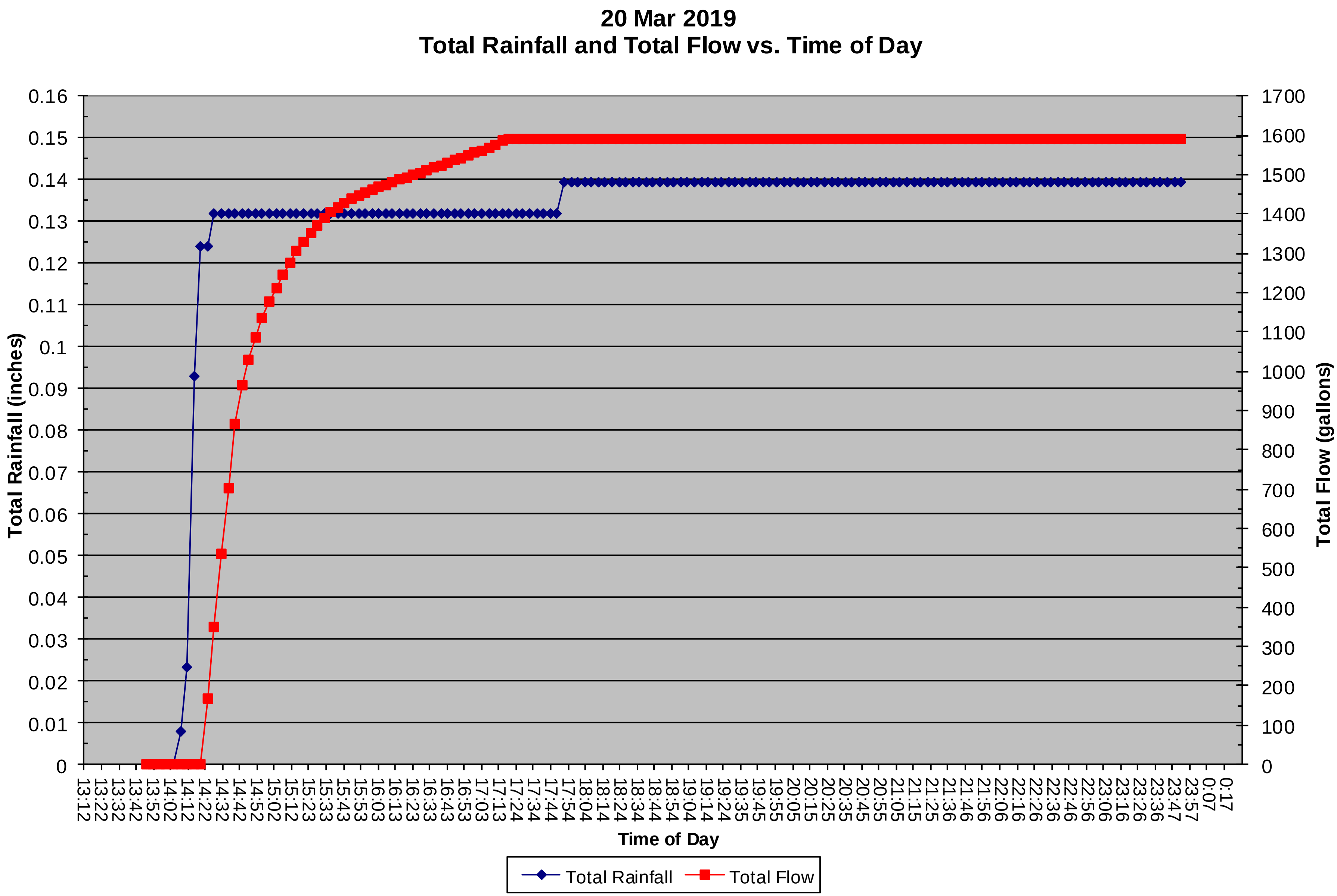
2 Mar 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

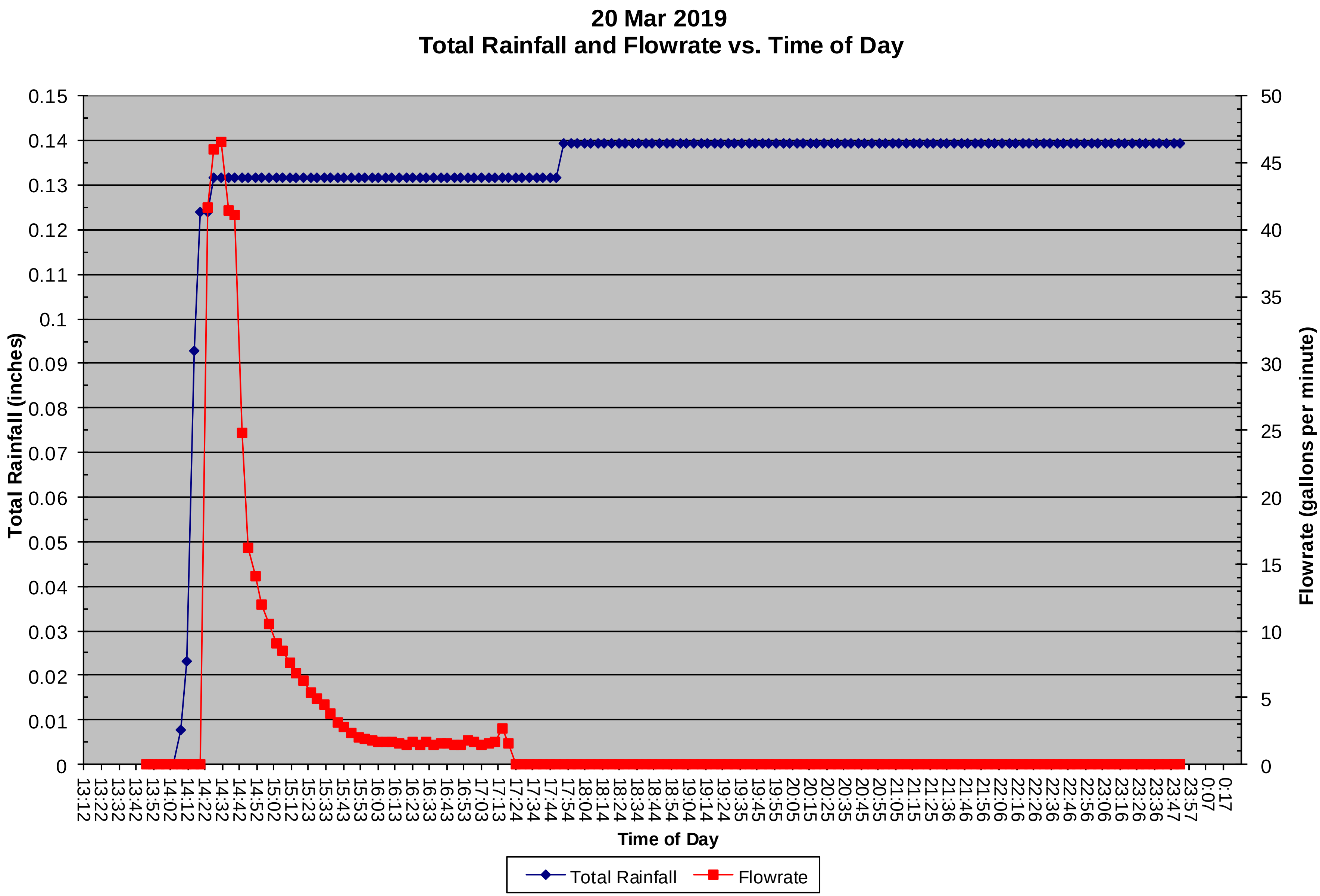

11 Mar 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

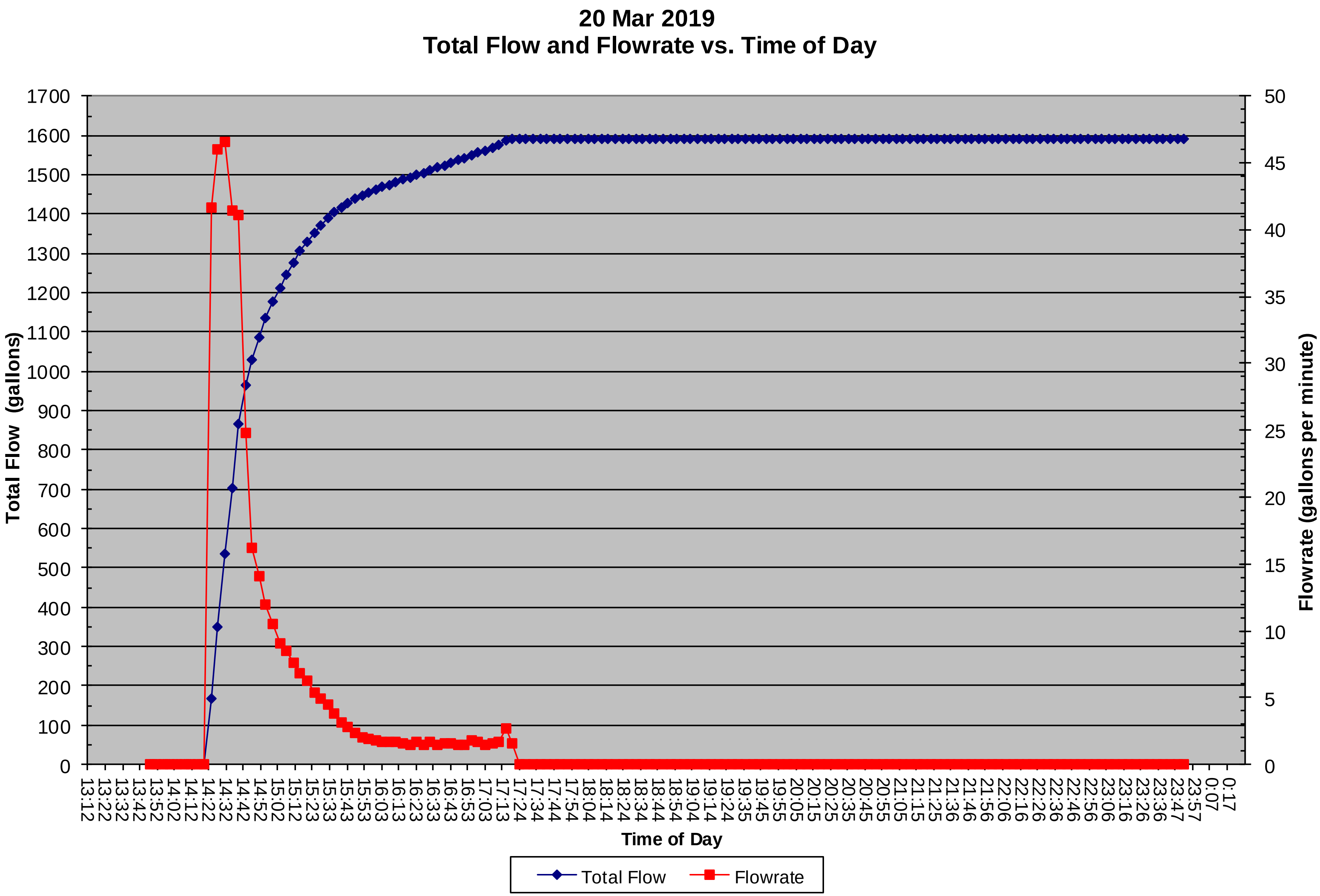

11 Mar 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

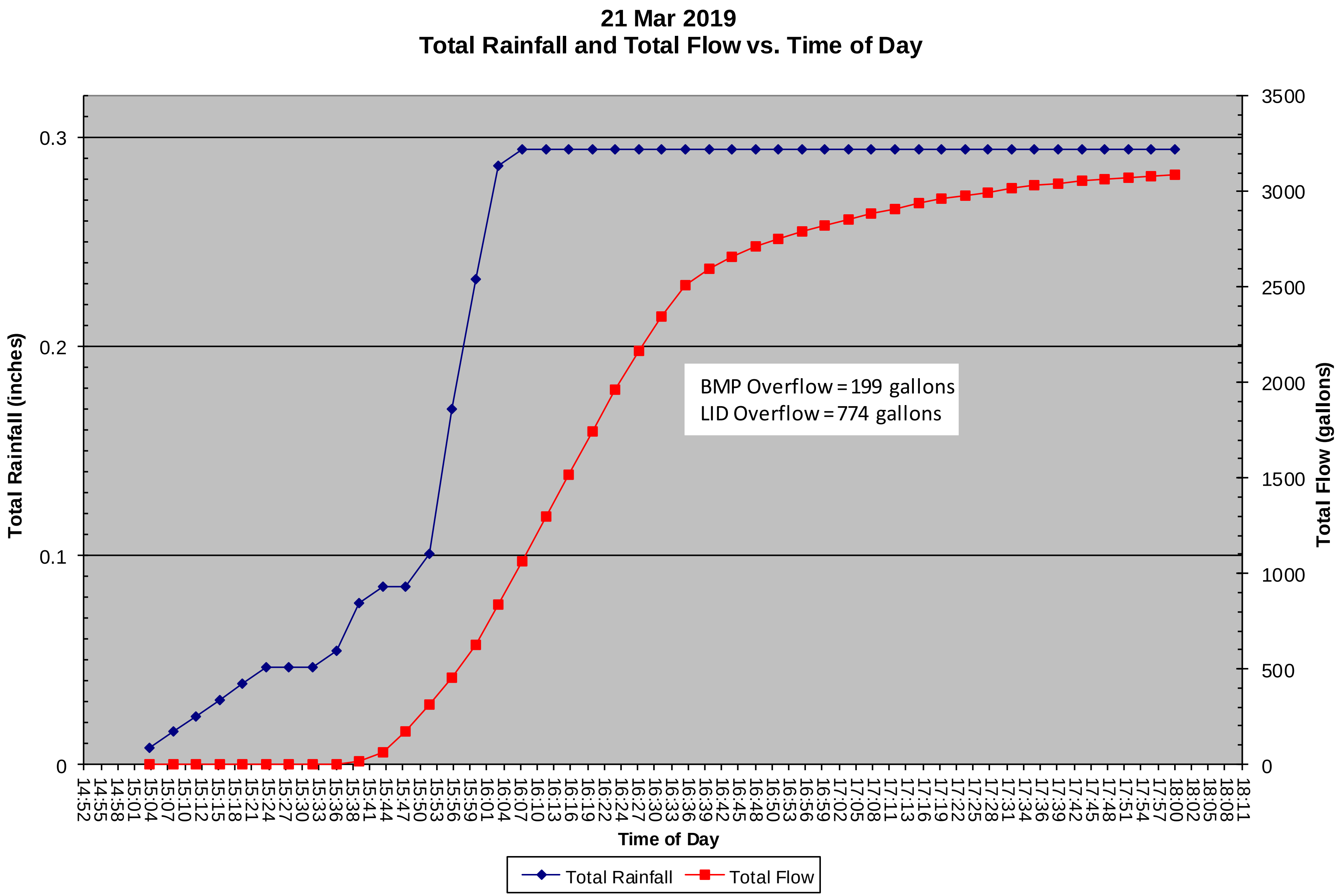


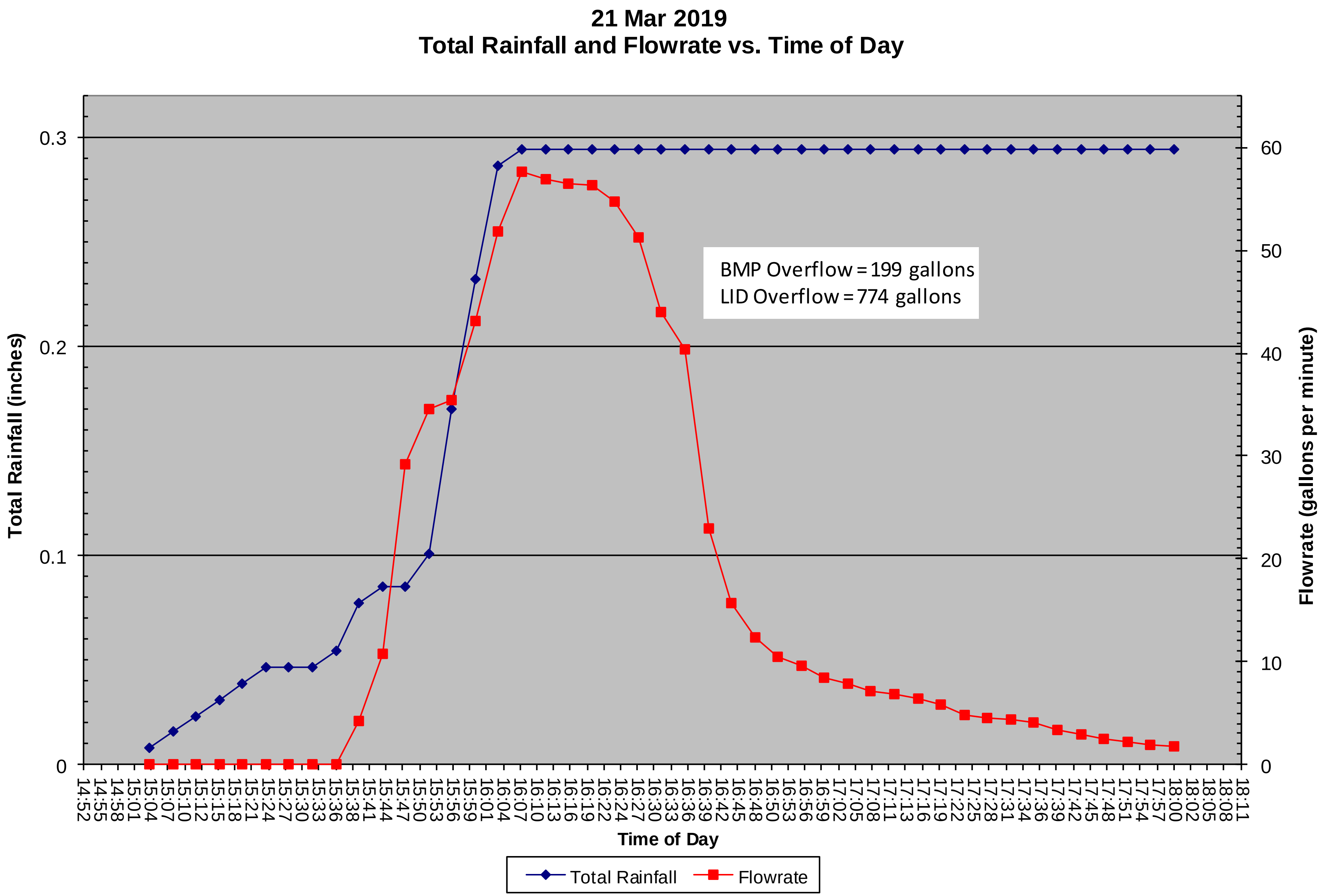
11 Mar 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate


20 Mar 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

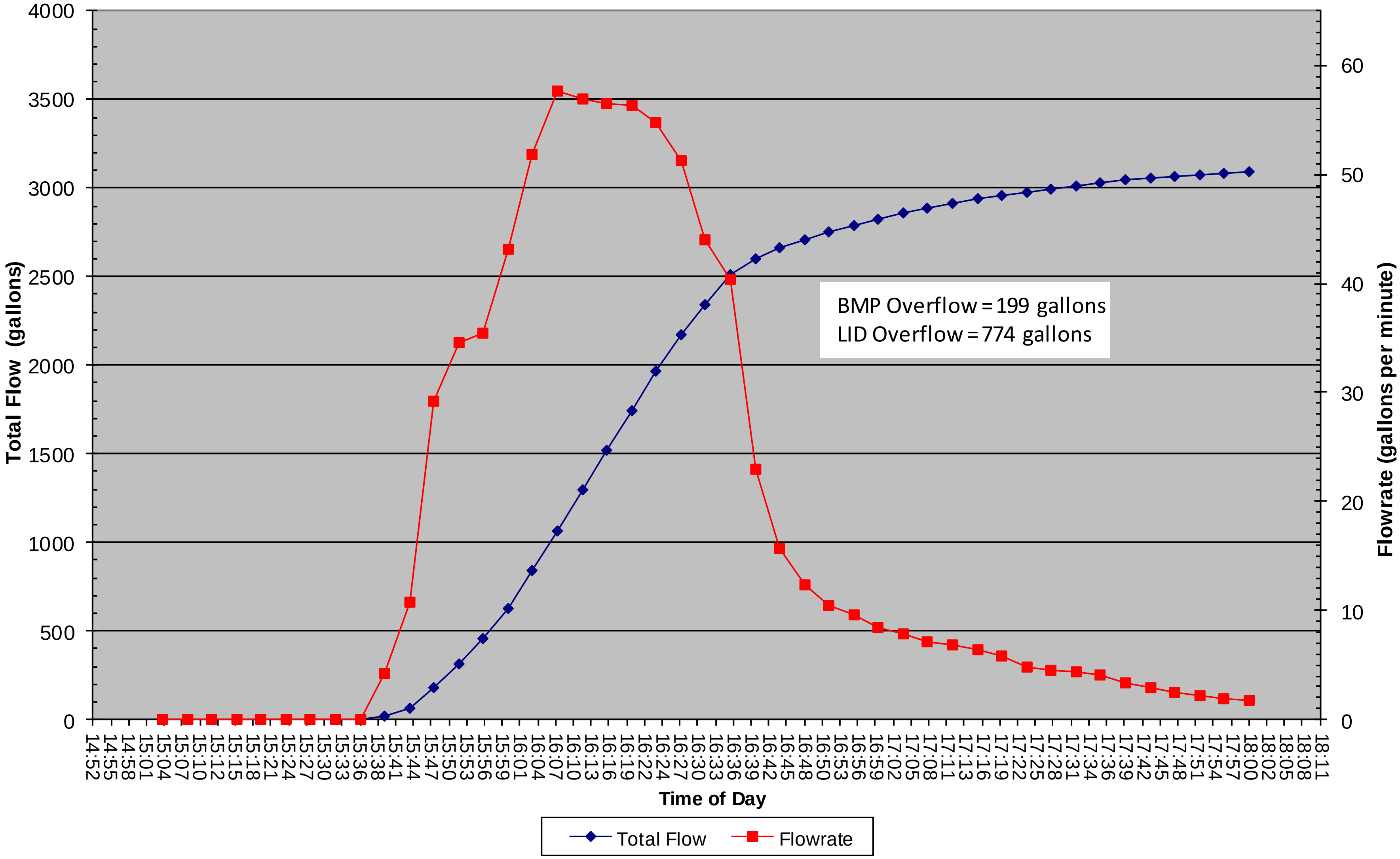

20 Mar 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
5
10
15
20
25
30
35
40
45
50

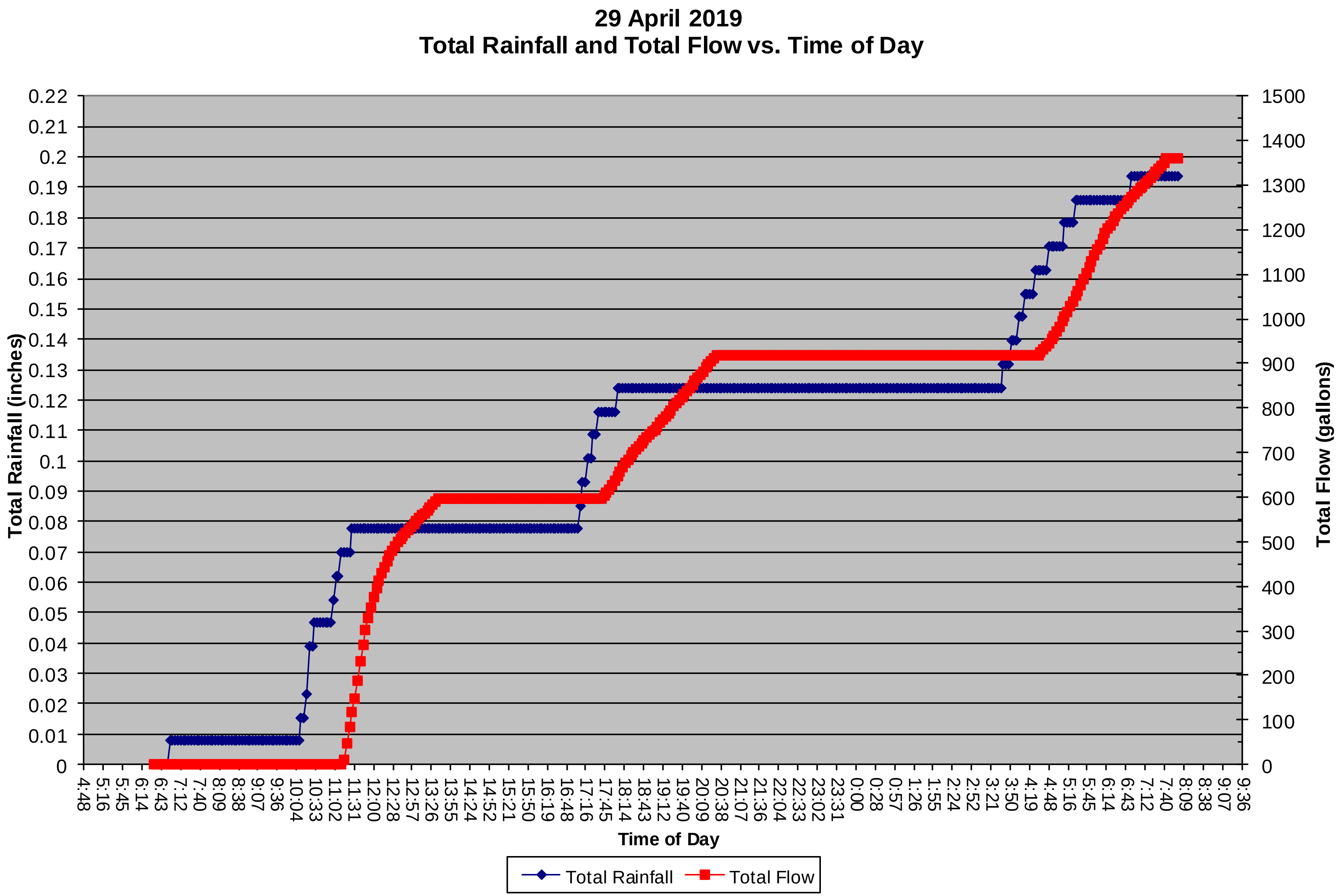

20 Mar 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

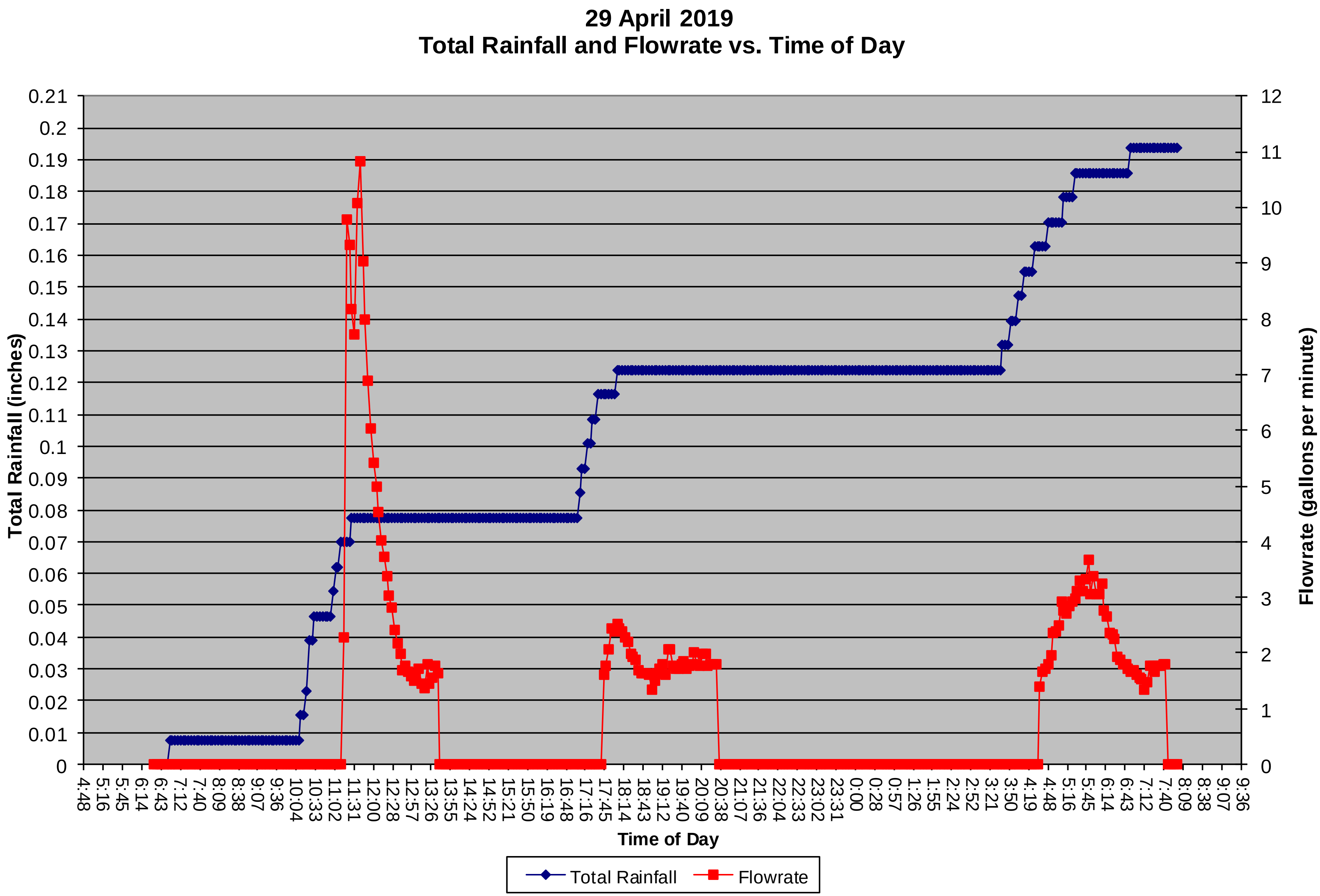

21 Mar 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
BMP Overflow = 199 gallons
LID Overflow = 774 gallons
Total Rainfall
Total Flow

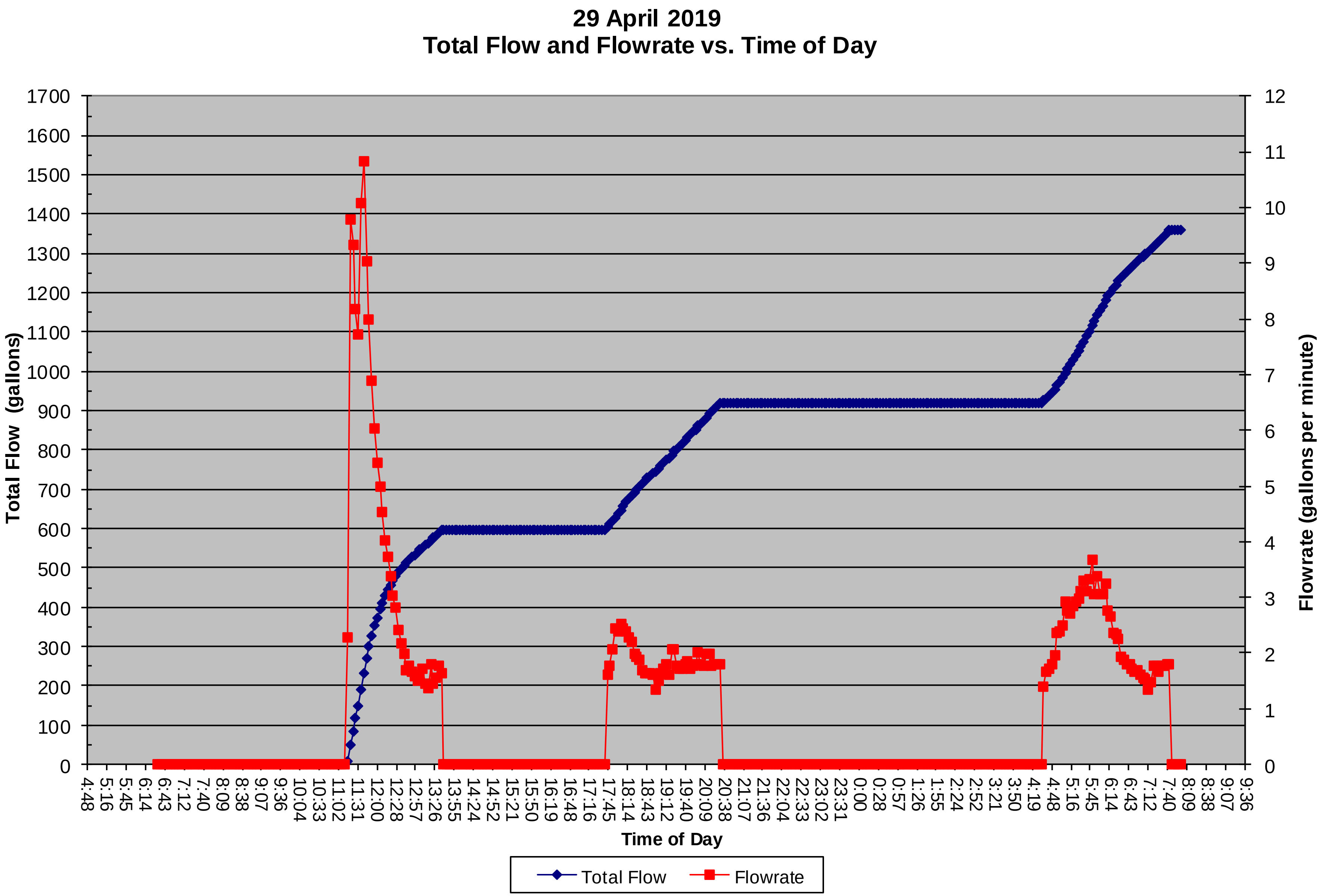

21 Mar 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
BMP Overflow = 199 gallons
LID Overflow = 774 gallons
Total Rainfall
Flowrate

21 Mar 2019
Total Flow and Flowrate vs. Time of Day

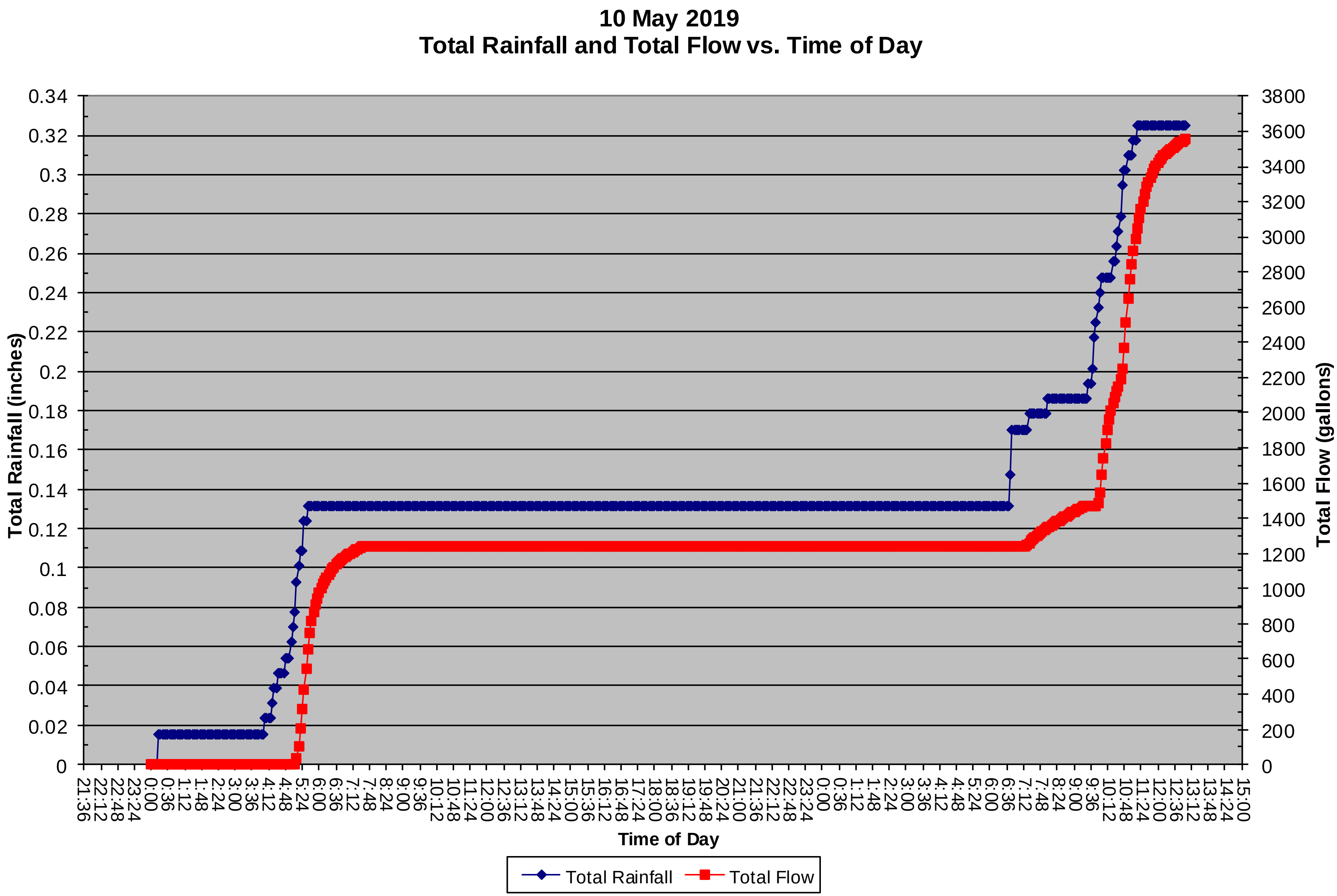



29 April 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow
0.22
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
4:48 5:16 5:45 6:14 6:43 7:12 7:40 8:09 8:38 9:07 9:36 10:04 10:33 11:02 11:31 12:00 12:28 12:57 13:26 13:55 14:24 14:52 15:21 15:50 16:19 16:48 17:16 17:45 18:14 18:43 19:12 19:40 20:09 20:38 21:07 21:36 22:04 22:33 23:02 23:31 0:00 0:28 0:57 1:26 1:55 2:24 2:52 3:21 3:50 4:19 4:48 5:16 5:45 6:14 6:43 7:12 7:40 8:09 8:38 9:07 9:36

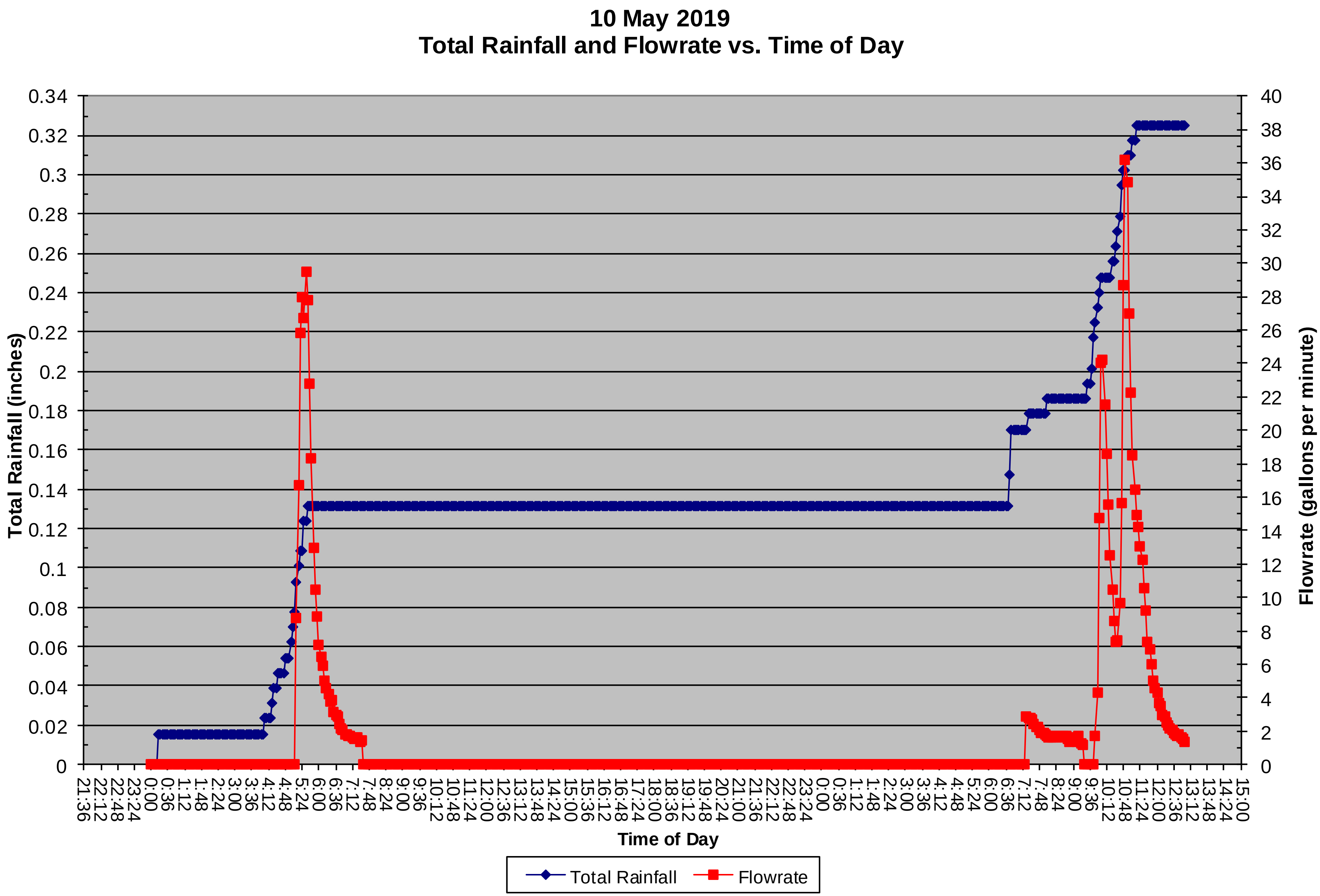

29 April 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Flowrate (gallons per minute)
12
11
10
9
8
7
6
5
4
3
2
1
0
4:48 5:16 5:45 6:14 6:43 7:12 7:40 8:09 8:38 9:07 9:36 10:04 10:33 11:02 11:31 12:00 12:28 12:57 13:26 13:55 14:24 14:52 15:21 15:50 16:19 16:48 17:16 17:45 18:14 18:43 19:12 19:40 20:09 20:38 21:07 21:36 22:04 22:33 23:02 23:31 0:00 0:28 0:57 1:26 1:55 2:24 2:52 3:21 3:50 4:19 4:48 5:16 5:45 6:14 6:43 7:12 7:40 8:09 8:38 9:07 9:36
Time of Day
Total Rainfall
Flowrate



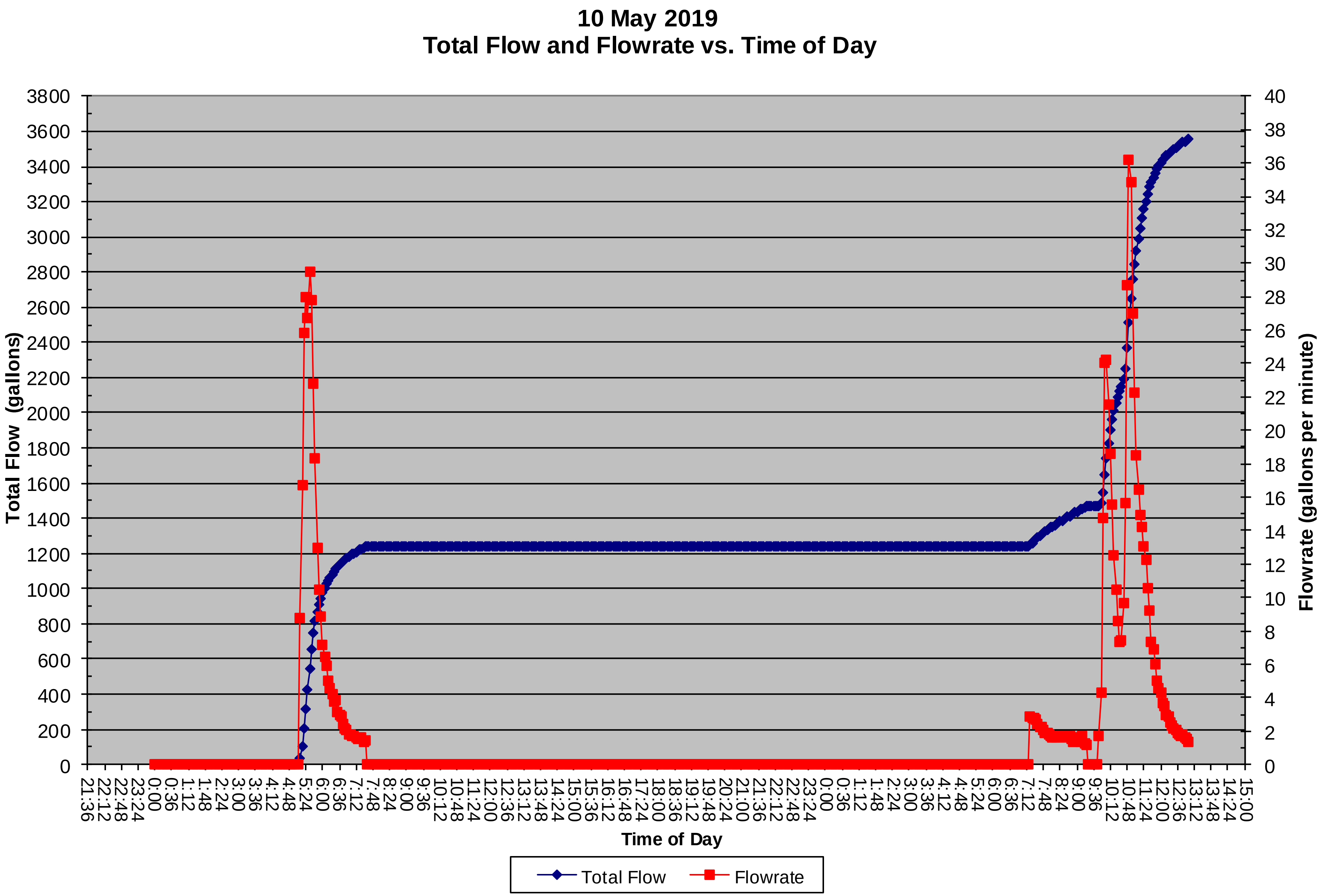
29 April 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate



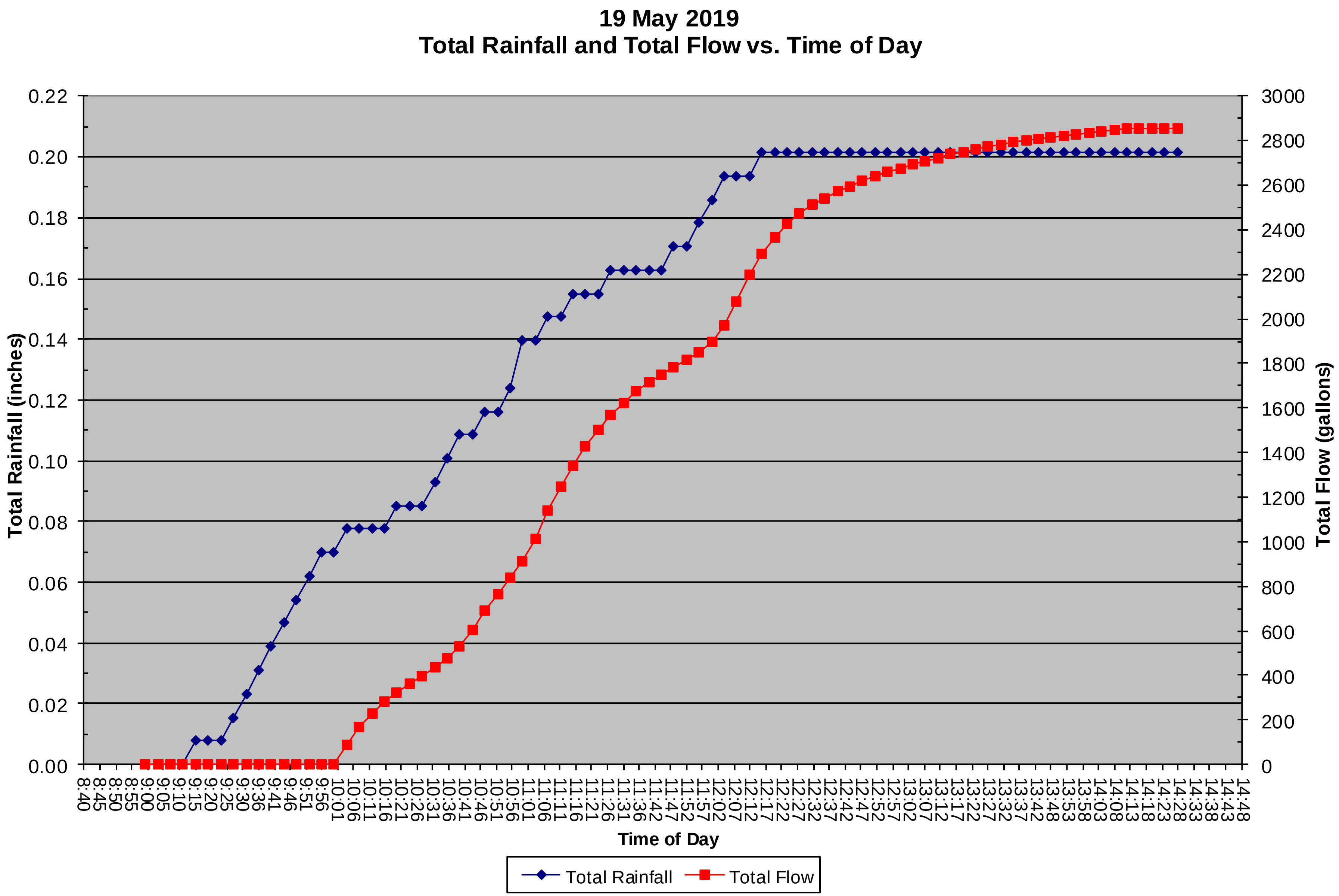
10 May 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow



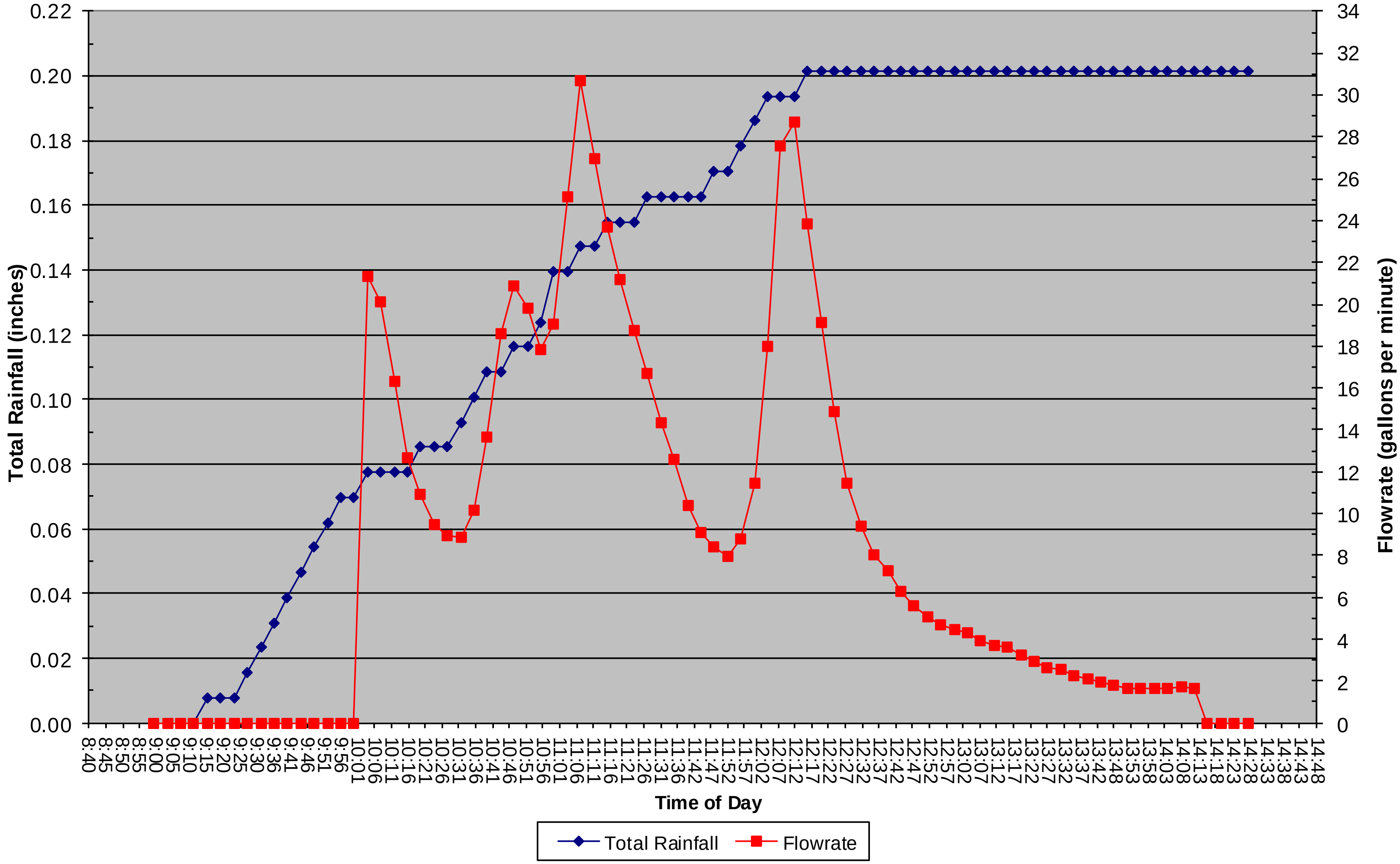
10 May 2019
Total Rainfall and Flowrate vs. Time of Day
Total Rainfall (inches)
Flowrate (gallons per minute)
Time of Day
Total Rainfall
Flowrate

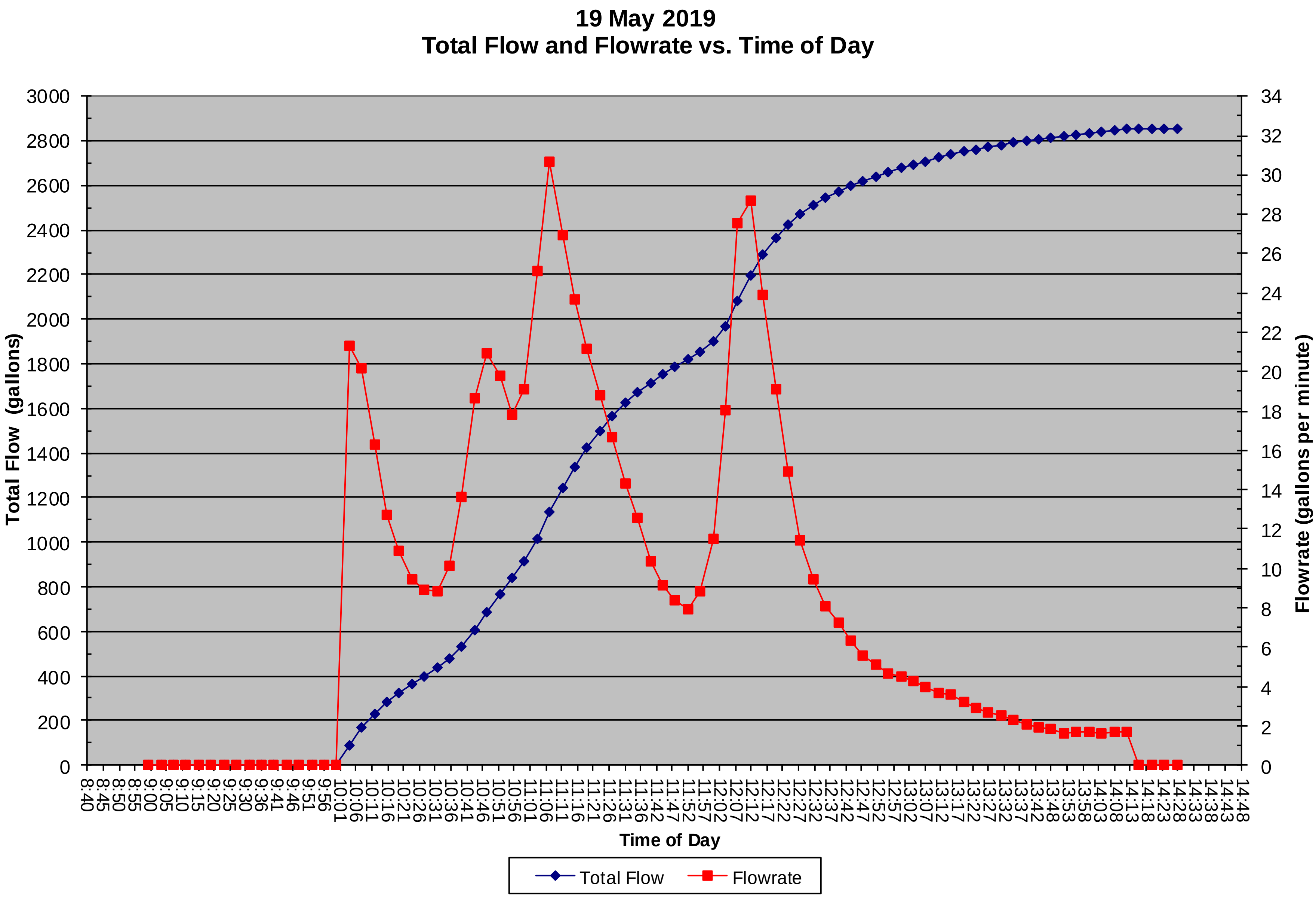

10 May 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

G-52


19 May 2019
Total Rainfall and Total Flow vs. Time of Day
Total Rainfall (inches)
Total Flow (gallons)
Time of Day
Total Rainfall
Total Flow

19 May 2019
Total Rainfall and Flowrate vs. Time of Day




19 May 2019
Total Flow and Flowrate vs. Time of Day
Total Flow (gallons)
Flowrate (gallons per minute)
Time of Day
Total Flow
Flowrate

This Page Intentionally Blank

Appendix H: Points of Contact

POC Name	ORGANIZATION Name Address	Phone E-mail	Role in Project
Gary Anguiano	EXWC 1000 23rd Ave, Port Hueneme, CA 93043	P: 805-982-1302 gary.anguiano@navy.mil	Principal Investigator: working with the customer, vendor, contractors, and technical support team
Mark Foreman	EXWC 1000 23rd Ave, Port Hueneme, CA 93043	P: 805-982-2644 mark.foreman@navy.mil	Lead Engineer: Design and project engineer providing technical support, testing design, construction oversight, and contract management
James Pilkington	EXWC 1000 23rd Ave, Port Hueneme, CA 93043	P: 805-982-1335 james.pilkington@navy.mil	Project Engineer: Test bed design and field support, technology transfer.
Rob Chichester	NAVFAC Southwest	P: (619) 553-0526 robert.a.chichester@navy.mil	NBPL Installation Environmental Program Director.
Mitch Whitson	Whitson Construction Company 11021 Via Frontera, Ste E, San Diego, CA 92127	P: 858-673-0966 mitch@whitsoncm.com	Contractor: Field supervisor, crew leader for installation

Appendix I: Infiltration Tests

This Page Intentionally Blank

California Filtration Specialists
www.californiafiltrationspecialists.com

Rub-I Infiltrometer Report

Project: Hybrid Low impact Development/Best Management practice for DoD Industrial Site Storm Water Runoff
Location: 271 Catalina Boulevard, San Diego, CA 92106
Date of Inspection & Testing: 7/26/19, 9:30 am
Certified Technician: Kevin Rettig

The Rub-I Infiltrometer is a device that verifies engineered soil performance, construction and long-term performance. The Rub-I Infiltrometer was designed to test the effectiveness of high flow soils and to ensure post-construction performance.

Test Methodology:

- Test locations are determined based on: 1) Location near the perimeter of the system 2) The footprint of the system (typically one test location per 200 sf).
- Cover material on top of engineered soil/media is removed to expose the soil.
- Soil profile depth is confirmed by using a shovel to dig to underdrain stone. Depth of soil is measured. Soil is replaced to its original location.
- A 6" PVC Pipe is driven into the soil until the pipe reaches the underlying bridging stone. The 6" PVC pipe will extend from the bridging stone to a minimum of 3" above the top of the soil (see figure 1).
- 2" dissipator stones are placed inside of the 6" PVC Pipe
- A gate valve and a clear PVC cylinder are attached to the 6" PVC Pipe.
- Measurements are taken from the original soil surface to 1 ft, 2ft, 3ft, 4ft and 5 ft gradations. These measurements are marked on the clear PVC cylinder.
- The clear PVC cylinder is filled with three gallons of water and released into the soil. This initial wetting creates a worst-case flow rate scenario (i.e. saturated condition). Once the water has dispersed from the PVC cylinder a drain down time of 25 minutes is allowed to ensure free water has drained through the media.
- Once 25 minutes has passed, the PVC cylinder is filled with water until the water level reaches the top of the PVC cylinder.
- The gate valve is slowly opened, and water is released into the soil. A timer is started as the water level reaches the 5 ft gradation and recorded at each gradation. The timer is stopped when the water level reaches the 1 ft mark.
- Pass/Fail Criteria is based on maximum drawdown tables shown in table 1.

Results:

Gradation	5 ft	4 ft	3 ft	2 ft	1 ft
Time	0	1 min 6 sec	2 min 12 sec	3 min 42 sec	5 min 37 sec

Media Depth: 15 inches
Maximum Allowable Drawdown Time: 22 min 51 sec
Pass/Fail: **PASS**

11021 Via Frontera, Suite E San Diego, CA 92127
P: 858-705-6483 F: 858-487-8355

FIGURE 1:

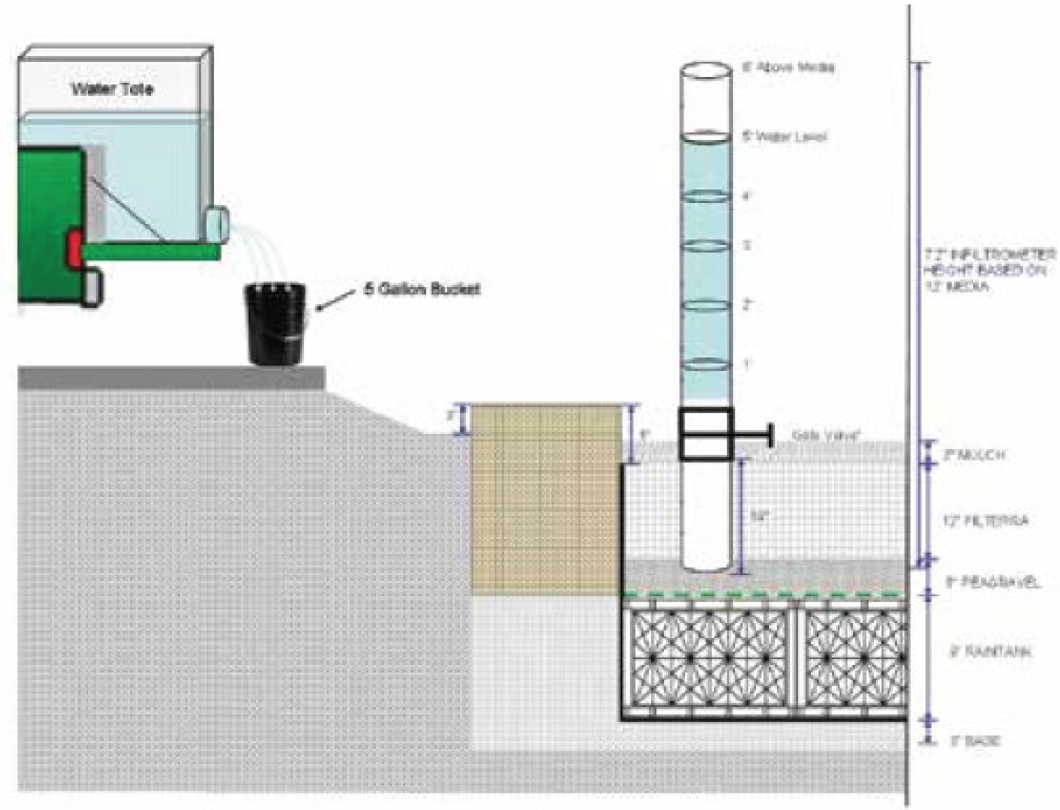


TABLE 1:

Media Depth (inches)	Max Drawdown Time (min:sec)
12	18:18
14	21:24
16	24:18
18	27:00
20	29:30
22	31:54
24	34:06
26	36:12
28	38:12
30	40:00
32	41:42
34	43:24
36	44:54
38	46:18
40	47:42
42	49:00
44	50:12
46	51:24
48	52:30

11021 Via Frontera, Suite E San Diego, CA 92127
P: 858-705-6483   F: 858-487-8355

Rub-I Infiltrometer Report

Project: Hybrid Low impact Development/Best Management practice for DoD Industrial Site Storm Water Runoff
Location: 271 Catalina Boulevard, San Diego, CA 92106
Date of Inspection & Testing: 12/18/19, 9:00 am
Certified Technician: Kevin Rettig

The Rub-I Infiltrometer is a device that verifies engineered soil performance, construction and long-term performance. The Rub-I Infiltrometer was designed to test the effectiveness of high flow soils and to ensure post-construction performance.

Test Methodology:

- Test locations are determined based on: 1) Location near the perimeter of the system 2) The footprint of the system (typically one test location per 200 sf).
- Cover material on top of engineered soil/media is removed to expose the soil.
- Soil profile depth is confirmed by using a shovel to dig to underdrain stone. Depth of soil is measured. Soil is replaced to its original location.
- A 6" PVC Pipe is driven into the soil until the pipe reaches the underlying bridging stone. The 6" PVC pipe will extend from the bridging stone to a minimum of 3" above the top of the soil (see figure 1).
- 2" dissipator stones are placed inside of the 6" PVC Pipe
- A gate valve and a clear PVC cylinder are attached to the 6" PVC Pipe.
- Measurements are taken from the original soil surface to 1 ft, 2ft, 3ft, 4ft and 5 ft gradations. These measurements are marked on the clear PVC cylinder.
- The clear PVC cylinder is filled with three gallons of water and released into the soil. This initial wetting creates a worst-case flow rate scenario (i.e. saturated condition). Once the water has dispersed from the PVC cylinder a drain down time of 25 minutes is allowed to ensure free water has drained through the media.
- Once 25 minutes has passed, the PVC cylinder is filled with water until the water level reaches the top of the PVC cylinder.
- The gate valve is slowly opened, and water is released into the soil. A timer is started as the water level reaches the 5 ft gradation and recorded at each gradation. The timer is stopped when the water level reaches the 1 ft mark.
- Pass/Fail Criteria is based on maximum drawdown tables shown in table 1.

Results:

Gradation	5 ft	4 ft	3 ft	2 ft	1 ft
Time	0	1 min 42 sec	2 min 48 sec	4 min 13 sec	6 min 07 sec

Media Depth: 15 inches
Maximum Allowable Drawdown Time: 22 min 51 sec
Pass/Fail: **PASS**

FIGURE 1:

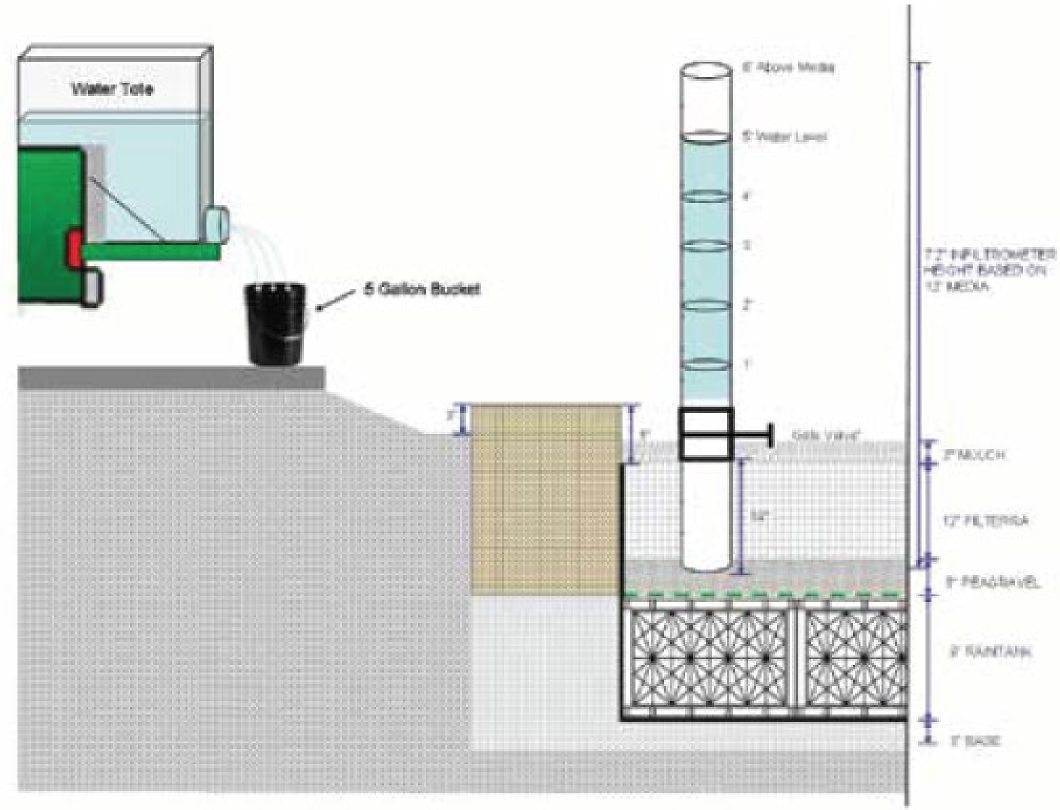


TABLE 1:

Media Depth (inches)	Max Drawdown Time (min:sec)
12	18:18
14	21:24
16	24:18
18	27:00
20	29:30
22	31:54
24	34:06
26	36:12
28	38:12
30	40:00
32	41:42
34	43:24
36	44:54
38	46:18
40	47:42
42	49:00
44	50:12
46	51:24
48	52:30

Appendix J: Quality Control Sampling Data

1.0 Quality Control Samples: Field Duplicates

Field duplicates are required for 10% of the total number influent and effluent samples (i.e. 14 storm events would result in 28 samples, therefore duplicate requirement is 3).

1.1 Metals Field Duplicates at Effluent

Table J-1. Metal Field Duplicates

Quality Control Samples: Metals Field Duplicates at Effluent				
Date	Total Copper (µg/L)	Dissolved Copper (µg/L)	Total Zinc (µg/L)	Dissolved Zinc (µg/L)
11/29/18	5.67	2.1	9.3	5.3
12/5/18	5.71	1.89	11.2	8.0
1/5/19	3.21	0.92	4.9	3.1

1.2 TSS Field Duplicates at Effluent

Table J-2. Total Suspended Solids Field Duplicates

Quality Control Samples: TSS Field Duplicates at Effluent	
Date	TSS (mg/L)
11/29/18	9.2
12/5/18	4.8
1/5/19	2.7

1.3 PSD Field Duplicates at Effluent

Table J-3. Particle Size Distribution Field Duplicates

Tape Quality Control Samples: PSD Field Duplicates at Effluent		
Date	PSD, >63 micron (mg/L)	PSD, <63 micron (mg/L)
1/5/19	2.4	3.4
1/14/19	2.3	3.4
2/13/19	3.4	2.8

1.4 Oil Duplicates, Total Petroleum Hydrocarbons at Effluent

Table J-4. Oil and Grease Duplicates

Quality Control Samples: O&G Duplicates at Effluent	
Date	**O&G (1664) (mg/L)**
11/29/18	ND^{U}
12/5/18	2.4^{J}
1/5/19	3.4^{J}
3/11/18	1.8^{J}
3/20/19	ND^{U}

^{J} <Minimum Reporting Limit, estimated value.

^{U} The analyte was analyzed for, but was not detected at or above the MRL/MDL

Table J-5. In Situ NWTPH-Dx Duplicates

Quality Control Samples: O&G Duplicates at Effluent		
Date	**DRO (µg/L)**	**RRO (µg/L)**
2/13/19	150^{J}	160^{J}
5/16/19	380^{Y}	370^{J}

^{J} <Minimum Reporting Limit, estimated value

^{Y} The chromatographic fingerprint of the sample resembles a petroleum product eluting in approximately the correct carbon range, but the elution pattern does not match the calibration standard.

1.5 Total Phosphorous Duplicates at Effluent

Table J-6. Total Phosphorous Duplicates

Quality Control Samples: Total Phosphorus Duplicates at Effluent	
Date	**TP (mg/L)**
11/29/18	0.030
12/5/18	0.024
1/5/19	0.012

1.6 Orthophosphate Duplicates at Effluent

Table J-7. Orthophosphate Duplicates

Quality Control Samples: Orthophosphate Duplicates at Effluent	
Date	**Orthophosphate (mg/L)**
11/29/18	ND[U]
12/5/18	ND[U]
1/5/19	ND[U]

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL

1.7 Total Hardness $CaCO_3$ Duplicates at Effluent

Table J-8. Total Hardness $CaCO_3$ Duplicates

Quality Control Samples: Total Hardness $CaCO_3$ Duplicates at Effluent	
Date	**Orthophosphate (mg/L)**
11/29/18	81.2
12/5/18	38.8
1/5/19	61.2

1.8 In Situ pH Duplicates at Effluent

Table J-9. pH Duplicates at Effluent

Quality Control Samples: In Situ pH Duplicates at Effluent	
Date	**pH (S.I.)**
11/29/18	7.4
2/13/19	8.7
5/16/19	7.8

2.0 Quality Control Samples: Influent Rinsate Blanks

The required number of rinsate blanks is three for TSS, TP, Orthophosphate, Total Dissolved Copper and Zinc, and Hardness $CaCO_3$.

Table J-1. Rinsate Blanks at Influent

Quality Control Samples: Field Rinsate Blanks at Influent			
Parameter	Date		
	29 Nov 2018	5 Dec 2018	14 Jan 2019
Total Copper (µg/L)	0.71	0.65	0.51
Dissolved Copper (µg/L)	0.36	0.37	0.31
Total Zinc (µg/L)	4.6	6.0	4.1
Dissolved Zinc (µg/L)	3.6	3.8	4.7
TSS (mg/L)	ND[U]	ND[U]	ND[U]
TP (mg/L)	0.005[J]	ND[U]	ND[U]
Orthophosphate (mg/L)	ND[U]	ND[U]	ND[U]
Total Hardness $CaCO_3$ (mg/L)	0.8[J]	ND[U]	ND[U]

[J] <Minimum Reporting Limit, estimated value.

[U] The analyte was analyzed for, but was not detected at or above the MRL/MDL

This Page Intentionally Blank