Task 4: Semiannual CSO Discharge Report No. 4

July 1, 2019 – December 31, 2019

CSO Post Construction Monitoring and Performance Assessment
MWRA Contract No. 7572

April 30, 2020

Project number: 60559027

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Definitions

Combined Sewer: A sewer that conveys stormwater and wastewater of domestic, commercial, and industrial origin. When wastewater and stormwater flows exceed the sewer capacity, overflows can occur. These overflows are called Combined Sewer Overflows (CSOs).

Combined Sewer Regulator: A CSO regulator controls flow by directing normal dry weather flow and a portion of wet weather flow to an interceptor for conveyance to full treatment. Excess wet weather flow is directed to an overflow conduit.

Continuity: A term used in fluid mechanics to describe the principle of conservation of mass. The continuity equation states that the flow rate for an incompressible fluid can be calculated by multiplying the area of flow by the average flow velocity.

Discharge Permits (NPDES): A permit issued by the U.S. EPA or a State regulatory agency under the National Pollutant Discharge Elimination System (NPDES) that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water. It also includes a compliance schedule for achieving those limits. The NPDES process was established under the Federal Clean Water Act.

Diversion Structure: A diversion structure that diverts flow to either the associated control facility (i.e., tunnel, storage tank, etc.) or the CSO outfall if the capacity of the control measure is exceeded.

Doppler Velocity Meter: A velocity measurement device using sound pulses emitted in the upstream direction. The device records the reflection of these pulses on particles in the water from which the flow velocity can be quantified

Depth and Velocity Sensor: A device used to measure velocity and water level at a monitoring location from which the flowrate can be quantified.

Hydrograph Analysis: Analysis of graphical plots comparing the rate of flow versus time.

Hyetograph: A graphical plot of precipitation data over time. Graph of rainfall intensity during a storm event.

Inclinometer: A measurement device that is mounted on a tide gate and used to measure the angle of opening of a tide gate as a function of time.

Intensity-Duration-Frequency (IDF) Curve: A mathematical function that relates the rainfall intensity with its duration and frequency of occurrence. These curves are commonly used in hydrology for flood forecasting and civil engineering for urban drainage design. IDF curves are also analyzed in hydrometeorology because of the interest in the time-structure of rainfall.

Intrusion Velocity: A velocity measurement made with a Peak Velocity sensor in which the sensor is facing towards a tide gate to spot reverse flow through a tide gate.

Level Sensor (or Level Meter): A device used to measure flow depth at a monitoring location.

Long-Term Control Plan: A phased approach required under the Environmental Protection Agency's CSO Control Policy and part of the strategy to control CSOs. LTCPs aim to reduce the frequency, duration, and volume of CSO events through system characterization, development and evaluation of alternatives, and selection and implementation of controls. For this report, the term LTCP refers to the plan developed by MWRA in the 1990s to reduce CSO volumes in the cities of Boston, Cambridge, Somerville and Chelsea.

Manning's Equation: An empirical equation for calculating flow rate or velocity that applies to uniform flow in open channels and is a function of the channel roughness, flow area, wetted perimeter and channel slope.

Meter: An instrument for measuring and recording data such as water level, velocity, or both. Flow meters typically measure water level and velocity from which the flowrate can be calculated.

Nine Minimum Controls (NMCs): Technology-based controls that address CSOs without extensive engineering studies or significant construction costs.

Precipitation: The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture.

Pressure Sensor (Dp): A device used to measure the depth of water by determining the force acting on the sensor based on the water level above the sensor.

Rain gauge: An instrument that measures the amount of rain that has fallen in a particular place at a set time interval.

Regression Analysis: A statistical process that produces a mathematical function (regression equation) that relates a dependent variable to independent variable.

Scattergraph: A plot of individual measurements of different values used to evaluate whether metered data adheres to hydraulic theory and forms expected hydraulic patterns. For this project, scattergraphs show either flow velocity vs. water depths for a flow monitor or the depth and intensity of rainfall required to generate overflows according to available data.

Sediment: Particulate material deposited at the bottom of a conduit or natural waterway.

Tributary: The area that contributes flow to a point in the sewer system.

Typical Year Rainfall or Typical Year: The performance objectives of MWRA's approved Long-Term CSO Control Plan include annual frequency and volume of CSO discharge at each outfall based on "Typical Year" rainfall from 40 years of rainfall records at Logan Airport, 1949-1987 plus 1992.
The Typical Year was a specifically constructed rainfall series that was based primarily on a single year (1992) that was close to the 40-year average in total rainfall and distribution of rainfall events of different sizes. The rainfall series was adjusted by adding and subtracting certain storms to make the series closer to the actual averages in annual precipitation, number of storms within different ranges of depth and storm intensities. The development of the Typical Year is described in MWRA's System Master Plan Baseline Assessment, June 15, 1994. The Typical Year consists of 93 storms with a total precipitation of 46.8 inches.

Ultrasonic Sensors (Du): A device used to measure depth of water by the use of ultrasonic waves, determined by the travel time between the emission and reception of the wave reflected back from the target.

Weir: A wall or plate placed perpendicular or parallel to the flow. The depth of flow over the weir can be used to quantify the flow rate through a calculation or use of a chart or conversion table.

1. Introduction

1.1 Purpose and Scope of the Semiannual CSO Discharge Report

On November 8, 2017, the Massachusetts Water Resources Authority (MWRA) commenced a multi-year study to measure the performance of its $912 million long-term combined sewer overflow ("CSO") control plan (the "Long-Term Control Plan" or "LTCP"). This is the fourth of seven planned semiannual reports on the progress of this study (Table 1-1).

Table 1-1. Semiannual CSO Discharge Reports

Report #	Data Collection Period	Schedule
1 - link	April 15 to June 30, 2018 (2.5 months)	Nov. 2018 - complete
2 - link	July 1 to December 31, 2018 (6 months)	Apr. 2019 - complete
3 - link	January 1 to June 30, 2019 (6 months)	Oct. 2019 - complete
4	July 1 to December 31, 2019 (6 months)	Apr. 2020 - complete
5	January 1 to June 30, 2020 (6 months)	Oct. 2020
6	July 1 to December 31, 2020 (6 months)	Apr. 2021
7	January 1 to June 30, 2021 (6 months)	Oct. 2021

MWRA's CSO performance assessment is the last scheduled milestone in the nearly 35-year-old Federal District Court Order in the Boston Harbor Case (U.S. v. M.D.C., et al, No. 85-0489 MA). MWRA has addressed 183 CSO-related court schedule milestones, including completion of the thirty-five (35) wastewater system projects that comprise the LTCP by December 2015 and commencement of the CSO performance assessment by January 2018 (which, as noted above, MWRA met in November 2017). The last court milestone requires MWRA to submit the results of its performance assessment to the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP) by December 2021[1]. This assessment will demonstrate whether the levels of CSO control specified in the LTCP have been achieved. MWRA's obligations for CSO control under the Court Order are defined in the March 15, 2006, *Second Stipulation of the United States and the Massachusetts Water Resources Authority on Responsibility and Legal Liability for Combined Sewer Overflow Control*, as amended on April 30, 2008 (the "Second Stipulation"). For more information about MWRA's federal court obligations for CSO control, see Section 1.3.5 in Semiannual CSO Discharge Report No. 2, May 3, 2019, at: http://www.mwra.com/cso/pcmpa-reports/2_050319_MWRA_w_appendices.pdf.

The CSO performance assessment includes the following key scope elements:

- Inspections at all CSO regulators addressed in the LTCP to confirm closed or active status and to confirm or update the physical and hydraulic conditions of the CSO regulators and outfalls that remain active
- Collection of extensive rainfall data and overflow related data (field measurements) at remaining CSO regulators
- Upgrade and improvement of the calibration of MWRA's hydraulic model of the wastewater system using inspection information and overflow data

[1] On July 19, 2019, Federal District Court Judge Richard G. Stearns issued an order extending the milestone for submission of the final report by one year, from December 31, 2020 to December 31, 2021. MWRA had requested the extension to provide the time necessary to perform receiving water quality modeling to support water quality assessments for the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River.

- Assessment of system performance for CSO control, and the consideration of performance improvements
- Assessment of the water quality impacts of remaining CSOs and compliance with Massachusetts Water Quality Standards

1.2 Progress of CSO Post-Construction Monitoring and Performance Assessment

MWRA has continued to make substantial progress with its CSO and rainfall monitoring programs and performance assessments. This fourth semiannual progress report documents data collection and analyses and CSO discharge estimates for the period July 1, 2019 through December 31, 2019, and other related work activities since issuance of the third semiannual report in October 2019. Completed and ongoing investigations, evaluations and interim performance assessments discussed in this report target the attainment of Long-Term Control Plan levels of control and support final assessments that MWRA will present in the December 2021 final report. Information presented herein includes:

- Description of MWRA's hydraulic model, recent model updates, improved model calibration, and an assessment of the accuracy of the model (Section 2)
- Collection and analyses of rainfall data and CSO discharge meter data for the period July 1 to December 31, 2019, and comparison of metered and modeled estimates of CSO discharges during calendar years 2018 and 2019 (Section 3)
- Comparison of Typical Year CSO discharges for 2019 system conditions and the Long Term Control Plan (LTCP) Levels of Control (Section 4)
- Investigations into the system conditions contributing to higher overflow activity at certain locations, and the evaluation of CSO regulator modifications and other system or system flow adjustments that may help to attain the LTCP levels of control (Section 5)
- Progress with the development of receiving water quality models for the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River, and supporting water quality sampling efforts (Section 6)
- Progress toward the fifth semiannual report (October 2020), with data collected January 1 to June 30, 2020 (Section 7)

1.2.1 Hydraulic Modeling

In early 2020, MWRA completed recalibration of its hydraulic model using extensive meter data collected in 2018. MWRA then updated the model to 2019 system conditions and verified the model's CSO predictions for 2019 rainfall against 2019 meter data. MWRA was then able to simulate the performance of the system with Typical Year rainfall and compare current CSO performance with the Long-Term Control Plan goals.

1.2.2 Data Collection and Analyses

MWRA has continued to collect and analyze rainfall data at the 20 gauges within the MWRA wastewater service area it has utilized for the CSO performance assessment since the beginning of the data collection efforts in April 2018. Most of these gauges are located in or near areas served by combined sewers. The rainfall data are analyzed to determine the rainfall characteristics of each storm in the collection period, including storm duration, total volume/depth of rain, average rainfall intensity, peak rainfall intensities and storm recurrence interval (e.g., 3-month storm, 1-year storm, etc.). The rainfall characteristics support a comparison of the collection period storms to the Typical Year (see Section 3.1.2) and the validation of measured CSO discharges (Section 3.2 and Appendix E). In addition, rainfall data are input to the calibrated model to produce storm-by-storm model-predicted CSO discharges (Section 3.3).

Section 3.2 presents a summary of the metering program and the meter results for the period July 1, 2019 through December 31, 2019. MWRA has continued to employ CSO metering technology at 36 potentially active CSO regulators, after removing temporary meters at 21 additional locations on March 1, 2019 (Section 3.2.1 and semiannual progress reports No. 2 and No. 3). Temporary meters at the 36 locations will remain in place and operational until June 30, 2020. MWRA will continue to collect, analyze and use data from these temporary meters, along with data from permanent meters at CSO treatment facilities and in MWRA's interceptor system and data from temporary or permanent CSO meters maintained by the CSO communities (Boston Water and Sewer Commission and the cities of Cambridge, Chelsea and Somerville). Some of the 36 temporary meter installations will remain in place beyond June 2020 to support ongoing site-specific investigations and the evaluation of potential system modifications that may improve CSO performance (Section 5). Meters will remain in place at all CSO regulators associated with outfalls along the Charles River, the Alewife Brook and the Upper Mystic River to support CSO notification requirements as included in the variance requirements for the Alewife/Mystic and Lower Charles River/Charles Basin.

1.2.3 Interim Assessment of Typical Year Performance and Attainment of LTCP Levels of Control

Updated calibration of MWRA's hydraulic model has allowed MWRA to use the model to simulate current system performance under Typical Year rainfall and compare the results with the Long-Term Control Plan's Typical Year levels of control. Section 4 presents and evaluates the model results, identifies the locations where CSO discharges are eliminated (all of the outfalls required to be closed and several additional outfalls closed by the CSO communities), the discharge locations that the model predicts currently meet the LTCP levels of control, and the discharge locations where additional investigations are needed. Section 5 discusses how MWRA has been responding, with the support of its CSO communities, to locations where significant differences are predicted between the current CSO discharge estimates and the LTCP levels of control.

1.2.4 Site-Specific Overflow Activity Investigations

Since 2018, when it began to obtain information from its temporary CSO meters, MWRA has been conducting investigations for the regulators and outfalls where CSO discharge estimates indicate significantly higher CSO activity than the LTCP goals. MWRA has closely coordinated these investigations with its CSO communities, which continue to provide critically needed support. The investigations include identifying the current site-specific wastewater system conditions that may be contributing to higher activity and evaluating and recommending maintenance protocols or system adjustments that can reduce CSO discharges toward meeting LTCP goals.

From these investigations, certain maintenance and system adjustments have already been implemented and incorporated into MWRA's hydraulic model. Other recommended system adjustments may be implemented by MWRA and the CSO communities during the performance assessment if determined to be effective without causing adverse impacts (e.g., unacceptable wastewater levels in upstream or downstream systems). Section 5 describes the progress and findings of these site-specific investigations.

1.2.5 Water Quality Assessments, Receiving Water Quality Modeling, and Water Quality Sampling

The scope of MWRA's post-construction monitoring and CSO performance assessment also includes assessments of whether remaining CSO discharges comply with Massachusetts Surface Water Quality Standards (also see Section 1.4 "Massachusetts Water Quality Standards and CSO Variances,"). For waters designated Class B (Neponset River) or Class SB (Constitution Beach, South Dorchester Bay and North Dorchester Bay), CSO is prohibited, i.e., must be eliminated. For the South Boston beaches of North Dorchester Bay, a 25-year storm level of CSO control is considered "effective elimination." For waters designated Class B(cso) (Muddy River/Back Bay Fens) or Class SB(cso) (Mystic/Chelsea Confluence, Boston Inner Harbor, Fort Point Channel and Reserved Channel), CSO discharges comply with Water Quality Standards if they meet the Long-Term Control Plan levels of control.

For the waters designated Class B(CSO Variance), including the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River, limited CSO discharges are authorized for the period that CSO variances to Water Quality Standards are in effect (currently through August 31, 2024). MWRA anticipates supporting DEP in their efforts to issue long-term water quality standards designations and associated required levels of CSO control after the CSO variance period and with information obtained in part through conditions in the variances. For these variance waters, MWRA reached agreement with EPA and DEP in 2019 to add receiving water quality modeling and supporting water quality sampling to its CSO performance assessment. MWRA will use receiving water model results to assess the water quality impacts of remaining CSO discharges to these waters for compliance with water quality standards. Section 6 of this report describes MWRA's progress with development of the receiving water quality models and the water quality sampling program, and supporting assistance from its CSO communities that lie along these waters.

1.3 LTCP Levels of CSO Control

The long-term levels of CSO control recommended by MWRA in the LTCP, approved by EPA and DEP, and accepted by the Court are included in Exhibit B to the Second Stipulation and presented in Table 1-2, below. Table 1-3 presents the LTCP levels of control on a receiving water segment basis, along with the LTCP projects and costs that contribute to meeting the level of control for each water segment. The 35 LTCP projects were completed and brought into beneficial service in the period 2006 through 2015 in compliance with court schedule milestones for design and construction of each project. Information describing each of the LTCP projects, along with cost and schedule, was presented in the first and second semiannual progress reports, which are posted to MWRA's website at http://www.mwra.com/cso/pcmapa.html.

Table 1-2. LTCP Levels of Control from Exhibit B to the Second Stipulation (1 of 3)

CSO OUTFALL	LONG TERM CONTROL PLAN	
	TYPICAL YEAR	
	Activation Frequency	Volume (MG)
ALEWIFE BROOK		
CAM001	5	0.19
CAM002	4	0.69
MWR003	5	0.98
CAM004	To be closed	N/A
CAM400	To be closed	N/A
CAM401A	5	1.61
CAM401B	7	2.15
SOM001A	3	1.67
SOM001	Closed	N/A
SOM002A	Closed	N/A
SOM003	Closed	N/A
SOM004	Closed	N/A
TOTAL		**7.29**
UPPER MYSTIC RIVER		
SOM007A/MWR205A (Somerville Marginal)	3	3.48
SOM007	Closed	N/A
TOTAL		**3.48**
MYSTIC / CHELSEA CONFLUENCE		
MWR205 (Somerville Marginal)	39	60.58
BOS013	4	0.54
BOS014	0	0.00
BOS015	Closed	N/A
BOS017	1	0.02
CHE002	4	0.22
CHE003	3	0.04
CHE004	3	0.32
CHE008	0	0.00
TOTAL		**61.72**

Table 1-2. LTCP Levels of Control from Exhibit B to the Second Stipulation (2 of 3)

CSO OUTFALL	LONG TERM CONTROL PLAN	
	TYPICAL YEAR	
	Activation Frequency	Volume (MG)
UPPER INNER HARBOR		
BOS009	5	0.59
BOS010	4	0.72
BOS012	5	0.72
BOS019	2	0.58
BOS050	Closed	N/A
BOS052	Closed	N/A
BOS057	1	0.43
BOS058	Closed	N/A
BOS060	0	0.00
MWR203 (Prison Point)	17	243.00
TOTAL		**246.04**
LOWER INNER HARBOR		
BOS003	4	2.87
BOS004	5	1.84
BOS005	1	0.01
BOS006	4	0.24
BOS007	6	1.05
TOTAL		**6.01**
CONSTITUTION BEACH		
MWR207	Closed	N/A
TOTAL		**0.00**
FORT POINT CHANNEL		
BOS062	1	0.01
BOS064	0	0.00
BOS065	1	0.06
BOS068	0	0.00
BOS070		
BOS070/DBC	3	2.19
UPPS	17	71.37
BOS070/RCC	2	0.26
BOS072	0	0.00
BOS073	0	0.00
TOTAL		**73.89**
RESERVED CHANNEL		
BOS076	3	0.91
BOS078	3	0.28
BOS079	1	0.04
BOS080	3	0.25
TOTAL		**1.48**

Table 1-2. LTCP Levels of Control from Exhibit B to the Second Stipulation (3 of 3)

CSO OUTFALL	LONG TERM CONTROL PLAN	
	TYPICAL YEAR	
	Activation Frequency	Volume (MG)
NORTHERN DORCHESTER BAY		
BOS081	0 / 25 year	N/A
BOS082	0 / 25 year	N/A
BOS083	0 / 25 year	N/A
BOS084	0 / 25 year	N/A
BOS085	0 / 25 year	N/A
BOS086	0 / 25 year	N/A
BOS087	0 / 25 year	N/A
TOTAL		**0.00**
SOUTHERN DORCHESTER BAY		
BOS088	To be closed	N/A
BOS089 (Fox Point)	To be closed	N/A
BOS090 (Commercial Point)	To be closed	N/A
TOTAL		**0.00**
UPPER CHARLES		
BOS032	Closed	N/A
BOS033	Closed	N/A
CAM005	3	0.84
CAM007	1	0.03
CAM009	2	0.01
CAM011	0	0.00
TOTAL		**0.88**
LOWER CHARLES		
BOS028	Closed	N/A
BOS042	Closed	N/A
BOS049	To be closed	N/A
CAM017	1	0.45
MWR010	0	0.00
MWR018	0	0.00
MWR019	0	0.00
MWR020	0	0.00
MWR021	Closed	N/A
MWR022	Closed	N/A
MWR201 (Cottage Farm)	2	6.30
MWR023	2	0.13
SOM010	Closed	N/A
TOTAL		**6.88**
NEPONSET RIVER		
BOS093	Closed	N/A
BOS095	Closed	N/A
TOTAL		**0.00**
BACK BAY FENS		
BOS046	2	5.38
TOTAL		**5.38**

Table 1-3. LTCP Levels of Control by Receiving Water and Related Projects and Cost

Receiving Water	LTCP Levels of Control (Typical Year Rainfall) Activations	Volume (million gallons)	LTCP Projects*	Capital Cost* ($ millions)
Alewife Brook/Upper Mystic River	7 untreated and 3 treated at Somerville Marginal	Untreated 7.3 Treated 3.5	• Cambridge/Alewife Sewer Separation • MWR003 Gate and Rindge Siphon Relief • Interceptor Connections/Floatables • Connection/Floatables at Outfall SOM01A • Somerville Baffle Manhole Separation • Cambridge Floatables Control (portion)	$110.0
Mystic River/Chelsea Creek Confluence and Chelsea Creek	4 untreated and 39 treated at Somerville Marginal	Untreated 1.1 Treated 57.1	• Somerville Marginal CSO Facility Upgrade • Hydraulic Relief at BOS017 • BOS019 Storage Conduit • Chelsea Trunk Sewer Replacement • Chelsea Branch Sewer Relief • CHE008 Outfall Repairs • East Boston Branch Sewer Relief (portion)	$92.0
Charles River (including Stony Brook and Back Bay Fens)	3 untreated and 2 treated at Cottage Farm	Untreated 6.8 Treated 6.3	• Cottage Farm CSO Facility Upgrade • Stony Brook Sewer Separation • Hydraulic Relief at CAM005 • Cottage Farm Brookline Connection and Inflow Controls • Brookline Sewer Separation • Bulfinch Triangle Sewer Separation • MWRA Outfall Closings and Floatables Control • Cambridge Floatables Control (portion)	$88.9
Inner Harbor	6 untreated and 17 treated at Prison Point	Untreated 9.1 Treated 243.0	• Prison Point CSO Facility Upgrade • Prison Point Optimization • East Boston Branch Sewer Relief (portion)	$47.5
Fort Point Channel	3 untreated and 17 treated at Union Park	Untreated 2.5 Treated 71.4	• Union Park Treatment Facility • BOS072-073 Sewer Separation and System Optimization • BWSC Floatables Control • Lower Dorchester Brook Sewer Modifications	$62.0
Constitution Beach	Eliminate		• Constitution Beach Sewer Separation	$3.7
North Dorchester Bay	Eliminate		• N. Dorchester Bay Storage Tunnel and Related Facilities • Pleasure Bay Storm Drain Improvements • Morrissey Blvd Storm Drain	$253.7
Reserved Channel	3 untreated	Untreated 1.5	• Reserved Channel Sewer Separation	$70.5
South Dorchester Bay	Eliminate		• Fox Point CSO Facility Upgrade (interim improvement) • Commercial Pt. CSO Facility Upgrade (interim improvement) • South Dorchester Bay Sewer Separation	$126.6
Neponset River	Eliminate		• Neponset River Sewer Separation	$2.4
Regional			• Planning, Technical Support and Land Acquisition	$55.1
TOTAL **Treated**		**410** **381**		**$912**

*Floatables controls at remaining outfalls are included in the listed projects and capital budgets.

1.3.1 Performance Tracking

MWRA has conducted annual CSO performance assessments and CSO discharge tracking for nearly two decades. These efforts have included:

- Annual collection and review of facility operating records, meter data and other system performance indicators
- Updates to the MWRA collection system hydraulic model with new information about system conditions
- Estimation, using model predictions and facility records, of CSO activations and discharge volume at all active outfalls during the previous calendar year
- Updated simulation of CSO discharges from Typical Year rainfall

MWRA has conducted these annual data reviews, updates, and discharge estimates to satisfy reporting requirements in the MWRA and CSO community NPDES permits and in the conditions of the CSO variances for the Charles River and Alewife Brook/Upper Mystic River. These annual updates and assessments, submitted to EPA and DEP by April 30 each year (for the previous calendar year), have also allowed MWRA to measure, track and understand system performance as it continued to implement the LTCP projects.

MWRA incorporates completed sewer system improvements, such as completed CSO projects, significant system or operational changes, and other new information about system conditions into the model. Modeled operations of MWRA facilities, such as pumping stations and CSO treatment facilities, are updated to reflect current operating protocols. While Typical Year simulations employ confirmed and updated standard operating procedures, these standard procedures are adjusted to reflect actual operating conditions from facility records when the model is used to simulate individual storms. Meter data and other system performance indicators are used to compare measured conditions to model results for selected storms.

In addition to modeling all of the actual rainfall events for the previous calendar year, MWRA also models the Typical Year rainfall with end-of-year updated system conditions for each annual report. This has allowed MWRA to compare updated system performance against the levels of control in the LTCP and to track progress toward the CSO control goals, which are based on Typical Year rainfall. To be able to understand and explain the estimated discharges for each calendar year, which can vary greatly from Typical Year predictions, MWRA performs a detailed review and comparison of the characteristics of the year's actual storms to the characteristics of the storms in the Typical Year.

The following sections discusses the changes made to the hydraulic model to better reflect current system conditions, the impact of these changes have on predictions of CSO performance in comparison to the LTCP, and MWRA and CSO Community's continued efforts to further reduce CSO discharges.

1.4 Massachusetts Water Quality Standards and CSO Variances

In 1998, EPA and DEP issued their approvals of MWRA's 1997 recommended CSO control plan. Along with these approvals, DEP issued water quality standards determinations for all CSO-affected receiving water segments. This brought the plan's approved levels of CSO control into compliance with Massachusetts Water Quality Standards. DEP's water quality standards determinations are shown in Table 1-4 on the following page, along with the associated required levels of CSO control.

MWRA's Long-Term Control Plan, a 2006 approved update to the 1997 plan, has eliminated or "effectively eliminated" (i.e., 25-year storm level of control at South Boston beaches) CSO discharges to the waters for which DEP maintained the classification of Class B or Class SB, where CSO discharges are prohibited primarily to protect beaches and shellfish beds. Class B waters are inland waters designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. Class SB waters are coastal and marine waters designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary recreation. The Class B or SB standard indicates that the water is "fishable and swimmable."

For the fresh water segment that DEP designated Class B (Neponset River) and the marine water segments designated Class SB, MWRA confirmed through its CSO performance assessment inspections in 2018 that all CSO regulators other than those tributary to the South Boston beaches are permanently closed, and, therefore, CSO discharges to these Class B and Class SB waters have been eliminated. The South Boston CSO Storage Tunnel captures overflows from all regulators associated with the five remaining CSO outfalls to the South Boston beaches. MWRA evaluated the tunnel's performance utilizing data collected in the many storms since the start-up of the tunnel in May 2011. The goal of the evaluation was to verify whether the tunnel is performing as intended for CSO and separate stormwater control and whether the data shows that the tunnel can provide total CSO capture up to and including the 25-year storm. Tunnel performance was assessed by analyzing record data, during and immediately after storm events, from the various sensors and operational controls installed throughout the South Boston Tunnel system. A 25-year, 24-hour event did not occur in the period of data analysis; therefore, it was necessary to extrapolate from available storm event data to assess whether the tunnel system could meet its 25-year, 24-hour event level of control. The results of the assessment show that the Tunnel has performed as designed and that MWRA has employed a responsive operation and control strategy that provides for attainment of the LTCP levels of control.

Table 1-4. Water Quality Standards and Required Levels of CSO Control

Water Quality Standard Classification	Receiving Water Segment	Required Level of CSO Control	CSO Control Status
Class B	Neponset River	CSO prohibited (25-year storm control for the South Boston beaches)	South Boston (North Dorchester Bay) storage tunnel captures CSO up to 25-year storm. All CSO outfalls to the other sensitive waters are now permanently closed.
Class SB	North Dorchester Bay South Dorchester Bay Constitution Beach		
Class B(cso)	Back Bay Fens	>95% compliance with Class B or SB ("fishable/swimmable") Must meet level of control for CSO activation and frequency in the approved Long-Term Control Plan (LTCP)	All LTCP projects are complete, and CSO discharges are greatly reduced. Ongoing performance assessment is intended to verify whether LTCP levels of control are attained.
Class SB(cso)	Mystic/Chelsea Rivers Confluence Boston Inner Harbor Fort Point Channel Reserved Channel		
Class B (CSO Variance)	Alewife Brook Upper Mystic River Charles River	Class B standards sustained with temporary authorizations for CSO discharges as the LTCP is implemented and verified (1998-2020)	All LTCP projects are complete, and CSO discharges are greatly reduced. Ongoing performance assessment is intended to verify whether LTCP levels of control are attained and to support long-term WQS designations.

For the water segments DEP designated B(cso) or SB(cso), CSO discharges must meet Class B or SB standards (i.e., no CSO impact) at least 95% of the time, or meet a higher level of compliance in accordance with the levels of CSO control in the approved LTCP. For waters designated Class B(cso) or SB(cso) in Table 1-4, compliance with water quality standards will be demonstrated by verifying attainment of the LTCP levels of CSO control (i.e., Typical Year activation frequency and volume).

DEP did not change the Class B designations for the Charles River and the Alewife Brook/Upper Mystic River, but instead issued variances to Class B water quality standards for CSO. Since 1998, DEP has issued a series of multiple-year CSO variances. Each variance acknowledged that it was not feasible to attain the Class B bacteria criteria and associated recreational uses for these receiving waters within the variance period. The variances apply only to the permitted CSO outfalls to these receiving waters and do not otherwise modify Class B water quality standards. The variances allow MWRA and the CSO communities to continue to discharge limited levels of CSO to these waters, provided the variance conditions are met. The conditions are intended to ensure progress on CSO control and mitigation of water quality impairments. Specifically, the variances include detailed requirements in the following categories: levels of control, receiving water quality modeling, performance assessment, public notification of CSO discharges, other actions to minimize CSOs and their impacts, and updated CSO control planning.

On August 30, 2019, DEP issued Final Determinations for CSO variances for Lower Charles River/Charles Basin and Alewife Brook/Upper Mystic River for a five-year period through August 31, 2024. There are two variances, one for the Lower Charles River/Charles Basin to CSO permittees MWRA and the City of Cambridge, and a second for the Alewife Brook/Upper Mystic River to CSO permittees MWRA and the Cities of Somerville and Cambridge. The Final Determinations, including conditions, as well as related fact sheets, are posted to DEP's website at: https://www.mass.gov/guides/sanitary-sewer-systems-combined-sewer-overflows#-2019-charles-river-basin-and-alewife/upper-mystic-river-final-combined-sewer-overflow-variances-.

For the variance waters, in addition to verifying whether the LTCP levels of CSO control are attained, DEP has required MWRA to conduct water quality monitoring and receiving water quality modeling. These efforts are described in Section 6 of this report. MWRA will utilize the receiving water models for the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River, to assess the impacts of remaining CSO discharges and the level of compliance with water quality standards. These assessments are intended to support eventual use attainability analyses, water quality standards reviews and designations, and associated CSO determinations for these waters by the regulatory agencies.

2. Hydraulic Modeling

2.1 Description, Purpose and Use of the Hydraulic Model

The MWRA's hydraulic model is the primary tool used to evaluate the performance of the MWRA system against the Long Term Control Plan's (LTCP) Typical Year levels of control. Environmental variables such as rainfall, tide, and evaporation serve as inputs to the model. These inputs are used by the model to estimate the flow entering the sewer system, as well as the hydraulic performance of the system at regulators. Hydraulic modeling has historically served as the basis for evaluating performance of the CSO system. The hydraulic model was first established in 1992 during early development of the LTCP using the USEPA Storm Water Management Model (SWMM) software[2]. It was then updated and converted to InfoWorks CS in the early 2000's to improve the simulation of hydraulic conditions and better serve MWRA's needs during LTCP implementation. The InfoWorks CS model was recently converted to InfoWorks ICM, the successor modeling software to InfoWorks CS, for this post-construction assessment.

The MWRA model includes the entire MWRA regional collection system, broken into north system (flows to Deer Island via the Columbus Park, Ward Street, Chelsea Creek and Winthrop Terminal headworks) and south system (flows to Deer Island via the Nut Island Headworks). The CSO system is contained in the north system model and includes many of the local sewers within the four CSO communities of Boston, Cambridge, Chelsea, and Somerville. The extent of the MWRA north system model is shown in Figure 2-1. The north system model includes approximately 8100 links, 7700 nodes, and 2500 subcatchments.

Figure 2-1. MWRA InfoWorks ICM Model

2.2 Model Calibration

From the spring of 2018 to early 2020, efforts were taken to upgrade and calibrate MWRA's 2017 system conditions model with recent inspection information and meter data, replicate observed wet weather responses and predict CSO activations. Model calibration is the process of adjusting the model so that the model predictions more closely replicate the observations. The model is run using a set of input data, and the modeled and metered responses are compared. Using the measurements and model predictions, model parameters are then adjusted so that the model more closely replicates the observed response.

[2] USEPA Stormwater Management Model (SWMM) Version 4

As part of the calibration efforts, numerous model parameters were adjusted based on observed measurements, including, but not limited to, time of concentration parameters, infiltration coefficients, in-pipe sediment depth, percentage of impervious area, and pipe roughness coefficients. These changes were made to the model where physical observations of the system and/or metering data suggested that the changes were necessary to reflect the physical state and hydraulic conditions of the sewer system. In assessing the integrity of the calibration, important comparisons include total flow volumes, peak flows, and the shape of the hydrographs for system flows and CSO discharges. At locations where measured and modeled responses were not rectified by standard calibration adjustments, additional investigations were conducted. In some cases, these investigations found missing elements, such as secondary pipes, interconnections, upstream (in-system) weirs, or other phenomena that had impacts on upstream or downstream hydraulics. These were added to the model as appropriate.

The 2018-2020 calibration efforts included thousands of model iterations to bring the model's predictions and the observations closer together. According to the 1999 EPA CSO Guidance for Monitoring and Modeling, an adequate number of storm events (usually 5 to 10) should be monitored and used in model calibration. However, there was significant rainfall in the April 15, 2018 through September 30, 2018 metering period, with approximately 50 storm events. The model simulated all storm events in the monitoring period, and calibration efforts focused on more than 20 storms, increasing the rigor and difficulty of the calibration by providing a variety of storm events with varying rainfall depths, intensities, and durations.

The model calibration followed a multiple-step process, outlined by the following five steps, which are further discussed in the sections to follow:

1. Identify the calibration period.
2. Collect and validate the data necessary for model calibration.
3. Update the model's physical configuration at the regulators based on site inspections, record drawings, manhole rim measurements, manhole rim to sewer invert measurements, and other pertinent and available information.
4. Calibrate the dry weather and wet weather flows at the influent meters.
5. Calibrate the overflow meters to achieve as close a match as possible to the observed CSO activations.

While the 5-step calibration process outlined above shows a linear procedure, the calibration was an iterative process. For example, calibrating an overflow meter in Step 5 could result in impacts on regulators that are hydraulically related, requiring re-calibration of an influent meter. An additional field investigation resulting from the inability to reconcile differences between the modeled and observed responses could result in further updates to the physical configuration of the system in the model. Attempts to calibrate to the overflow meters in Step 5 sometimes resulted in reverting to Steps 2 and 3 of the calibration process.

2.2.1 Calibration and Model Verification Periods

The metering period used for model calibration was April 15, 2018 through September 30, 2018. Meter data collected after September 30, 2018 were used as an independent check, or verification, of the calibration. The calibration period includes several storms of varying sizes and intensities occurring during spring conditions when groundwater is typically high, and several storms during fall conditions when groundwater is typically lower. The model was calibrated to many storms within the calibration period, comparing the depth, peak flows and volumes for the system flows and the volumes for the CSO flows. MWRA's meters (see Section 3.2) collected data during approximately 50 rainfall events during the calibration period. The calibration efforts simulated all 50 storm events, with calibration analysis focused on CSO overflow volumes as well as volumes and peak flows for system flows of the 20 larger storm events providing a variety of storm depths and intensity within the period.

2.2.2 Data for Model Calibration

Data collection efforts to support model calibration began in early 2018, with the identification of the necessary data types, data collection methodologies, and the approaches for analyzing the collected data. The detailed approaches were described in Semiannual Reports No. 1, 2, and 3.

Data sources for model calibration included the following:

CSO Inspections: Regulators within the MWRA and CSO community systems were investigated through field inspections and record drawing reviews to confirm that the locations and physical conditions of regulators that contribute CSO to receiving waters are accurately represented in the hydraulic model. The regulator inspection data included the location, type, configuration and dimensions of the regulator, the location and dimensions of the associated influent pipes and outfall pipe, and the presence and condition of a tide gate(s), where applicable. Measurements were taken of all pipe dimensions, tide gate size, overflow elevation, and sediment depth if present. Additional observations were made on the hydraulic conditions and site-specific influences on the hydraulics (such as a sudden change in flow direction, slope change or a drop connection).

Depth and Velocity Metering Data: Depth and velocity data were obtained from temporary project meters and permanent community meters at CSO regulators and outfalls, and permanent MWRA meters at CSO treatment and storage facilities and in the interceptor system. At some locations, only depth was measured to measure flow levels and CSO activations (depth above an overflow elevation). In locations where both depth and velocity were measured flow rate was calculated using the continuity equation.

Rim Measurements: The rim elevations at each of the metered regulator locations were surveyed and used, with internal regulator measurements, to calculate invert and weir elevations.

Rainfall: 15-minute rainfall data were collected from 20 rain gauges. Following the guidelines outlined in the EPA's 1999 CSO Guidance for Monitoring and Modeling, rain gauges were spaced at a density of approximately three miles apart. In some cases, NOAA radar data were referenced to assess the spatial variation of a storm event over the collection system.

Temperature: Daily temperature data were downloaded from NOAA and used to compute potential evapotranspiration (PET).

Tide: Hourly tidal data were used as a boundary condition at outfalls and were downloaded from NOAA.

MWRA Storm Reports: Following a large storm event in which a CSO treatment facility activates, MWRA generates a storm report that summarizes the system's response for the given event. These reports provide data such as duration of choking at Chelsea Creek, Ward Street, and Columbus Park Headworks, time-series flows at headworks and at the Deer Island treatment plant, activations (start/end, duration, total discharge volume) at Cottage Farm, Prison Point, Somerville Marginal, and Union Park CSO treatment facilities, and volumes captured at CSO storage facilities. Additional comments are noted on any anomalies observed in the system during the storm event. These storm reports were referenced as part of the calibration efforts.

SCADA Data: MWRA SCADA data were used to assess whether there were operational anomalies or issues that differed from the typical operations that are the basis for the facilities' operational settings in the hydraulic model.

Facility Operation Procedures and Records: CSO treatment facility and other facility operation records were reviewed for detailed data on storm-specific operations. Important data included, for instance, the influent flow levels at which CSO treatment facility gates were opened and closed.

Record Drawings: Record drawings were used as a secondary source of data for comparison to field measurements. These provided historical documentation on modifications to the regulators and guided additional field investigations where necessary.

GIS Records: Community Geographic Information System (GIS) records at key locations were also reviewed as part of the calibration effort to understand interconnections. These were cross referenced against CSO field inspections, record drawings, and community models.

After careful design of the metering plan and installation of equipment, the accuracy of the collected data were checked and validated (see Section 3.2.2) before using it to adjust parameters of the hydraulic model. Data were compared to multiple sources of information to corroborate measurements. Metered overflows were compared to metered influent flows and tide gate inclinometer readings. Rain gauge measurements were compared to neighboring rain gauges and MWRA storm reports. Measured CSO activations were correlated against rainfall depths and intensities. Field measurements were checked against secondary sources. For example, surveyed rim elevations at each regulator were compared to secondary sources such as record drawings and/or LIDAR data. Records from communities and field inspections were compared at key locations, and discrepancies were investigated. Additional information on the procedures for the QA/QC of rainfall data and metering data can be found in Semiannual Report No. 2's Section 2 Rainfall and Rainfall Analyses and Section 4 Metered CSO Discharge Review.

If adjustments to model parameters were not sufficient to calibrate the model to the measurement(s), then information from record drawings, community models, and/or GIS records were reviewed to identify the reason the model predictions did not adequately correlate with observations. Where necessary, field inspections were conducted to resolve the discrepancy. As these data were collected throughout the calibration efforts, they were incorporated into the model. Additional investigations were conducted at regulators upstream of the following outfalls to collect supplemental data for the calibration efforts at the following locations:

- CAM002
- CAM401A
- CAM401B
- SOM01A
- BOS013
- BOS014
- CHE004
- BOS009
- BOS010
- BOS012
- BOS060
- BOS003
- BOS004
- BOS005
- BOS070/DBC
- CAM005
- MWR010

The East Boston regulators are an example of where additional investigation for the calibration efforts was necessary. The calibration of these regulators suggested significant losses had to be added to the regulators' dry-weather flow connections to simulate the observed overflows. Field investigations found nozzles in the dry weather flow connections to the interceptors at several East Boston regulators. The model was adjusted by increasing head loss coefficients to restrict the flow to the interceptor to simulate the hydraulic impacts of the nozzles. The locations where the nozzles were found include: RE003-12; RE004-6; RE010-2; RE012-2; RE013-1, and RE014-2.

2.2.3 Network Changes for Calibration

The model's physical configuration at the regulators was updated based on site inspections, record drawings, rim measurements, and other available information.

Added/Removed Regulators

Inspections were conducted at all remaining active regulators and the regulators that were closed under the LTCP. These inspections were performed by ADS Environmental Services and SDE Environmental. Limited differences between the field conditions and what was already in the model were discovered during these inspections. Field inspections found that RE046-80 (upstream of outfalls MWR023 and BOS047) was closed, although it was still configured to be open in the model. Regulators RE046-54 and RE078-2 were identified as open, but not included in the 2017 version of the model. RE046-54 is one of several regulators that contribute CSO to outfalls MWR023 and BOS046 and where CSO discharges were reduced with the Stony Brook Sewer Separation project. RE078-2 is one of two regulators associated with Outfall BOS078 on the Reserved Channel, where CSO discharges were reduced with the Reserved Channel Sewer Separation project. The 2019 version of the model reflects the findings of these field investigations, with RE046-80 closed and RE046-54 and RE078-2 added.

Community Models

The BWSC, Cambridge, and Somerville community sewer system models were used as an information source to update the MWRA model where appropriate. In some locations, the community models provided more detailed model configurations characterizing the sewer systems and/or provided detailed subcatchment delineations (subareas draining to MWRA's system). The City of Chelsea's hydraulic model has recently become available and is being reviewed to assess how it can be used to improve the accuracy of MWRA's model in Chelsea.

Regulator Configuration

The physical configuration of the metered regulators in the model were reviewed and compared to the measurements and observations that were conducted as part of the inspections, base mapping and meter installation efforts in early 2018. The inspection data included measurements of pipe diameters, rim elevation survey, internal measurements from manhole rims to pipe inverts and overflow levels (typically top of a weir or invert of a high outlet pipe), and physical observations of regulator conditions such as sediment depth and physical evidence of overflows. The model was updated to with the inspection data as part of the calibration efforts.

Facility Operation

Operation of CSO treatment facilities, headworks and pumping stations can have significant impacts on upstream flow levels and CSO activations. MWRA operates these facilities to minimize untreated CSO discharges and sanitary sewer overflows. The collection system model was configured to operate the facilities based on each facility's standard operating procedures. However, operators may deviate from the standard operating procedures to response to forecasted intense storm conditions, system performance (SCADA) data that is monitored during the event, and to maximize the transport capacity of the system and delivery of flows to the Deer Island Treatment Plant or to a CSO treatment facility in response to storm specific hydraulic conditions. Data by storm event were provided on the operation of the Cottage Farm, Prison Point, Somerville Marginal and Union Park CSO treatment facilities, the Ward Street, Columbus Park and Chelsea Creek headworks, the Alewife Brook, Delauri and Caruso pumping stations, and other facilities that can influence CSO system performance. Real time control (RTC) in the model simulates variable attributes of the model including gates, pumps and bending weirs. Based on a review of the storm event data, the RTC used in the model for the CSO facilities was adjusted to mimic the actions taken by the operators for each storm event.

BWSC Maintenance Weir in South Boston Interceptor

Discussions with BWSC identified the existence of a maintenance weir in the South Boston Interceptor - North Branch (SBI-NB). This weir, which had the purpose of preventing movement of sediment during a cleaning operation, was added to the model as part of the 2018 Model calibration, along with sediment that the metering data suggested had accumulated upstream of the weir. BWSC recently completed cleaning of the sediments in the SBI-NB and removed the weir and continues to remove sediments in upstream connecting pipes. The model will be updated to represent clear pipes in this system which may impact some related CSO discharges. MWRA will continue to employ meters at associated regulators through June 2020.

2.2.4 Dry Weather Calibration

Dry weather calibration involved adjusting parameters in the model that affect dry weather flows to more accurately correlate with the meter data. During dry weather conditions, the sanitary flow, as shown in Figure 2-2, is regulated through the dry weather flow connection to the interceptor where it is conveyed to the treatment facility. The period of August 29, 2018 to September 2, 2018 was used as the dry weather calibration period, as there was continuous dry weather during this period. An example dry weather calibration plot is shown in Figure 2-3.

When a significant difference was noted between the base flows observed in the spring and summer, then the groundwater impacts were assessed. Base flow was calibrated for the summer period, and the groundwater infiltration module of ICM was used to adjust base flow during the spring when groundwater impacts occur. This is discussed in Section 2.2.6 below.

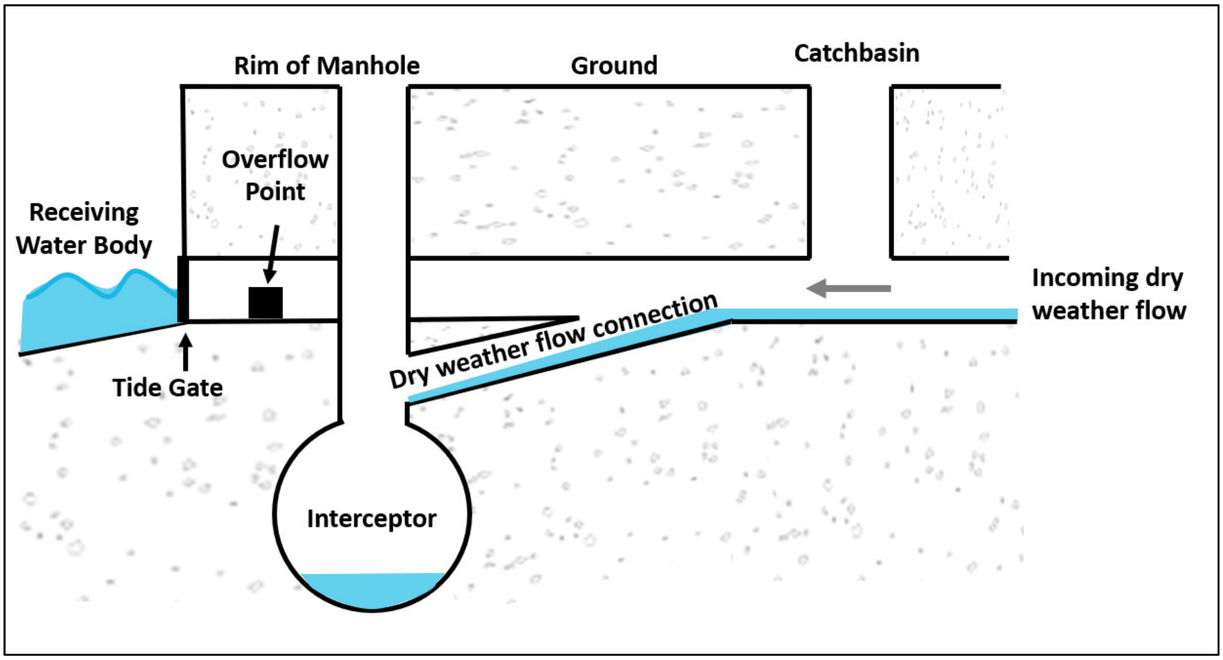

Figure 2-2. Dry Weather Flow at Regulator

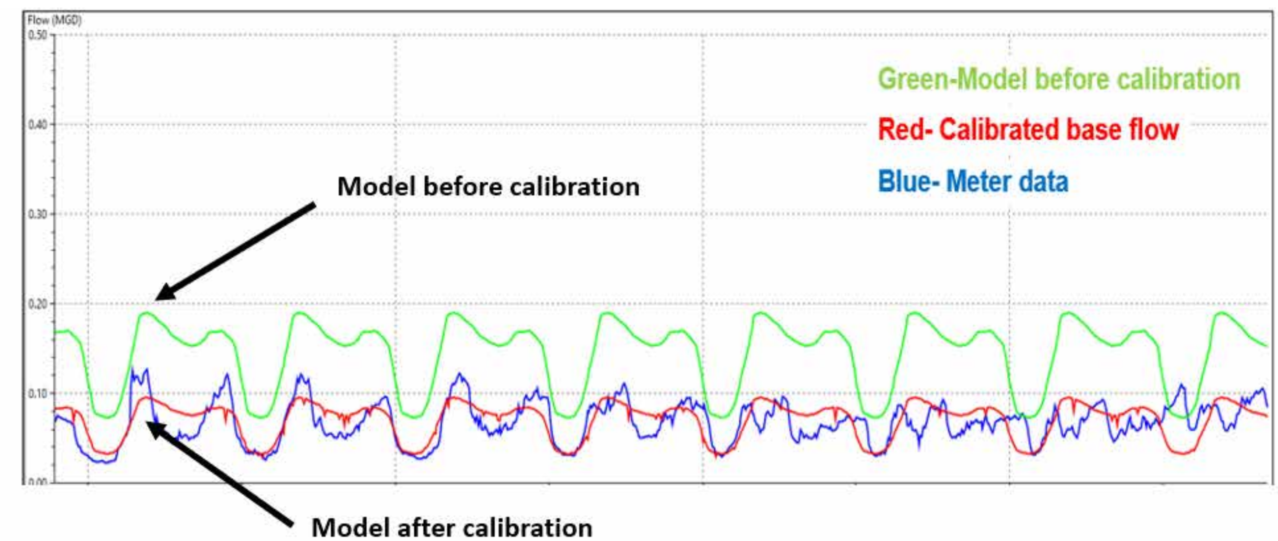

Figure 2-3. Base Flow Calibration

2.2.5 Wet Weather Calibration

Wet weather calibration involved adjusting certain model parameters as necessary and appropriate to attempt to match the response measured by the influent meters during wet weather events and then by the overflow meters for wet weather events that resulted in CSO discharge. Adjustments include changes to hydrology parameters (rain induced infiltration, subcatchment width, etc.) used by the model to predict total volume or peak flow entering CSO regulators. Adjustments to modeling parameters used to represent how flow gets from the regulator to the wastewater interceptor, such as adjustment of dry-weather pipe friction or other head loss coefficients, were then sometimes made to calibrate the model's ability to predict CSO discharges from the regulators. As shown in Figure 2-4, the capacity of the interceptor, the size and properties of the dry weather connection, as well as the system's storm response were considered.

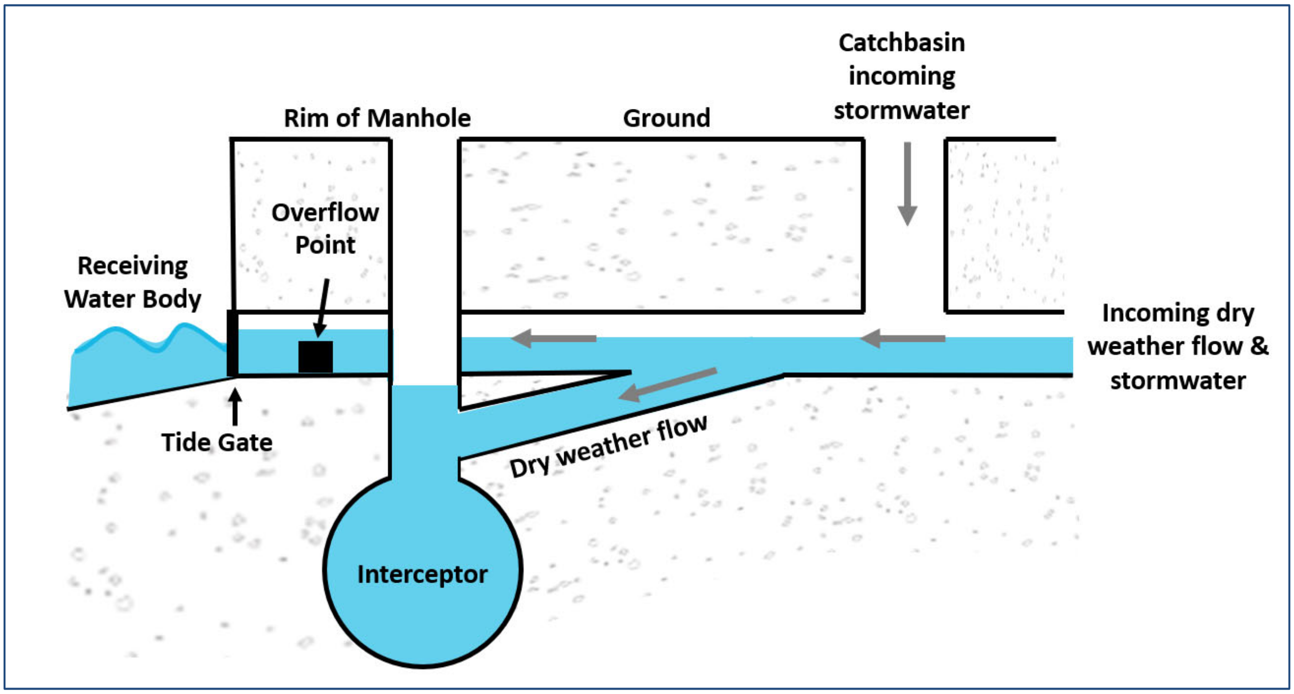

Figure 2-4. Wet Weather Flow at Regulator

The metered storm response volume in million gallons (MG) and peak flow in million gallons per day (MGD) were calculated for a number of storm events and compared to the modeled response in correlation plots such as the ones shown in Figure 2-5. Each red dot represents a storm event. If the metered and modeled volumes and peak flows matched exactly, the red dots would fall on the dotted blue line. However, one variable that can impact how well the model and meter data match is rainfall gauge coverage and rainfall variability. The rainfall gauge may be located some distance away from the subcatchment area that contributes flow to the meter location. As a result, the rainfall recorded by the rain gauge may be different from the actual rain that falls in the subcatchment area, which may contribute to differences between the metered flow and the flow predicted in the model. Rainfall can also vary across a very large subcatchment area, such as the area that contributes flow to the Boston Marginal Conduit and outfalls MWR018, MWR019 and MWR020. Even when a gauge is located in one part of a large subcatchment area, rainfall may vary in other parts of the area. The model assumes consistent rainfall across the geographical area the gauge represents.

The approach used for model calibration was to simulate numerous storms and then adjust the calibration so that approximately half of the storms fall above the dotted blue line, and half fall below. The lines on either side of the dotted blue line represent the calibration standards set forth by the Chartered Institution of Water and Environmental Management (CIWEM) in the UK, which state that a calibrated model should predict volumes and peak flows within the range of +20% and -15% (CIWEM, 2017). While a UK standard, the CIWEM is the accepted standard for collection system model calibration in the U.S.

Predicted volumes and peak flows for most storm events should fall within the lines on either side of the dotted blue line. Due to the spatial variation of rainfall, especially during isolated thunderstorm events, not all of the storm events will fall within those lines. Additional modeling parameters that impact model calibration and model accuracy are discussed in Section 2.4 below.

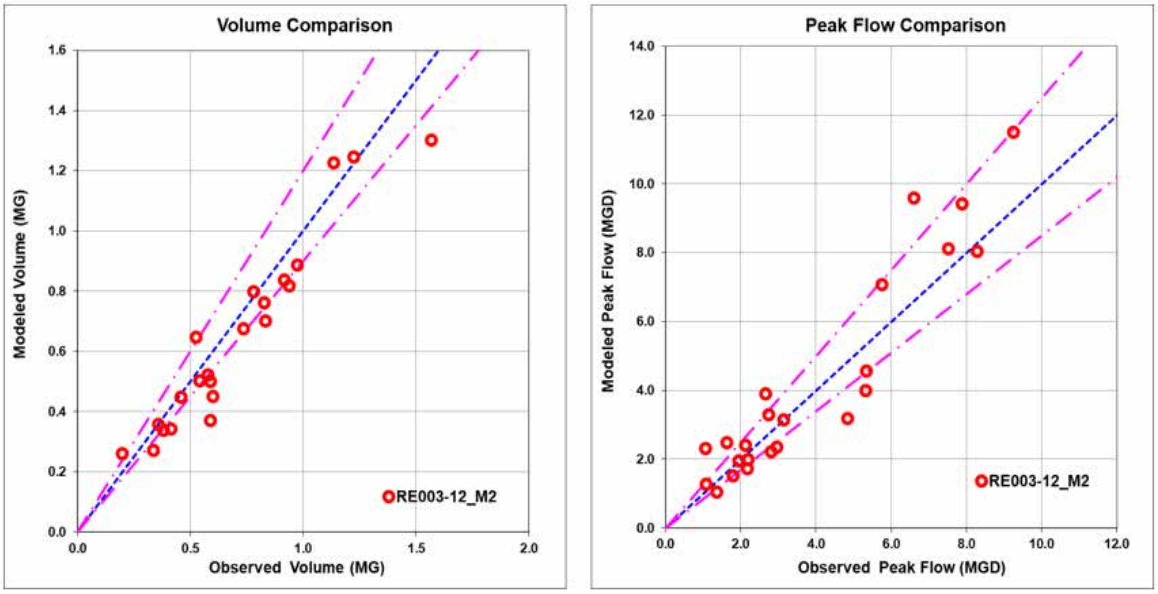

Figure 2-5. Storm Volume and Peak Flow Calibration Plots

In addition to assessing the model's ability to simulate total measured volume and peak flow rate, the calibration process also considered the model's ability to simulate the entire flow regime measured by the meter during the storm event The model and meter data should follow similar shapes during the storm response, as shown in Figure 2-6.

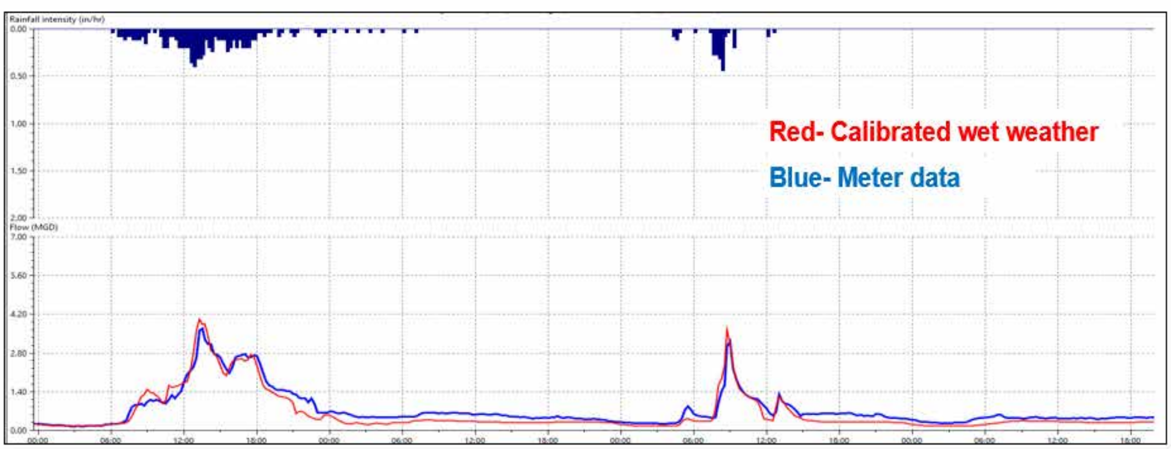

Figure 2-6. RE003-12 Influent Meter Calibration Plot

Calibration of the influent flow meters at the regulators is important to check that the model is predicting volumes similar to the metered volumes. Figure 2-7 demonstrates an overall comparison of the modeled and metered volumes for all influent calibration meters. Each point in Figure 2-7 represents one of the 58 influent meters used to calibrate the model. The top panel shows how well the model compares with influent meter data for the whole April 15, 2018 – September 30, 2018 calibration period, while the bottom panel shows the model to meter comparison for the single September 25-29, 2018 storm period. If the model matched the flow meters perfectly, then the points would fall on the blue line. Points above the blue indicate the model is over-predicting the volume, while points below the line indicate the model is under-predicting the volume. The lines on either side of the dotted blue line represent the calibration standards by CIWEM with the top line representing +20% and the bottom line representing -15% (CIWEM, 2017). As noted previously, correlation between model predictions and observations can be impacted by spatial variation in rainfall, accuracy of meter data from storm to storm, and other conditions discussed below.

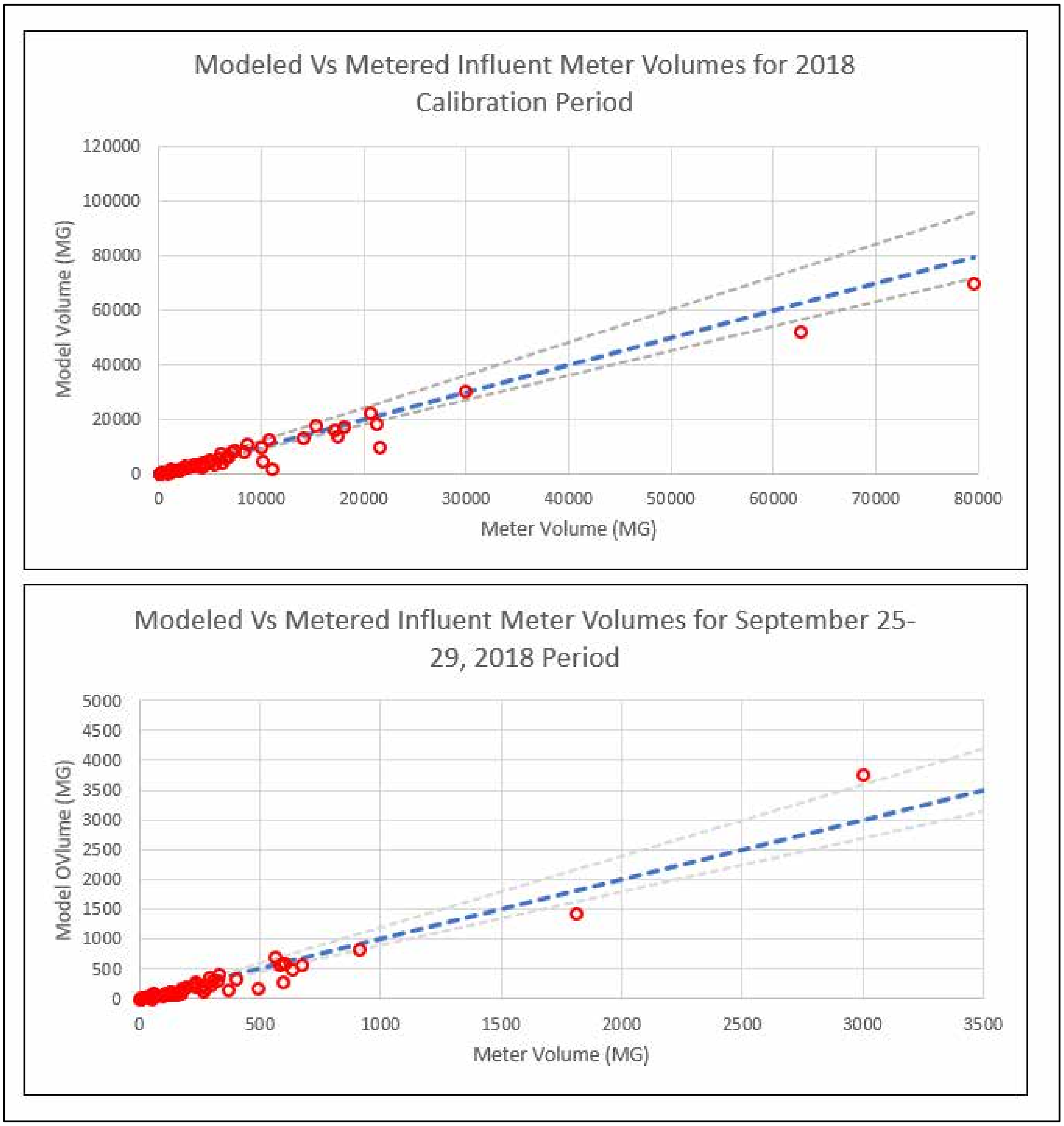

Figure 2-7. Modeled and Metered Influent Meter Volumes

Once the model was calibrated to the influent meters, it was then calibrated to the measured overflows at each regulator. Overflow calibration involved adjusting model parameters to correlate the model predictions to the observed overflow frequency and volume. Calibrating the model to the metered overflow data typically involved controlling the distribution of flow volumes through the dry weather flow connection to the downstream sewer and to the overflow pipe. Scatterplots similar to those shown in Figures 2-5 and 2-7 above were prepared to show model vs. metered CSO discharge volumes for each measured CSO discharge. At locations where calibrating the model to the influent meters was not sufficient for correlating to the overflow measurements, improving the overflow calibration could be achieved at some regulators by adjusting the roughness of the dry weather flow connection or by modifying the diameter of the dry weather flow connection (if supported by field observations/data). This portion of the calibration process also required consideration of the downstream conditions in the interceptor, as those conditions can affect the flow through the dry weather connection. To calibrate overflows from regulators where the CSO overflow meter was not available or provided poor data quality, the predicted depths were compared against measured depths taken in the regulator structure, and the model was adjusted as appropriate.

2.2.6 Groundwater Calibration

Measurable seasonal groundwater impacts were observed at some metering locations. The groundwater infiltration module in the model was used to simulate the seasonal groundwater inflow in the upstream catchment areas of 14 regulators in order to improve the calibration and the model's flow predictions. Simulating groundwater impacts improved model predicted results for storm events during the spring and fall months where this phenomenon was observed. Figure 2-8 demonstrates the impact that the groundwater module had on the calibration results at one location. As demonstrated in the figure, adding the seasonal groundwater module greatly improved the ability of the model to simulate the significant groundwater inflow observed in the spring season. The model simulation with the groundwater turned on (green) closely matches the meter data (blue), while the results shown with the groundwater turned off (red) shows greater variation between the meter and model predicted flows.

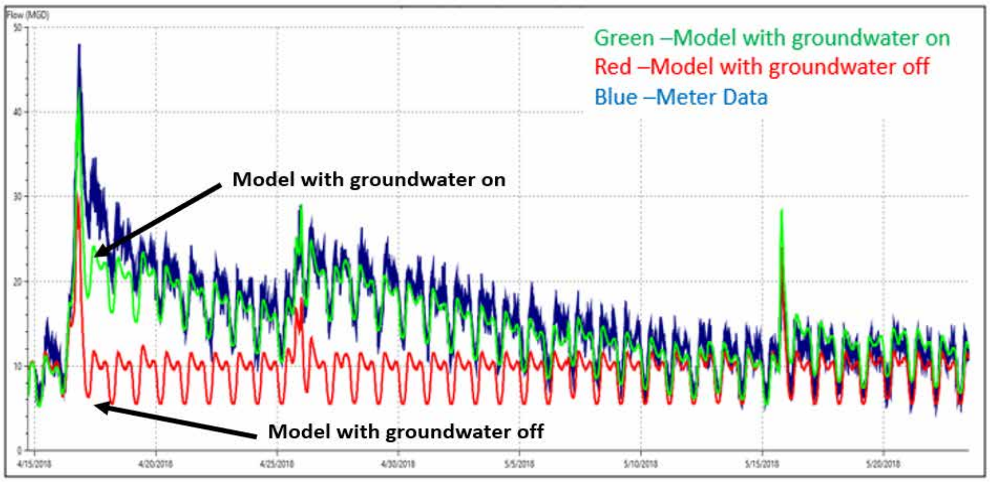

Figure 2-8. Groundwater Calibration

2.2.7 Model Calibration Refinements and Review

To review the model calibration, the model was run from April 15, 2018 through December 31, 2019 and compared to available metered CSO discharges. Comparisons of modeled and metered discharges were made for the entire period and are presented in Section 3.3.

Comparisons were also made on a storm-by-storm basis for the 2018 calibration period, as well as the verification periods as shown in Table 2-1. An example of a storm-by-storm metered and modeled comparison is presented in Table 2-2 for regulator RE070/8-3. The table presents all storm events for which the model or meter showed an activation. Inspection of Table 2-1 shows that the model is consistently conservative in predicting activation frequency. While the model slightly under-predicts CSO volume for the 2018 calibration period and the 2018 full period, the model slightly over-predicts CSO volume for both the October 1 – November 30, 2018 and January 1 – December 31, 2019 verification periods.

Table 2-1. Summary of Storm-by-Storm Model Meter Comparison for RE070/8-3

Activation Frequency	Metered Activations	Modeled Activations	Meter Volume (MG)	Model Volume (MG)
2018 Calibration Period (April 15-September 30, 2018)	9	9	2.15	1.58
2018 Verification (October 1-November 30, 2018)	1	2	0	0.13
2018 Full Period (April 15-December 31, 2018)	10	11	2.14	1.71
2019 Full Period (January 1-December 31, 2019)	11	14	2.53	3.04

Table 2-2. Storm-by-Storm Model Meter Comparison for RE070/8-3

Storm	Storm Period [1]	Meter Volume (MG)	Meter Duration (min)	Model Volume (MG)	Model Duration (min)
1	**4/15/2018**	0.05	20	No modeled activation	
2	**5/15/2018**	0.11	27.8	0.19	57.9
3	**6/27/2018**	0.31	54.6	0.19	62.5
4	**7/17/2018**	0.89	253	0.4	309.6
5	**7/25/2018**	0.15	29	0.1	33.9
6	**8/4/2018**	0.03	12.6	0.14	60.6
7	**8/8/2018**	0.24	40.5	0.17	37.3
8	**8/11/2018**	0.08	22.5	0.04	36.5
9	**9/18/2018**	No metered activation		0.19	95.8
10	**9/25/2018**	0.29	54.9	0.16	70.6
11	**11/2/2018**	<0.005	60.2	0.12	121.8
12	**11/9/2018**	No metered activation		0.01	191.8
13	**4/14/2019**	<0.005	38.3	0.08	52.3
14	**4/22/2019**	No metered activation		0.01	28.2
15	**4/26/2019**	No metered activation		0.03	33.7
16	**6/21/2019**	0.31	67.5	0.18	63
17	**6/30/2019**	0.02	10.5	No modeled activation	
18	**7/6/2019**	0.78	63.1	0.49	93.8
19	**7/17/2019**	0.02	10.9	0.04	28.4
20	**7/22/2019**	No metered activation		<0.005	46.9
21	**7/31/2019**	0.33	42.8	0.7	70.5
22	**8/7/2019**	0.77	177.1	1.05	201.6
23	**8/28/2019**	<0.005	15.9	<0.005	29.4
24	**9/2/2019**	0.13	28.9	0.08	33.5
25	**10/16/2019**	0.14	114.8	0.18	190.5
26	**10/27/2019**	No metered activation		0.09	43.1
27	**11/24/2019**	0.03	14.1	0.1	45.6

The model under-predicts the 7/17/2018 storm event which accounts for 40% of the metered CSO discharge during the calibration period and about 19% for the 2018 and 2019 periods. Analysis of the measured rain gauges as well as the radar for the 7/17/2018 storm event indicates that rainfall in this storm was highly variable and rainfall variation may have caused the discrepancy. The 9/18/2018 storm event was also identified as an event with high rainfall variability, as indicated by Figure 2-9. This figure shows that a narrow band of high intensity rainfall occurred with notably lower intensity rainfall just to the north and south. Rain gauges outside of the band of high intensity rainfall would not have recorded high intensity precipitation yet the high intensity rainfall would have impacted CSOs and measurements. Assessment of the 2018 and 2019 verification periods as presented in Tables 2-1 and 2-2 suggest that the model is well calibrated for the regulator RE070/8-3 subsystem, as the majority of storm events missed by either the model or meter had CSO discharge volumes less than 0.01 MG (storms 12, 14, 15, 17, 20 and 26 in Table 2-1).

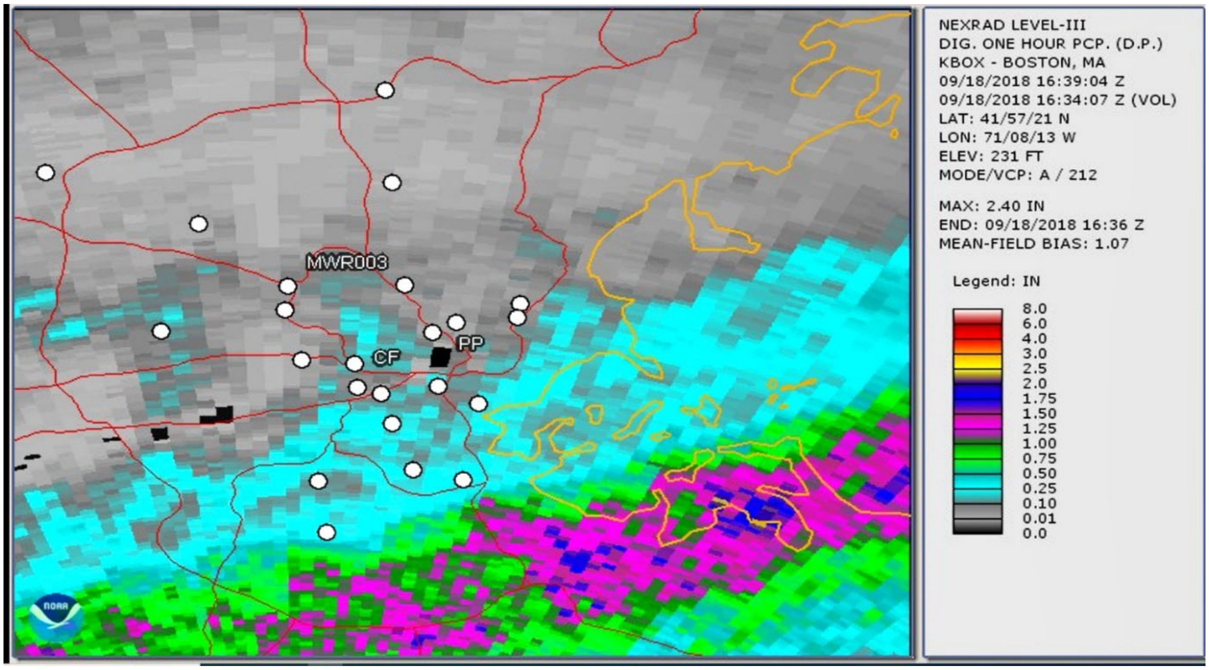

Figure 2-9. Rainfall Variation for the 9/18/2018 Storm

Comparing modeled and metered CSO discharges provides a basis of evaluating the likelihood of CSO discharge events. The New York City Department of Environmental Protection conducted a multiple-year metering pilot program to identify favorable methodologies to quantify overflows. A Water Environment Research Foundation report dated May 2015 summarizes this work. The report concluded that differences between metered and modeled discharges are not always due to an incorrect model. Rather, when CSO discharges recorded by a meter are significantly different from model predictions, the modelers should compare CSO discharges against an independent data source.

In general, the model was able to replicate the storm responses for the majority of storm events in the calibration period. However, it is not possible to closely match all of the modeled and metered activations for every meter and storm event, nor was an exact match an expected outcome from the calibration process. Factors affecting the match between modeled and metered activations and volumes include:

- Rainfall data and variation
- Unknown transient conditions in the collection system
- Accuracy of metering data.
- Modeled approximations of hydraulic conditions in pipes and structures
- Unknown transient conditions in the collection system

Further discussion of these factors is presented in Section 2.4 below.

<u>Calibration Refinements</u>

The model calibration was substantially complete in the fourth quarter of 2019. However, comparison of model predictions to measurements in the verification period suggested that additional improvements to the calibration were warranted at some regulators. Detailed assessments of the differences between the modeled and metered activations were conducted at ten locations where the comparison suggested that additional calibration refinement efforts could potentially improve the model's ability to predict the meter observed CSO activations during the 2018 and 2019 metering periods. The ten locations are presented in Table 2-3, with a brief description of the calibration refinement efforts. Additional information on each of these ten locations can be found in Appendix A, "Detailed Assessments into Meter/Model Differences at Ten Locations," which was previously submitted as Attachment A to the MWRA Supplemental Progress Report as of February 14, 2020 filed with the Federal District Court.

2.3 Model Changes-Comparison of 2019 Conditions to 2017 Conditions

Prior to the recent recalibration effort, predictions from MWRA's 2017 system conditions model showed achievement of the system-wide Typical Year CSO volume goal in the LTCP of 404 MG (compared to 3,300 MG in the late 1980's). The 2017 model results also showed achievement of the LTCP levels of control at a majority of the discharge locations. Predictions from the newly calibrated model, 2019 system conditions, show a system-wide Typical Year CSO volume of 428 MG and identify challenges at some discharge locations that MWRA is working to assess, understand and overcome (see Section 5).

The predicted number of CSO activations and discharge volume has increased at a number of regulator locations after recalibrating the 2017 model and updating the calibrated model to 2019 conditions. A comparison of the models was made to assess why this increase in modeled activations may have occurred. The comparisons focused on the physical changes to the regulators and the adjustments to the hydrology tributary to the regulators since these were the most significant changes to the model during calibration. The metering program collected 5-minute data for regulator influent sewers, dry weather flow connections, and the overflow lines. The five-minute data with the multiple meters at each regulator provided detailed information on the flows coming into each regulator structure. This allowed more accurate calibration of the hydrology contributing to flow and overflows. In contrast, the flow monitoring conducted for the Long Term CSO Control Plan in 1992 focused on quantifying the CSO overflows at each regulator.

Physical Changes to Regulators

The physical configuration of the regulators was inspected as part of the base mapping and meter installation efforts. In some cases, incorporating the inspection data decreased the overflow elevation, decreased the diameter of the dry weather flow connection, and/or increased the headloss of the dry weather flow connection. These changes to the modeled regulator structure may have increased modeled CSO discharges at some of the locations. Decreasing a weir elevation requires a smaller increase in the hydraulic grade line within the regulator structure to trigger an overflow. Decreasing the diameter of the dry weather flow connection reduces the amount of influent flow that reaches the interceptor. As a result, the flow is more likely to rise in the regulator structure and exceed the overflow elevation. Similar to decreasing the diameter of the dry weather flow connection, increasing head loss in the dry-weather flow connection also limits the amount of flow that can be conveyed from the regulator to the downstream sewer. The percentage of locations where physical changes to regulators were made to the 2019 version of the model are summarized in Table 2-4.

Table 2-3. Summary of Detailed Assessments into Meter/Model Differences

Location	Initial Model-Meter Comparison	Summary of Investigation	Modification to Model
BOS070, RE070/7-2	Model over predicted activation frequency and volume	The majority of metered activations were small volume activations. Modifying Horton infiltration rate to a value similar to surrounding subcatchments improved the model's ability to replicate the smaller activations.	Horton infiltration value
CAM401B	Model over predicted activation frequency and volume	Community model has lower head loss at regulator structure than MWRA model. Reducing regulator head loss in MWRA model resulted in a better calibration.	Reduced regulator head loss by decreasing Manning's n value on the dry weather flow connection
CHE004	Model over predicted activation frequency and volume	The field inspection during the meter installation indicated the DWF connection was 12 inches. A new field inspection was conducted and found the DWF connection to be 24-inches.	The DWF pipe size was updated in the model and changed Manning's n of the dry weather flow connection to 0.33
MWR201 (Cottage Farm Facility)	Model under predicted activation frequency and volume	The influent gates to the facility in the model were being closed too early for the 4/22/18 storm event. Additionally the model under predicted when groundwater levels were high. The modeled groundwater response had to be increased to match the CB-BO-1 meter.	Adjustment to modeled facility operation for 4/22/18 storm event and additional groundwater added to CB-BO-1
MWR018, 19, 20	Model over predicted activation frequency (*meter volume is not measured at these outfalls*)	Hydraulic grade line of Prison Point impacts activations. Other activations match reasonably well with the exception of the 9/18/2018 storm that was found to have high rainfall variability.	No direct modifications made; adjustments made to Prison Point impacted activations.
MWR203 (Prison Point Facility)	Model under predicted activation frequency and volume	The influent gate was being closed too early for the 11/03/18 storm event. For other storm events, rainfall variation in large tributary area to facility impacted results.	Adjustment to modeled facility operation for 11/03/18 storm event. No other modifications made as it is believed that rainfall variation contributes to modeled and metered differences.
BOS060, RE060-7	Model under predicted activation frequency and volume	Further investigation into the model configuration of the regulator.	Configuration of the connection between the regulator and the interceptor was revised to better reflect the physical configuration of the regulator.
MWR003	Model over predicted activation frequency and volume for the 2018 calibration period.	Further investigation into the model configuration of the regulator and the capacity of the Alewife Brook Conduit was conducted. System modifications were made to SOM01A and CAM002 in early 2019. The model was run for the second half of 2019 and it was found that the meter and model were matched reasonably well for that period.	System updates downstream were incorporated in early 2019 which resulted in improved performance at MWR003. No direct modifications were made to MWR003.

Table 2-4 Adjustments to Physical Regulator Configuration, 2017 to 2019

	Decreased Overflow Elevation	Decreased Dry Weather Flow Connection Diameter	Increased Headloss at Dry Weather Flow Connection
Percentage of Regulators Changed from 2017 to 2019 Model	23%	14%	50%

Hydrology within Areas Tributary to Regulators

A comparison of the calibrated 2019 model and the existing 2017 model was conducted to assess the changes made to the hydrologic conditions in subcatchment areas tributary to regulators. Adding groundwater, increasing the percentage of impervious area, and increasing the width of the subcatchment area may result in increased modeled CSO discharges. The groundwater module was used at locations where metering data suggested a seasonal groundwater response was observed. A groundwater response at a regulator may have resulted in a regulator activating more frequently when the groundwater table is higher. In locations where the metering data suggested that the model required additional inflow to the regulator, the percentage of impervious area was increased. This increased the total volume of flow to the regulator, potentially impacting activation frequency and discharge volume. The subcatchment width is a hydrologic parameter that is adjusted during model calibration to represent the speed at which water reaches the regulator and is a function of the length of overland flows in the subcatchment area. Increasing the width of the subcatchment decreases the time it takes for runoff to join and enter the stormwater or combined sewer system, resulting in a higher peak storm response. Increasing the peak of the storm response results in a higher likelihood of an overflow. Table 2-5 summarizes the percentage of regulators where changes to hydrology tributary to regulators were made between the 2017 and 2019 models.

Table 2-5. Adjustments to Tributary Area Subcatchments of Regulators, 2017 to 2019

	Added Groundwater	Increased the Percentage of Impervious	Increased Width of Subcatchment
Percentage of Regulators Changed from 2017 to 2019 Model	22%	45%	43%

2.4 Factors Affecting Model Calibration Performance

As noted above, the collection system model is a tool that has been used over the years to evaluate the performance of the MWRA's collection and transport system, and in particular to provide estimates of CSO frequencies and volumes. The model is not intended to provide exact representations of CSO volumes for every outfall for every storm event, since the model cannot replicate all the variability associated with rainfall distribution, ground conditions affecting runoff characteristics, flow conditions within the pipe network, and other variables. The calibration process described above showed that for individual storms, the model may over- or under-predict CSO volume. However, over the course of the metering period, the model does a good job of estimating the total activations and volumes measured at the CSO regulators, thereby providing a level of confidence that the model can be used to represent system performance, particularly over an extended period.

This section provides further discussion of factors that can affect the ability of the model to replicate measurements of CSO activation frequency and volume and presents an analysis of the ability of the model to replicate metered CSO activations.

2.4.1 Rainfall Measurements

As identified in the previous example analysis of RE070/8-3, rainfall variation can cause discrepancies between metered and modeled CSO discharges. Rainfall input to the model is derived from 20 rain gauges distributed throughout the project area as discussed in Section 3. The area covered by the model is 151 square miles, so on average, each rain gauge would represent approximately 7.5 square miles of model tributary area. The actual area associated with each rainfall varies based on the distances and positions of the adjacent rain gauges. Therefore, localized rainfall variations are imperfectly captured. This is particularly relevant for thunderstorms, which can have localized bursts. Widespread storms with uniform rainfall will generally be more accurately represented by measurements at the system gauges than localized storms or storms with more variable rainfall across the project area. The accuracy of the recorded rainfall at each gauge can also be affected by factors such as wind, freezing temperatures, and frequency of maintenance.

2.4.2 Measurement Accuracy

The measurements to which model predictions are compared are subject to a certain level of uncertainty, particularly measurements of overflow volumes. Overflow volumes are estimated using several methods depending on the CSO configuration. In some cases, the volume is calculated based on flow measurements downstream of the overflow point. In other cases, the volumes are calculated based on measurement of water levels above the overflow weir using weir equations and the scattergraph method. In yet other cases, volumes are not estimated for one of several reasons.

Each CSO regulator has a unique flow metering configuration designed to estimate CSO activations or confirm that the regulator is not active. However, regulators are inherently complicated structures with unique hydraulic conditions and are sometimes difficult to meter. Turbulence present in these structures can interfere with recorded measurements. Additionally, sedimentation in a pipe can impact volume calculations. Metering is also susceptible to fouling, creating false positive activations as well as missing activations due to meter failure. The longevity of the metering program has increased confidence in characterizing overflow activations, with the ability to generate scattergraphs (presented in Appendix E) that portray the rainfall intensity and depth that correlates to a CSO activation at each regulator.

In general, the flow measurement accuracy in CSO outfalls is less than in interceptors because, for most of the time, CSO outfalls have no flow and flowmeters are less accurate when not in continuous use. Measurements can also be affected by deposition at or upstream of the flowmeter locations. Flowmeters are designed and verified through third party testing to be within 5% of actual flow under ideal flow measurement conditions. For field applications in round pipes with no silt and uniform flow, flowmeter accuracy is generally estimated at +/- 10%. In CSO outfalls, however, the accuracy can be as low as +/- 30% particularly for outfalls with less frequent overflows, where the flowmeter is rarely submerged.

Volumes estimated from water level measurements and weir equations are affected by the fact that the weir equations assume ideal conditions, including uniform approach flow conditions, which are rarely met in CSO regulators. The accuracy of such volume estimations depends on the regulator configuration, but it can also be as low as +/- 30%.

2.4.3 Model Approximations of Hydraulic Conditions in Pipes and Structures

The model represents the main parameters that affect CSO activation and volume in mechanistic fashion, i.e., by simulating the relevant phenomena based on basic, well established equations. Flows in the interceptors, community combined and separate sewers, and regulators is modeled using the Saint Venant equations, which are very accurate provided the system is correctly specified. Conduit dimensions and invert elevations have been field-verified in relevant locations, as well as sediment depths. However, many regulators and other structures are often less than ideally configured, which can lead to simulation discrepancies. Certain complex hydraulic structures may be represented in a more simplified fashion in InfoWorks ICM.

The hydrologic conditions which control the flow inputs to the model are simulated in detail. However, the catchments are inevitably large and all the parameters that affect runoff are not individually specified. The model flows are calibrated at numerous connection points and are generally within +/- 15% of the measurements.

2.4.4 Unknown Transient Conditions in the Collection System

The MWRA model is a simplification of a complex and dynamic system. While CSO inspections and subsequent field investigations identified many previously unknown conditions in the MWRA system affecting the hydraulics of regulators, additional unknown transient conditions may exist. For example, a temporary blockage in 2019 would result in metered CSO activations that the 2018 calibrated model would be unable to replicate. New interconnections, changes in groundwater/seasonal variation, and leaking tide gates are all other examples of unknown transient conditions that could impact the comparison of modeled and metered activations.

2.4.5 Assessment of Modeled Activation Predictions

The model calculates flows and water levels at thousands of points but for a CSO evaluation, activation or non-activation of CSOs is a key statistic in terms of assessing the reliability of a model. To assess the model reliability relative to this metric, an evaluation was conducted comparing the level of agreement between the model and the meter data regarding predicted versus measured overflows. Specifically, for the overall sum of the model-predicted activations at all CSOs system-wide in the April 15, 2018 to December 31, 2019 period, the number that were reported by the meters was compared to the number that were not reported by the meters. Similarly, for each storm event that occurred in the April 15, 2018 to December 31, 2019 period, the number of outfalls where the model did not predict an activation was summed. For the total non-activations for that period, the number that were confirmed as non-activations by the meter was compared to the number where the meter recorded an activation. The analysis did not include the MWRA's CSO treatment facilities, the BOS-019 storage facility, outfalls MWR018, MWR019, MWR020, or locations where meters were removed on March 1, 2019. Table 2-6 summarizes the findings of this analysis. Salient results are:

- Overall, 98% of the events for which the model predicted no overflow were confirmed by the measurements. Only 2% of the times when the model predicted no overflow did the measurements indicate that an overflow occurred.
- In general, the model slightly overpredicted activation frequency: The frequency at which the model did not predict a measured activation (2%) was much smaller than the frequency at which the model predicted an activation that did not occur (28%).
- Overall, for 72% of the events when the model predicted an overflow, the measurements concurred and for 28% of the events when the model predicted an overflow, the measurements did not.
- For small events (less than 0.1 MG discharge) 68% of the activations predicted by the model were confirmed by measurements. For medium and large events, the percent agreement was larger, up to 91% for large events.

Table 2-6 Comparison of Metered and Modeled CSO Activations for April 15, 2018 to December 31, 2019

	Count/Percentage of Modeled Overflows (1)			Count/Percentage of Potential Regulator Events with no Modeled Overflows (1)		
Model Predicted Overflow	**YES**	**YES**	**Total**	**NO**	**NO**	**Total**
Meter Overflow	**YES**	**NO**		**NO**	**YES**	
OVERALL	494 72%	192 28%	686 (2)	10,286 98.1%	200 1.9%	10,486 (2)
LARGE Overflow **Volume > 1 MG**	32 91.4%	3 8.6%	35	N/A	3	3
MEDIUM Overflow **Volume 0.1 - 1 MG**	187 88.2%	25 11.8%	212	N/A	24	24
SMALL Overflow **Volume < 0.1 MG**	190 68%	88 32%	278	N/A	33	33
Not classified **(no measured volume)**	85	76	161		140	140

Notes:

(1) From April 15, 2018 to December 31, 2019: 196 Storms x 57 Regulators = 11,172 potential regulator-events. 686 + 10486 = 11,172.

(2) The table does not include CSO Facilities and BOS019, MWR018, MWR019, MWR020, takes into consideration meters that were removed on March 1, 2019.

2.4.5 Summary

In summary, a number of factors affect the overall ability of a model to replicate measured values, and it is not appropriate to assign a specific value to the overall model "accuracy" (i.e. "the model is X-percent accurate"). The computational engine of the model will make accurate calculations based on the input provided, but the multitude of inputs into the model all carry some level of approximation, error or uncertainty. Flow measurements, physical dimensions and condition of the features represented in the model, rainfall measurements, and runoff parameters are all examples of potential sources of approximation, error or uncertainty. However, the calibration process described above has demonstrated that over the course of the metering period, the model reasonably estimates the total activations and volumes measured at the CSO regulators, thereby providing a level of confidence that the model can be used to represent system performance, particularly over an extended period.

2.5 Model Updates to 2019 System Conditions

The MWRA wastewater collection system is continuously improving, and as a result the model is constantly being updated with known changes to the physical configuration of the system. Following calibration, the model was updated to more accurately represent the 2019 system conditions These conditions included the following modifications from the 2018 calibration model:

- **SOM001A:** A restricting orifice plate was removed from the dry weather flow connection between the City of Somerville's Tannery Brook Conduit and MWRA's Alewife Brook Conduit, changing the connection from a 24-inch diameter opening to the equivalent of a 36-inch diameter opening, thereby increasing the hydraulic capacity of the connection. This connection was updated in the model for 2019.
- **CAM002:** A plate was removed from the weir, changing the overflow elevation from 112.08 feet-MDC to 111.08 feet-MDC. An additional plate was removed which opened a connection between the influent line to CAM002 and the MWRA downstream interceptor (Alewife Brook Conduit). These changes were updated in the model.
- **BOS003, RE003-12.** In the summer of 2019, BWSC found rags and debris in the RE003-12 regulator connection to the East Boston Branch Sewer. The connection was cleaned by BWSC, and the model was recalibrated to incorporate the cleaned connection.
- **Alewife Brook Pump Station:** The model had a bypass pump configuration that was employed during rehabilitation of this MWRA facility. The rehabilitation project was completed at the end of 2018, and the model was configured to reflect the rehabilitated pump station conditions.
- **CSO Facility gate operation data:** As part of the 2018 model calibration, the control logic in the model was adjusted to reflect actual gate operation based on data from the MWRA's SCADA system. MWRA also provided gate operation data for storm events during the 2019 monitoring period, and the model was updated to include these data as well.

The 2019 version of the model was used for storms that occurred in 2019, while model calibration was evaluated using the 2018 conditions. Both the 2018 and 2019 models include the updates made to the 2017 version as part of the calibration efforts.

3. Data Collection and CSO Discharge Estimates

3.1 Rainfall and Rainfall Analyses

Rainfall is a driving factor in the analysis of CSOs, as the occurrence of overflows within the MWRA sewer system is dependent on rainfall intensity and/or depth. This section presents the rainfall data measured during the period of July 1 through December 31, 2019. It also describes the analysis of the rainfall data used to characterize the return period of each storm event and a comparison of measured rainfall for this period and the full 2019 period to the rainfall included in the Typical Year.

3.1.1 Rainfall Data Collection & Processing

Rainfall has been quantified for this analysis using 15-minute rainfall data collected at 20 rain gauges distributed over the MWRA system. Rain gauges are listed in Table 3-1 and the locations are shown in Figure 3-1.

Table 3-1. Rain Gauges

Gauge Code	Name	Owner	Gauge Code	Name	Owner
BO-DI-1	Ward St.	MWRA	DT	Dorchester -Talbot	BWSC
BO-DI-2	Columbus Park	MWRA	Rox	Roxbury	BWSC
BWSC001	Union Park Pump Sta.	BWSC	CH-BO-1	Chelsea Ck.	MWRA
BWSC002	Roslindale	BWSC	FRESH_POND	USGS Fresh Pond	USGS
BWSC003	Dorchester Adams St.	BWSC	HF-1C	Hanscom AFB	MWRA
BWSC004	Allston	BWSC	RG-WF-1	Hayes Pump Sta.	MWRA
BWSC007	Charlestown	BWSC	SOM	Somerville Remote	MWRA
EB	East Boston	BWSC	Lex	Lexington Farm	Project
BWSC008	Longwood Medical	BWSC	SP	Spot Pond	Project
HP	Hyde Park	BWSC	WF	Waltham Farm	Project

Quality assurance and quality control are provided by reviewing the data based on geographic location, comparing total rainfall depth and rainfall intensity values by month and for individual storm events. The shape of rainfall hyetographs is reviewed for irregularities. Rain gauges with significantly higher or lower total rainfall depths than other gauges, and unusual hyetograph shapes, are flagged as suspect and further reviewed.

Suspect or missing rain gauge data were replaced with data from the rain gauge in closest linear proximity. If the closest gauge also had suspect data, the second closest rain gauge was used (Table 3-2). Replacement of suspect data was recorded in Table 3-3. Rainfall data used for the analysis are provided in Appendix B.

Intensity-Duration-Frequency (IDF) analysis was used to characterize the return periods of the storm events in the January through December 2019 metering period. Storm recurrence intervals for 1-hour, 24-hour, and 48-hour durations were identified for each storm event based on the IDF analysis. Storm recurrence intervals were based on Technical Paper 40, Rainfall Frequency Atlas of the United States (TP-40), and Technical Paper 49, Two-To Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States (TP-49), with values extrapolated for the 3- and 6-month storms.

Additional information on the methodologies for rainfall data collection and processing can be found in Semiannual Reports No. 1 and 2.

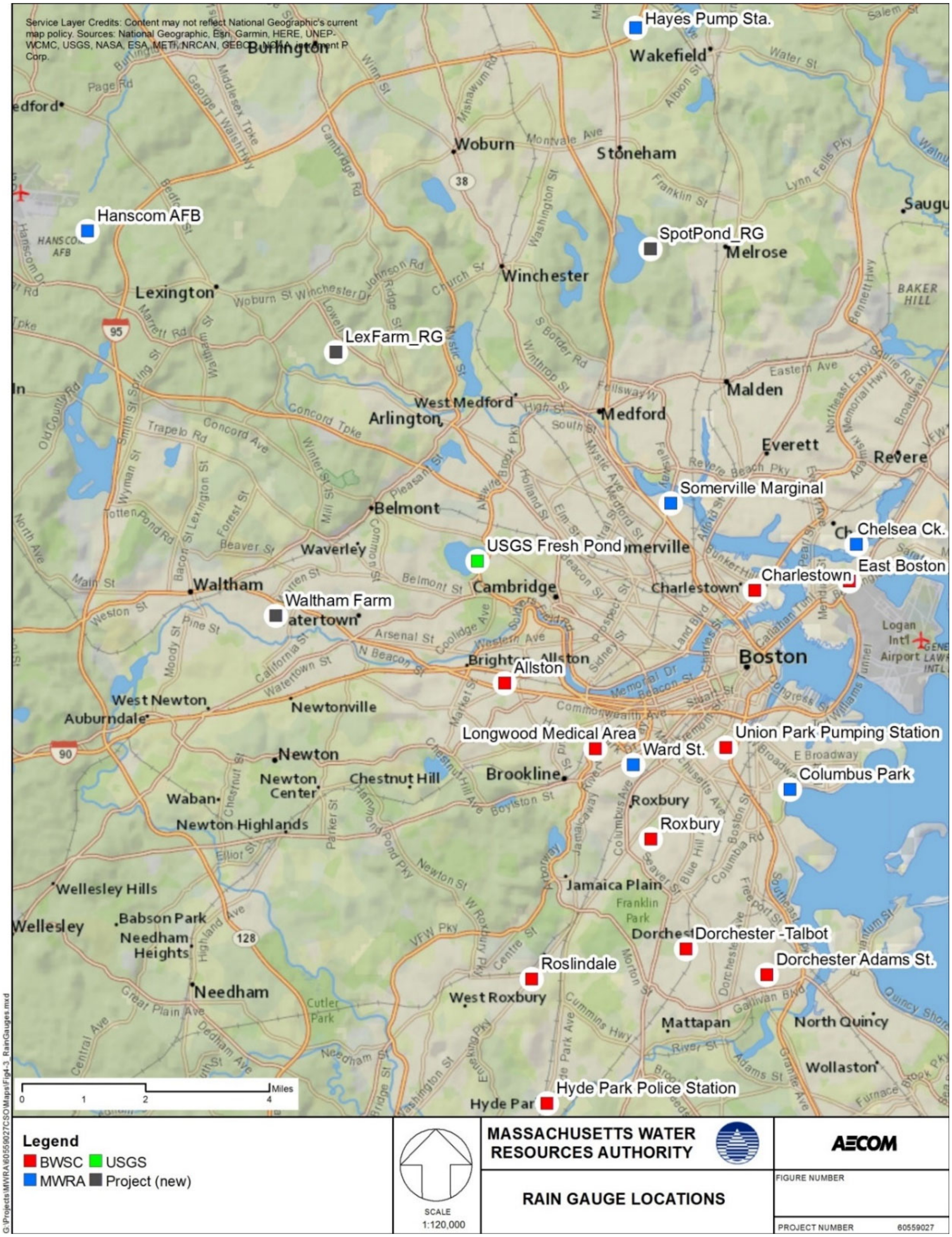

Figure 3-1. Rain Gauge Location Plan

Table 3-2. Closest Rain Gauges for Data Substitution

Origin Gauge		Closest Gauge		Second Closest Gauge	
Gauge Name	**Gauge Code**	**Gauge Code**	**Distance (mi)**	**Gauge Code**	**Distance (mi)**
Ward St.	BO-DI-1	BWSC008	0.66	Rox	1.23
Columbus Park	BO-DI-2	BWSC001	1.24	Rox	2.39
Union Park Pumping Station	BWSC001	BO-DI-2	1.24	BO-DI-1	1.52
Roslindale	BWSC002	BWSC005	2.02	BWSC006	2.54
Dorchester Adams St.	BWSC003	BWSC006	1.37	Rox	2.88
Allston	BWSC004	BWSC008	1.81	FRESH_POND	2.03
Hyde Park Police Station	BWSC005	BWSC002	2.02	BWSC006	3.36
Dorchester -Talbot	BWSC006	BWSC003	1.37	Rox	1.86
Charlestown	BWSC007	EB	1.53	CH-BO-1	1.80
Longwood Medical Area	BWSC008	BO-DI-1	0.67	Roxbury	1.71
Chelsea Ck.	CH-BO-1	EB	0.60	BWSC007	1.80
East Boston	EB	CH-BO-1	0.60	BWSC007	1.53
USGS Fresh Pond	FRESH_POND	BWSC004	2.21	SOM	3.26
Hanscom AFB	HF-1C	Lex	4.47	WF	6.92
Lexington Farm	Lex	FRESH_POND	4.08	WF	4.37
Hayes Pump Sta.	RG-WF-1	SP	3.58	Lex	7.13
Roxbury	Rox	BO-DI-1	1.23	BWSC008	1.71
Somerville	SOM	BWSC007	1.95	CH-BO-1	3.07
Spot Pond	SP	SOM	4.12	Lex	5.34
Waltham Farm	WF	FRESH_POND	3.37	BWSC004	3.86

Table 3-3. Summary of Rainfall Data Replacement, July –December 2019

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Allston	July 1, 2019 0:00	July 7, 2019 12:00	Longwood Medical
Ward St. (BO-DI-1)	July 1, 2019 0:00	October 1, 2019 0:00	Longwood Medical
Columbus Park (BO-DI-2)	December 29, 2019 18:00	December 31, 2019 12:00	Roxbury
Chelsea Ck. (CH-BO-1)	July 19, 2019 5:00	July 19, 2019 5:15	East Boston
	July 30, 2019 13:00	July 30, 2019 13:15	East Boston
	December 29, 2019 18:00	December 31, 2019 12:00	East Boston
Dorchester Adams	July 1, 2019 0:00	December 1, 2019 0:00	Roxbury
Dorchester Talbot	July 1, 2019 0:00	December 1, 2019 0:00	Roxbury
Hanscom AFB (HF-1C)	July 1, 2019 0:00	October 7, 2019 17:45	Lexington Farm
	October 7, 2019 18:00	October 13, 2019 0:00	USGS Fresh Pond
	October 13, 2019 0:15	December 31, 2019 23:45	Lexington Farm
Lexington Farm	October 7, 2019 18:00	October 13, 2019 0:00	USGS Fresh Pond
Hayes Pump Sta. (RG-WF-1)	December 29, 2019 18:00	December 31, 2019 12:00	Somerville Marginal
USGS Fresh Pond	November 24, 2019 0:00	December 31, 2019 23:45	Allston
Union Park Pump Station	September 23, 2019 0:00	December 29, 2019 17:45	BO-DI-2-Columbus Park
	December 29, 2019 18:00	December 31, 2019 12:00	Roxbury

3.1.2 Monitored Storms and Comparison of Storms to Typical Year Storms

For the period of July 1 to December 31, 2019, the rainfall data at each rain gauge were analyzed and summarized, providing the date and time, duration, volume, average intensity, peak 1-hour, 24-hour, and 48-hour intensities and storm recurrence intervals for each storm. The storm recurrence intervals were assigned values of <3 months, 3 months, 3-6 months, 6 months,1 year, or the nearest year, based on comparison to the IDF values from TP-40/TP-49. Table 3-4 presents the summary of storm events for Ward Street Headworks for the period July to December 2019. These data show that 51 storm events occurred in the 6-month period July to December 2019 at the Ward Street Headworks rain gauge (BO-DI-1). The majority of events were three-month storm events or less. There were two storm events that had a 1-hour recurrence interval of 3-6 months (August 28, 2019 and September 2, 2019). Two storm events had 1-hour recurrence intervals of six months (October 16, 2019 and October 30, 2019). The largest storm events based on the 1-hour recurrence interval were on July 6, 2019, with a 6 month-1-year recurrence interval and August 7, 2019 which had a 2.5 year 1-hour recurrence interval. However, all storms at Ward Street had a recurrence interval of 6 months or less based on a 24-hour duration. Tables summarizing the storm events from July to December 2019 for the other rain gauges are provided in Appendix C.

Table 3-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for July to December 2019

Event	Date & Start Time (2)	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.5	1.13	0.32	0.84	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.25	0.71	0.03	0.19	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 16:30	17	1.07	0.06	0.46	0.04	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	22.25	2	0.09	0.41	0.08	0.04	<3m	3m	N/A
5	7/24/2019 2:15	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/31/2019 14:15	1.75	0.29	0.17	0.24	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:30	12.75	2.45	0.19	1.26	0.10	0.05	2.5 yr	6m	N/A
8	8/18/2019 0:15	0.5	0.12	0.24	0.12	0.01	0.00	<3m	<3m	N/A
9	8/18/2019 15:45	0.5	0.05	0.10	0.05	0.01	0.00	<3m	<3m	N/A
10	8/19/2019 15:30	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 15:00	11.75	1.2	0.10	0.61	0.05	0.03	3-6m	<3m	N/A
14	9/2/2019 16:15	2	0.74	0.37	0.67	0.03	0.00	3-6m	<3m	N/A
15	9/4/2019 17:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
16	9/7/2019 0:45	3	0.11	0.04	0.05	0.00	0.00	<3m	<3m	N/A
17	9/12/2019 6:45	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
18	9/14/2019 12:45	12.25	0.31	0.03	0.21	0.01	0.01	<3m	<3m	N/A
19	9/23/2019 22:45	2.5	0.23	0.09	0.22	0.01	0.00	<3m	<3m	N/A
20	9/26/2019 16:00	2.5	0.36	0.14	0.17	0.02	0.01	<3m	<3m	N/A
21	10/1/2019 5:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
22	10/2/2019 13:45	3	0.28	0.09	0.15	0.01	0.00	<3m	<3m	N/A
23	10/3/2019 22:00	9.75	0.13	0.01	0.05	0.01	0.01	<3m	<3m	N/A
24	10/7/2019 20:00	11	0.22	0.02	0.12	0.01	0.00	<3m	<3m	N/A
25	10/9/2019 16:00	17	0.12	0.01	0.06	0.01	0.01	<3m	<3m	N/A
26	10/11/2019 11:45	21.75	0.62	0.03	0.17	0.03	0.01	<3m	<3m	N/A
27	10/16/2019 20:30	11.75	1.85	0.16	0.7	0.08	0.04	6m	3m	N/A
28	10/22/2019 18:45	13	0.43	0.03	0.13	0.02	0.01	<3m	<3m	N/A
29	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A

Table 3-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for July to December 2019

Event	Date & Start Time (2)	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
30	10/27/2019 9:00	10.75	1.69	0.16	0.54	0.07	0.04	3m	<3m	N/A
31	10/28/2019 10:00	16	0.06	0.00	0.02	0.07	0.04	<3m	<3m	N/A
32	10/29/2019 20:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
33	10/30/2019 17:30	30.25	0.2	0.01	0.01	0.00	0.00	<3m	<3m	N/A
34	11/1/2019 2:00	3	0.05	0.02	0.02	0.00	0.00	<3m	<3m	N/A
35	11/5/2019 11:15	10.75	0.45	0.04	0.3	0.02	0.01	<3m	<3m	N/A
36	11/7/2019 17:00	17.5	0.29	0.02	0.09	0.01	0.01	<3m	<3m	N/A
37	11/12/2019 11:00	2.5	0.1	0.04	0.05	0.00	0.00	<3m	<3m	N/A
38	11/18/2019 12:30	5	0.3	0.06	0.09	0.01	0.01	<3m	<3m	N/A
39	11/19/2019 5:30	2.75	0.21	0.08	0.11	0.02	0.01	<3m	<3m	N/A
40	11/20/2019 2:15	17.5	0.21	0.01	0.05	0.01	0.01	<3m	<3m	N/A
41	11/22/2019 13:45	1.75	0.08	0.05	0.06	0.00	0.00	<3m	<3m	N/A
42	11/24/2019 3:15	17.5	1.38	0.08	0.3	0.06	0.03	<3m	<3m	N/A
43	11/27/2019 17:15	19	0.32	0.02	0.14	0.01	0.01	<3m	<3m	N/A
44	12/1/2019 22:45	42	0.99	0.02	0.12	0.02	0.02	<3m	<3m	N/A
45	12/6/2019 15:30	1.25	0.02	0.02	0.01	0.00	0.00	<3m	<3m	N/A
46	12/9/2019 7:30	18.5	0.56	0.03	0.18	0.02	0.01	<3m	<3m	N/A
47	12/10/2019 14:15	20.5	0.47	0.02	0.07	0.02	0.02	<3m	<3m	N/A
48	12/13/2019 18:15	17.5	1.54	0.09	0.26	0.06	0.03	<3m	<3m	N/A
49	12/15/2019 12:45	0.25	0.01	0.04	0.01	0.00	0.03	<3m	<3m	N/A
50	12/17/2019 6:30	14.75	0.66	0.04	0.17	0.03	0.01	<3m	<3m	N/A
51	12/29/2019 21:30	35.75	1.91	0.05	0.16	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest year.

(2) Ward St. rainfall data were replaced with Longwood Medical rainfall data from July 1, 2019 0:00 through October 1, 2019 0:00.

The characteristics of the rain events that occurred in the January 1 through December 31, 2019 monitoring period were compared to rainfall characteristics from the Typical Year to help interpret the measured CSO activations and volumes in comparison to Typical Year performance.

The total rainfall and number of storms at each rain gauge were identified for the period of January 1 through December 31, 2019, and the number of storms by depth identified. These values were then compared to the values from the Typical Year. Table 3-5 presents this comparison. As indicated in Table 3-5, during 2019, rain gauges measured an average of 112 storms with total rainfall volume of 49.07 inches, compared with 93 storms and 46.8 inches in the Typical Year. This majority of rain gauges had total rainfall depths greater than the Typical Year and all locations had more storms than the Typical Year. Storm frequencies for the 0.5 to 1.0-inch range were similar to the Typical Year, while the numbers of storms in the greater than 2-inch range were less than the Typical Year. There were significantly more storm events in the less than 0.25 inch, 0.25 to 0.5 inch, and 1.0 to 2.0-inch ranges in 2019 as compared to the Typical Year. These observations suggest that more small-volume storms and fewer large-volume storms occurred during 2019 than in the Typical Year. CSO activation frequencies may be impacted by this difference in rainfall characteristics, since the short duration, higher intensity storm events that occurred in 2019 can cause small short duration CSO events.

Table 3-5: Frequency of Events within Selected Ranges of Total Rainfall for January-December, 2019

Rain Gauge	Total Rainfall (inches)	Total Number of Storms	Number of Storms by Depth				
			Depth < 0.25 inches	Depth 0.25 to 0.5 inches	Depth 0.5 to 1.0 inches	Depth 1.0 to 2.0 inches	Depth ≥2.0 inches
Typical Year	46.8	93	49	14	16	8	6
January-December 2019 Metering Data							
Average of 20 Rain Gauges							
Average	49.07	112	58	24	14	12	4
MWRA Rain Gauges							
Ward Street	50.14	113	56	25	18	11	3
Columbus Park	52.47	115	57	24	16	14	4
Chelsea Creek	49.18	116	63	26	9	17	1
Hanscom Air Force Base	47.53	111	57	29	12	8	5
Hayes PS	45.78	110	55	28	11	15	1
BWSC Rain Gauges							
Allston	44.44	110	62	23	13	8	4
Charlestown	46.09	115	61	28	11	13	2
Dorchester-Adams (1)	51.12	112	58	22	15	13	4
Dorchester-Talbot (1)	51.12	112	58	22	15	13	4
Hyde Park	54.72	116	56	25	15	16	4
East Boston	50.42	116	62	26	12	13	3
Longwood	48.74	115	61	22	18	10	4
Roslindale	55.53	115	58	25	16	11	5
Roxbury	51.47	113	58	24	16	10	5
Union Park	49.57	113	55	25	19	10	4
USGS Rain Gauge							
Fresh Pond	45.43	108	60	19	15	10	4
Project Gauges							
Lexington Farm	45.44	110	58	29	13	8	4
Spot Pond	46.8	111	55	28	15	11	2
Somerville	46.54	111	56	27	13	14	1
Waltham Farm	51.18	116	63	23	13	12	5

(1) Data was replaced for Dorchester-Adams and Dorchester-Talbot, resulting in identical storm statistics

Storms with greater than two inches of total rainfall at the Ward Street, Columbus Park, Chelsea Creek Headworks, and USGS Fresh Pond rain gauges were identified and compared to storms with greater than two inches of total rainfall in the Typical Year (Table 3-6). Experience has shown that large storms often account for a disproportionate volume of CSO. Table 3-6 indicates there were five storm events (April 22, 2019, July 22, 2019, August 7, 2019, October 14, 2019 and December 29, 2019) where rainfall depths observed at Ward Street, Columbus Park and/or USGS Fresh Pond were greater than two inches.

The April 22, 2019 storm had recorded rain depths greater than 2 inches at Ward Street, Columbus Park, Chelsea Creek, and USGS Fresh Pond rain gauges, indicating a storm event with uniform rainfall in contrast to the July 22, 2019 storm for which 2.34 inches of rain was recorded only at Columbus Park. This suggests that the July storm was a more geographically isolated rain event. The 2019 monitoring period had a lower frequency of 2-inch or greater storm events compared to the Typical Year, with the largest storm of the rain gauges presented below recording 2.98 inches of rainfall. The largest storm in the Typical Year had 3.89 inches of rainfall. While the 2019 rainfall depths were smaller than the Typical

Year, the average intensities and peak intensities were generally higher, and the storm durations were generally shorter.

Table 3-6. Comparison of Storms Between January 1 and December 31, 2019 and Typical Year with Greater than Two Inches of Total Rainfall

Rain Gauge	Date	Duration (hr)	Total Rainfall (in)	Average Intensity (in/hr)	Peak Intensity (in/hr)	Storm Recurrence Interval (24-hr)
Typical Year	12/11/1992	50	3.89	0.08	0.20	1y
	8/15/1992	72	2.91	0.04	0.66	3m
	9/22/1992	23	2.76	0.12	0.65	1y
	11/21/1992	84	2.39	0.03	0.31	3m
	5/31/1992	30	2.24	0.07	0.37	3m-6m
	10/9/1992	65	2.04	0.03	0.42	<3m
January-December 2019 Metering Data						
Ward Street	4/22/2019	17.75	2.66	0.15	0.36	1-2yr
	8/7/2019	12.75	2.45	0.19	1.26	6m
Columbus Park	4/22/2019	17	2.59	0.15	0.40	6m-1yr
	7/22/2019	23.75	2.34	0.10	0.55	6m
	8/7/2019	13.25	2.05	0.15	0.87	3-6m
Chelsea Creek	4/22/2019	18.75	2.63	0.14	0.44	6m-1yr
Fresh Pond (USGS)	8/7/2019	13	2.98	0.23	1.41	1.5 yr
	4/22/2019	18.5	2.15	0.12	0.47	3-6m
	12/29/2019	36.25	2.09	0.06	0.17	<3m
	10/16/2019	9	2.07	0.23	0.66	<3m

Storms with peak rainfall intensities greater than 0.40 in/hr at the Ward Street, Columbus Park, Chelsea Creek Headworks, and USGS Fresh Pond rain gauges were identified and compared to storms with greater than 0.40 in/hr of peak intensity in the Typical Year (Table 3-7). Storms with intensities greater than 0.40 in/hr are of importance because higher intensity storms have been found to produce more CSO activations and volumes than lower intensity storms. The Typical Year has nine storm events with intensities greater than 0.40 inches per hour, while the 2019 monitoring period had more storm events with intensities greater than 0.40 inches per hour.

Table 3-7. Comparison of Storms with Peak Intensities Greater than 0.40 inches/hour Between January 1 and December 31, 2019 versus the Full Typical Year

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Hourly Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
Typical Year	10/23/1992	4	1.18	0.29	1.08	1-2y
	8/11/1992	11	0.87	0.08	0.75	6m-1y
	8/15/1992	72	2.91	0.04	0.66	3m-6m
	9/22/1992	23	2.76	0.12	0.65	3m-6m
	5/2/1992	7	1.14	0.16	0.63	3m-6m
	9/9/1992	1	0.57	0.57	0.57	3m
	9/3/1992	13	1.19	0.09	0.51	< 3m
	6/5/1992	18	1.34	0.07	0.44	< 3m
	10/9/1992	65	2.04	0.03	0.42	< 3m
January-December 2019 Metering Data						
Ward Street Headworks	8/7/2019	12.75	2.45	0.19	1.26	2.5 yr
	7/6/2019	3.5	1.13	0.32	0.84	6m-1yr

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Hourly Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
(BO-DI-1)	10/16/2019	11.75	1.85	0.16	0.7	6m
	9/2/2019	2	0.74	0.37	0.67	3-6m
	4/14/2019	17.75	0.93	0.05	0.65	3-6m
	6/21/2019	13.25	0.83	0.06	0.64	3-6m
	8/28/2019	11.75	1.2	0.1	0.61	3-6m
	10/27/2019	10.75	1.69	0.16	0.54	3m
	4/26/2019	27.75	1.66	0.06	0.48	<3m
	7/17/2019	17	1.07	0.06	0.46	<3m
	7/22/2019	22.25	2	0.09	0.41	<3m
Columbus Park Headworks (BO-DI-2)	7/31/2019	2.25	1.69	0.75	1.61	6 yr
	7/6/2019	3.5	1.42	0.41	1.14	2 yr
	8/7/2019	13.25	2.05	0.15	0.87	6m-1yr
	10/16/2019	8.5	1.91	0.22	0.84	6m-1yr
	6/21/2019	13	1.03	0.08	0.79	6m-1yr
	7/22/2019	23.75	2.34	0.1	0.55	3m
	4/14/2019	17.5	0.77	0.04	0.54	3m
	9/2/2019	1.5	0.58	0.39	0.53	3m
	11/24/2019	17.5	1.84	0.11	0.53	3m
	7/17/2019	18.5	1.28	0.07	0.52	<3m
	8/28/2019	10.5	1.26	0.12	0.48	<3m
	10/27/2019	11.75	1.48	0.13	0.48	<3m
	4/22/2019	17	2.59	0.15	0.4	<3m
Chelsea Creek Headworks (CH-BO-1)	7/6/2019	4	1.69	0.42	1.26	2.5 yr
	8/7/2019	13.5	1.92	0.14	0.88	6m-1yr
	9/2/2019	1.75	0.93	0.53	0.8	6m-1yr
	6/21/2019	13	1.03	0.08	0.79	6m-1yr
	10/16/2019	9	1.62	0.18	0.69	6m
	7/17/2019	5.75	0.71	0.12	0.63	3-6m
	4/14/2019	17.5	0.77	0.04	0.54	3m
	4/14/2019	17.5	0.77	0.04	0.54	3m
	10/27/2019	11.75	1.34	0.11	0.47	<3m
	11/24/2019	17.25	1.54	0.09	0.44	<3m
	8/28/2019	13	1.02	0.08	0.42	<3m
	4/22/2019	17	2.59	0.15	0.4	<3m
Fresh Pond (USGS)	8/7/2019	13	2.98	0.23	1.41	3.5 yr
	9/2/2019	6.5	1.41	0.22	1.25	2.5 yr
	7/6/2019	3.75	1.09	0.29	0.82	6m-1yr
	7/17/2019	9	0.75	0.08	0.67	3-6m
	10/16/2019	9	2.07	0.23	0.66	3-6m
	4/15/2019	17.25	0.86	0.05	0.65	3-6m
	7/31/2019	1.5	0.64	0.43	0.62	3-6m
	8/28/2019	10.25	1.37	0.13	0.6	3m
	4/22/2019	18.5	2.15	0.12	0.47	<3m
	6/20/2019	33	1.02	0.03	0.44	<3m
	7/12/2019	20.25	1.05	0.05	0.41	<3m

For storms with peak rainfall intensities greater than 0.4 in/hr at Ward Street Headworks, Columbus Park Headworks, Chelsea Creek Headworks, and USGS Fresh Pond rain gauges, hyetographs were developed. These hyetographs show the 15-minute rainfall intensities and show the distribution of rainfall during the storm. Rainfall distribution during a storm can impact the behavior of system hydraulics due to soil saturation. For example, a storm where the peak rainfall occurs towards the end of the event will generally create more CSO than a storm with similar total rainfall and peak intensity, where the peak occurs at the beginning of the storm. An example hyetograph is shown in Figure 3-2 with the remaining hyetographs in Appendix D.

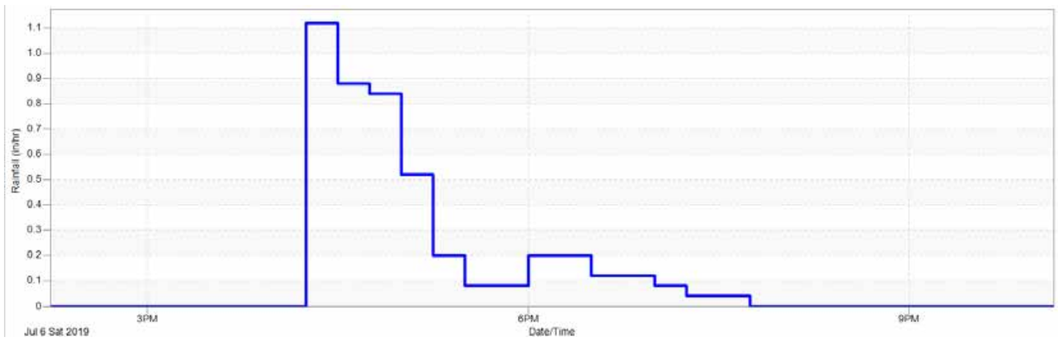

Figure 3-2. Hyetograph from the Ward Street Headworks Gauge for July 6, 2019

Comparisons of the 2019 monitoring period to the Typical Year suggest that 2019 had similar annual rainfall depth, however the storms in 2019 tended to be shorter in duration but higher in intensity. The following is a summary of the rainfall comparison of 2019 to the Typical Year:

- The Typical Year has 93 storm events, while 2019 averaged 112 storm events (Table 3-5).
- The total average rainfall depth for 2019 (49.07 inches) was similar to but slightly greater than the Typical Year (46.80 inches) (Table 3-5).
- 2019 had more storm events with depths less than 0.25 inches than the Typical Year. 2019 had an average of 58 storm events with depths less than 0.25 inches while the Typical Year had 49 such storm events (Table 3-5).
- The 2019 storm events had a higher average frequency of events with depths 1.0 to 2.0 inches than the Typical Year. 2019 had an average of 12 storms in that depth range while the Typical Year had eight (Table 3-5).
- The Typical Year had six storm events with depths greater than 2 inches, while 2019 only had an average of four such storm events. Five of the 20 rain gauges only recorded one or two storms with depths greater than 2 inches (Table 3-5).
- Storm events with depths greater than 2 inches in 2019 tended to have shorter durations and higher intensities than storms in the same size range in the Typical Year (Table 3-6).
- Storm events with intensities greater than 0.40 in/hr in 2019 tended to have higher peak intensities than storms with greater than 0.40 in/hr intensities in the Typical Year (Table 3-7).

3.2 Metering of CSO Discharges

Each CSO regulator was configured with a unique flow metering configuration designed to estimate CSO activations or confirm that the regulator was not active. Meter configurations were intended to quantify the CSO activation frequency, duration, and volumes at most locations, as well as calibrate MWRA's hydraulic model. Additional information on the CSO Metering Plan can be found in Section 3 of Semiannual Report No. 2.

A variety of methods were used for the assessment of metered CSO discharges. Not all of the methods were applicable to each of the meter configurations, but the intent was to use available information to assess the accuracy and reasonableness of the measured CSO activations. Depending on the particular meter configuration, the review of meter data may have included the following methods:

- Direct measurement of meter data
- Comparison with other meters
- Analysis of influent meter scattergraphs of flow and depth to assess how well the influent meters conformed to hydraulic theory
- Comparison of influent meter volume with rainfall to assess how well the volumes correlated with rainfall
- Field inspection of level only meter configurations to check for evidence of CSO discharges
- Correlation of CSO activation with rainfall depth and intensity using scattergraphs. Updated scattergraphs which include the activation and non-activation events from April 15, 2018 to December 31, 2019 are provided in Appendix E.
- Calculation of CSO discharge volume using alternate methods
- Evaluation of reasonableness of meter data

When the meter data indicated that an activation occurred, the duration of the overflow was identified and in locations where possible, the CSO volume was calculated. The method of calculating the CSO volume depended on the meter configuration.

In locations where the necessary depth and velocity sensors were installed, measurements were used to calculate flowrate and total volume of CSO activations. CSO flowrate was calculated by using one of three methods: Continuity, Continuity by subtraction, or a weir equation. The Continuity (Qc) method used the cross-sectional area of the pipe in flow (estimated by depth measurement) multiplied by the velocity measurement to estimate the flow. The Continuity by subtraction (Qs) method used the flow difference from two separate pipes (i.e. influent and DWF connection) as calculated by depth and velocity measurements. The Weir (Qw) method used a depth measurement over a weir structure and an appropriate weir equation. In each case, CSO volume was computed by integrating CSO flowrate over time.

In locations where CSO flowrates and volumes could not be measured by depth/velocity sensors in the outfall, an attempt was made to estimate the overflow volume using other means such as Continuity by subtraction or a weir equation as described above or using Manning's Equation or the Scattergraph method. Table 3-8 identifies the locations where alternative CSO calculation methods to the continuity equation were applied. In locations where the continuity methods or alternative methods could not be used, the overflow was reported as duration only.

Table 3-8. Locations Using Alternative (Non-Continuity Equation) CSO Calculation Methods

Outfall/Regulator	Calculation Method
BOS014 RE014-2	Scattergraph Method
BOS09 RE09-2	Scattergraph Method
BOS010 RE010-2	Scattergraph Method
BOS057 RE057-6	Weir Equation
BOS060 RE060-7	Scattergraph Method
BOS004 RE04-6	Scattergraph Method

At some locations, volumes were not estimated. Volumes were not calculated using alternate means for a number of reasons:

- Use of the weir equation assumes a free discharge condition. Therefore, the presence of backwater from conditions such as high tide may prevent use of this method.
- CSO volumes were not calculated at level-only sites.

- At some locations CSO volumes were not able to be verified and were thus considered inconsistent. This occurred at regulators RE401A (CAM401A), RE011 (CAM001), RE021 (CAM002), CAM005, and CAM017.

The total CSO volume from the upstream BOS046/MWR023 regulators that can overflow to BSWC Stony Brook Conduit is proportioned between outfalls MWR023 and BOS046 for reporting purposes during periods when Boston Gatehouse No. 1 is open. However, Boston Gatehouse No. 1 was not reported to be opened during the 2019 monitoring period, and any overflow from the upstream regulators would be reported as being conveyed to the MWR023 outfall as long as the gates at Boston Gatehouse No. 1 were not overtopped. It should also be noted that the total volume indicated for outfall MWR023 would not include volume that may have discharged from upstream regulators that were level-only sites, where volumes could not be estimated based on available data.

3.2.1 Adjustment of Metering Program

With sufficient meter data for calibration and a general understanding of the rainfall depth, intensity, and duration that typically results in a regulator activating, the metering program was adjusted on March 1, 2019. Metering data are continuing to be collected and analyzed at regulator locations that may impact the Variance waters, as well as at regulators where further investigations where required given higher than anticipated activation frequency and volume. These meters will continue to collect data to identify CSO activation frequency, duration, and volumes through June 2020. Table 3-9 identifies locations where the meters were removed from the program as of March 1, 2019. In locations where the meter was removed, modeled results are presented in Section 3.3 for the entire period, while metering data reflect the period of January 1 to March 1, 2019.

Table 3-9. Meters Removed from the Metering Program as of March 1, 2019

Outfall	Regulator
BOS013	RE013-1
BOS014	RE014-2
BOS017	RE017-3
BOS009	RE009-2
BOS010	RE010-2
BOS012	RE012-2
BOS003	RE003-2
BOS003	RE003-7
BOS004	RE004-6
BOS005	RE005-1
BOS062	RE062-4

Outfall	Regulator
BOS064	RE064-4
BOS064	RE064-5
BOS068	RE068-2 (1a)
BOS070/RCC	RE070/5-3
BOS076	RE076/4-2
BOS078	RE078-1
BOS078	RE078-2
BOS078	TG 78 at outfall for RE078-1 & RE078-2
BOS079	RE079-3
BOS080	RE080-2B

3.2.2 Review of Meter Results

Metering data were used to identify CSO activation frequency, duration, and volumes where applicable. Based on the evaluations of meter data supporting previous Semiannual Reports, suspect data were generally found to fall into one or more of the following categories.

- Level sensor activations
- Unreasonable data
- Inconsistent CSO volumes
- Questionable overflow elevations

Level sensor-only configurations were installed at locations where the hydraulic model predicted that no overflows would occur during either the typical year and/or the 2-year design storm. Metering equipment can occasionally become fouled and produce unreasonable results or fail to record any data. Metering data were reviewed to assess reasonableness based on neighboring meters, storm characteristics, and system conditions. The CSO volumes at some regulators including RE401A (CAM401A), RE011

(CAM001), RE021 (CAM002), CAM005, and CAM017 were not able to be verified and were thus considered inconsistent.

CSO discharges to outfall CAM401A were anticipated to be estimated using a weir equation. However, a screening facility with brushes makes a standard weir equation not applicable. Additional investigation into estimating the CSO discharge volume using alternative weir equations provided by the City of Cambridge is ongoing. At outfalls CAM001 and CAM002, it was anticipated that the Cambridge meters on the outfall pipes could be used to quantify CSO discharge volumes. Confidence in the volumes estimated at these locations is low due to concerns with the quality of the meter data, and therefore these locations are being treated as level-only sites. At outfall CAM005, flow meters were installed on the influent and at key locations on the regulator. The city of Cambridge also had meters installed, including an overflow meter. There appear to be blockages in the outfall pipe as well as an obstruction on the dry weather connection to the interceptor. As a result, it was not possible to correlate the CSO flows from the Cambridge meter with the MWRA meter, therefore only CSO activation frequency could be identified at this site. CAM017 is a complex site with three bending weirs and multiple meters, including an inclinometer. The Cambridge influent meters and the MWRA level sensor on the dry weather flow connection were used to analyze the activation frequencies at this location, however, volumes were not calculated.

3.3 Metered and Modeled CSO Discharge Estimates, 2018 and 2019 Rainfall

Metered and modeled predicted activations using the recently calibrated model are presented in this section. The MWRA's recently calibrated model was used to simulate the storm events from April 15, 2018 to December 31, 2019. The model simulated CSO discharges are compared to the metered CSO discharges. Modeled CSO discharges for 2018 are based on the 2018 calibrated model with 2018 system conditions, while the CSO discharges for 2019 are based on the 2018 calibrated model with 2019 system conditions. Changes between the 2018 and 2019 model network are summarized in Section 2.2.

3.3.1 Differences Between Metered and Modeled CSO Discharge Estimates

In general, the meter and model predicted activations were similar in the majority of locations, with the 2018 calibration of the model resulting in improved prediction of CSO activations and frequencies. However, the MWRA model is a numerical representation of a complex and dynamic system and meters are susceptible to fouling and failure. As a result, in some locations metered and model predicted activation frequencies and volumes differed. While hydraulic models can be used to effectively simulate CSO events and meters can effectively monitor CSO discharge activation frequencies, durations, and volumes, both models and meters are susceptible to error. For the 2018 and 2019 model and metered results, the differences between modeled and metered discharges were assessed on a storm-by-storm basis as part of the calibration and verification analysis. The differences between metered and model predicted activations were primarily a result of the following:

- **Meter data uncertainty**: Flow meters are susceptible to fouling, creating false positive activations as well as missing activations due to meter failure. Figure 3-3 shows an example of a meter fouling. Metering in regulators is more challenging than metering in single pipe structures. The turbulence present in a regulator structure can interfere with recorded measurements. In addition, regulators are inherently complicated structures and it is sometimes difficult in the field to identify the proper location to place the meter.

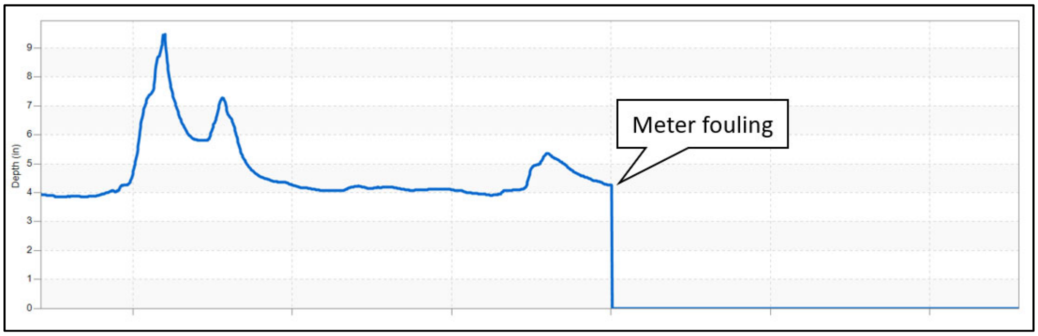

Figure 3-3. Meter Fouling

- **Rainfall spatial variation:** Rain gauges throughout the system are spaced approximately three miles apart, however, rainfall spatial variation exists between gauges. This is particularly noticeable in short duration, high intensity storm events for regulators with significant tributary areas.
- **Groundwater/seasonal variation:** The groundwater module was used for model calibration in 2018 in areas where significant groundwater inflow was observed. Groundwater inflow is a complex process and is influenced by antecedent conditions, evaporation, rainfall, and snowfall. These conditions are likely different for 2019 compared to 2018, and therefore the predicted groundwater response for a model calibrated for 2018 conditions may be higher or lower for 2019 conditions.
- **Interconnections:** Some regulators are interconnected, creating difficulties in simulating activations at both regulators. As a result, activation frequency and volumes may be more similarly correlated between outfall and receiving waters than by individual regulators.
- **Transient system conditions:** The MWRA and CSO community systems are constantly undergoing maintenance and cleaning and is also susceptible to changes due to conditions such as sediment build up and leaking tide gates. These transient system conditions, especially outside of the calibration period, could prevent the model from replicating metered responses for a storm event.
- **Facility operation:** The model's facility operation has been enhanced with real-time control (RTC), enabling the model to mimic the reported operation of the facilities during storm events. Differences in modeled peak storm response and facility operation, deviation from the facility's reported operation, and/or other changes to facility operation may result in differences in metered and model predicated activations, especially at regulators impacted by facility operation.
- **Unmodeled impacts from snowfall and/or snowmelt:** The model is not configured to simulate snowmelt and rain gauge data during freezing weather. In addition, some of the rain gauges are not heated and may not accurately measure the amount of precipitation during colder periods. This makes the ability to accurately measure precipitation and predict CSO more difficult during freezing conditions.

The model was calibrated to metering data and the system conditions of 2018. However, modifications were made to the system in 2019, especially within two regulators which have the potential to discharge to the Alewife Brook at SOM001A and CAM002. As a result, modeled and metered results specific to 2019 may vary as a result of modifications to the system in 2019 that were not present in 2018. As noted previously, debris and ragging were discovered in the connection from the RE003-12 regulator in 2019 and were subsequently cleaned by the BWSC. The build-up of these debris and ragging resulted in greater CSO discharges during the model 2018 model calibration period. After the debris was removed in July of 2019, model calibration adjustments were required to address the model's over predictions of CSO at this location. The greater amount of flow entering the interceptor from this location resulted in changes to hydraulically interconnected regulators in East Boston, resulting in minor impacts to modeled CSO discharges at these locations.

3.3.2 2019 Metered and Modeled CSO Discharge Estimates

MWRA's recently calibrated model was used to simulate the storm events from January 1 to December 31, 2019. The model simulated and metered CSO discharges are presented in Table 3-10. The CSO discharges for 2019 are based on the 2018 calibrated model with 2019 system conditions. Changes between the 2018 and 2019 model network are summarized in Section 2.5.

In some locations, direct comparisons between modeled and metered discharges are not possible because the meters were not installed for the entire 2019 period. In these locations metered CSO discharges are not provided for the few storm events that occurred between January 1 to March 1, 2019, given the model results present the full 2019 period and a comparison would be inappropriate.

3.3.3 2018 Metered and Modeled CSO Discharge Estimates

The previous semiannual reports only presented metered CSO discharges as the model was not yet calibrated. With calibration complete, MWRA's recently calibrated model was used to simulate the storm events from April 15 to December 31, 2018 and from January 1, 2019 to December 31, 2019. The CSO discharges for 2018 are based on the 2018 calibrated model with 2018 system conditions. The comparison of metered and modeled CSO discharges from April 15 to December 31, 2018 is presented in Table 3-11.

Table 3-10. Summary of January 1-December 31, 2019 Modeled and Metered CSO Discharges

Outfall	Regulator	Level Only	Meter Removed 3/1/19[1]	January 1 - December 31, 2019			
				Meter		Model	
				Activation Frequency	Volume (MG)[2]	Activation Frequency	Volume (MG)
Alewife Brook							
CAM001	RE-011	Y		7	N/A	3	0.16
CAM002	RE-021			1	N/A	2	0.20
MWR003	RE-031			3	2.99	3	5.34
CAM401A	RE-401			20	N/A	10	6.25
CAM401B	RE-401B			6	1.04	6	1.69
SOM001A	RE-01A			9	7.98	7	9.08
Upper Mystic River							
SOM007A/MWR205A		Y		12	N/A	8	14.52
Mystic/Chelsea Confluence							
MWR205 (Somerville Marginal Facility)				27	96.41	26	98.89
BOS013	RE013-1		Y	-	-	19	1.79
BOS014	RE014-2		Y	-	-	18	4.76
BOS017	RE017-3		Y	-	-	12	0.90
CHE003	RE-031	Y		0	0.00	0	0.00
CHE004	RE-041			28	1.44	12	2.70
CHE008	RE-081			18	3.34	17	8.01
Upper Inner Harbor							
BOS009	RE009-2		Y	-	-	22	1.39
BOS010	RE010-2		Y	-	-	15	3.31
BOS012	RE012-2		Y	-	-	22	3.25
BOS019	RE019-2	Y		3	N/A	1	0.14
BOS057	RE057-6			6	4.62	6	2.83
BOS060	RE060-7			4	0.58	7	1.13
	RE060-20			4	0.09	6	0.43
MWR203 (Prison Point)				17	276.63	15	260.96
Lower Inner Harbor							
BOS003	RE003-2		Y	-	-	6	0.40
	RE003-7		Y	-	-	12	3.80
	RE003-12			29	19.46	21	16.54
BOS004	RE004-6		Y	-	-	12	0.13
BOS005	RE005-1	Y	Y	-	-	0	0.00
Fort Point Channel							
BOS062	RE062-4		Y	-	-	14	1.65
BOS064	RE064-4		Y	-	-	2	0.11
	RE064-5	Y	Y	-	-	8	0.09
BOS065	RE065-2	Y		15	N/A	8	1.69
BOS068	RE068-1A	Y	Y	-	-	2	0.00
BOS070/DBC	RE070/8-3			11	2.53	14	3.09
	RE070/8-6	Y		1	N/A	2	0.01
	RE070/8-7	Y		7	N/A	8	0.34
	RE070/8-8	Y		2	N/A	1	0.00
	RE070/8-13	Y		5	N/A	2	0.03
	RE070/8-15	Y		4	N/A [3]	4	0.10
	RE070/9-4			15	3.24	14	4.61
	RE070/10-5			4	0.24	3	0.33
	RE070/7-2			15	0.90	24	7.07
MWR215 (Union Park)				10	41.88	11	31.01
BOS070/RCC	RE070/5-3	Y	Y	-	-	2	0.23
BOS073	RE073-4			2	0.55	2	0.01
Reserved Channel							
BOS076	RE076/2-3			3	0.01	3	0.09
	RE076/4-3			3	0.26	6	1.84
BOS078	RE078-1 RE078-2		Y	-	-	3	0.15
BOS079	RE079-3	Y	Y	-	-	3	0.00

Outfall	Regulator	Level Only	Meter Removed 3/1/19[1]	January 1 - December 31, 2019			
				Meter		Model	
				Activation Frequency	Volume (MG)[2]	Activation Frequency	Volume (MG)
BOS080	RE080-2B	Y	Y	-	-	3	0.09
Upper Charles							
CAM005	RE-051			17	N/A	10	1.71
CAM007	RE-071			2	1.43	3	4.43
Lower Charles							
CAM017	CAM017			3	N/A	1	0.95
MWR010	RE036-9	Y		0	0.00	1	0.00
	RE037	Y		0	0.00	0	0.00
MWR018		Y		1	N/A	2	6.50
MWR019		Y		0	0.00	2	3.20
MWR020		Y		0	0.00	2	2.57
MWR201 (Cottage Farm)				6	41.50	5	37.00
MWR023	RE046-19	Y		1	N/A	0	0.00
	RE046-30			1	0.01	0	0.00
	RE046-50	Y		0	0.00	0	0.00
	RE046-54	Y		0	0.00	0	0.00
	RE046-55	Y		0	0.00	0	0.00
	RE046-62A	Y		0	0.00	0	0.00
	RE046-90	Y		0	0.00	0	0.00
	RE046-100			4	0.00	4	0.17
	RE046-105			1	0.00	3	0.06
	RE046-381	Y		2	N/A	2	0.26
	RE046-192	Y		0	0.00	0	0.00
Back Bay Fens							
BOS046 [4]	Boston Gatehouse #1			N/A	N/A	2	0.35
GRAND TOTAL					-		543.47

(1) For locations indicated with a “Y” in the meter removed column, the meter was removed on March 1, 2019 and metered results are not presented. Modeled results reflect the entire 2019 period and as a result a direct comparison between modeled and metered results where the meter was removed cannot be made.

(2) Flow volumes are estimates based on information available. Direct measurements in the outfall pipe, weir equation, scattergraphs and other methods were used to estimate volumes. Where activations occurred and volume is reported as 0.00 MG, volumes were less than 0.01 MG. In locations where these methods were not applicable (N/A), such as the sites with level-only sensors, no volume was approximated.

(3) BWSC pipe cleaning operations along and tributary to the South Boston Interceptor-North Branch in the summer/fall of 2019 prevented accurate meter readings at regulator RE070/8-15.

(4) Boston Gatehouse 1 is primarily a stormwater discharge but may contain CSO if the upstream regulators overflow. The upstream regulators are monitored directly. The gatehouse is normally closed but may be opened for flood mitigation. Flow can discharge at the Gatehouse if either the gate is opened or if water overtops the gate. Based on model tracer studies, when a discharge occurs during model simulations at BOS046 it was estimated that 25% of the CSO from the upstream regulators discharges at the MWR023 outfall (Charles River) and 75% discharges at BOS046 (Back Bay Fens). The reported volumes for the model at BOS046 are based on 75% of the predicted CSO volume upstream.

Table 3-11. Summary of April 15-December 31, 2018 Modeled and Metered CSO Discharges

Outfall	Regulator	Level Only	April 15-December 31, 2018			
			Meter		Model	
			Activation Frequency	Volume (MG) [(1)]	Activation Frequency	Volume (MG)
Alewife Brook						
CAM001	RE-011	Y	3	N/A	2	0.01
CAM002	RE-021		4	N/A	4	0.63
MWR003	RE-031		0	0	2	0.46
CAM401A	RE-401		18	N/A	15	4.91
CAM401B [(2)]	RE-401B		3	0.00	3	0.22
SOM001A	RE-01A		14	14.64	13	8.98
Upper Mystic River						
SOM007A/MWR205A		Y	15	N/A	12	35.82
Mystic/Chelsea Confluence						
MWR205 (Somerville Marginal Facility)			33	103.68	26	99.67
BOS013	RE013-1		14	0.51	19	1.03
BOS014	RE014-2		11	2.25	19	2.23
BOS017	RE017-3		8	0.74	10	0.46
CHE003	RE-031	Y	0	0	0	0.00
CHE004	RE-041		17	1.79	10	1.62
CHE008	RE-081		19	3.46	20	5.06
Upper Inner Harbor						
BOS009	RE009-2		14	0.40	28	0.77
BOS010	RE010-2		7	1.35	10	1.87
BOS012	RE012-2		12	1.15	19	1.93
BOS019	RE019-2	Y	4	N/A	2	0.21
BOS057	RE057-6		4	2.98	5	1.58
BOS060	RE060-7 [(3)]		4	0.98	6	0.68
	RE060-20		4	N/A	9	0.42
MWR203 (Prison Point)			18	271.80	15	259.79
Lower Inner Harbor						
BOS003	RE003-2		3	0.00	2	0.05
	RE003-7		6	0.52	8	1.89
	RE003-12		30	19.91	31	17.29
BOS004	RE004-6		6	0.10	7	0.01
BOS005	RE005-1	Y	0	0	0	0.00
Fort Point Channel						
BOS062	RE062-4		11	0.11	14	1.23
BOS064	RE064-4		2	0.20	2	0.01
	RE064-5	Y	5	N/A	7	0.06
BOS065	RE065-2	Y	10	N/A	12	0.46
BOS068	RE068-1A	Y	1	N/A	1	0.00
BOS070/DBC	RE070/8-3		10	2.14	11	1.71
	RE070/8-6	Y	1	N/A	1	0.00
	RE070/8-7	Y	7	N/A	10	0.20
	RE070/8-8	Y	1	N/A	1	0.00
	RE070/8-13	Y	0	0	1	0.00
	RE070/8-15	Y	2	N/A	2	0.00
	RE070/9-4		12	2.25	11	1.47
	RE070/10-5		2	0.31	3	0.20
	RE070/7-2		25	1.81	25	2.13
MWR215 (Union Park)			7	23.88	11	31.18
BOS070/RCC	RE070/5-3	Y	2	N/A	4	0.17
BOS073	RE073-4		1	0.04	3	0.01

Outfall	Regulator	Level Only	April 15-December 31, 2018			
			Meter		Model	
			Activation Frequency	Volume (MG) [(1)]	Activation Frequency	Volume (MG)
Reserved Channel						
BOS076	RE076/2-3		0	0.00	3	0.06
	RE076/4-3		1	0.12	5	0.41
BOS078	RE078-1 RE078-2		1	0.11	3	0.08
BOS079	RE079-3	Y	0	0	1	0.00
BOS080	RE080-2B	Y	1	N/A	1	0.00
Upper Charles						
CAM005	RE-051		15	N/A	13	1.07
CAM007	RE-071		2	0.14	3	0.99
Lower Charles						
CAM017	CAM017		3	N/A	1	0.09
MWR010	RE036-9	Y	0	0	0	0.00
	RE037	Y	0	0	0	0.00
MWR018	Charles River		2	N/A	3	4.30
MWR019	Charles River		2	N/A	3	1.68
MWR020	Charles River		2	N/A	3	1.14
MWR201	Cottage Farm		4	30.14	4	27.72
MWR023 [(4)]	RE046-19	Y	0	0	0	0.00
	RE046-30		0	0	0	0.00
	RE046-50	Y	0	0	0	0.00
	RE046-54	Y	0	0	0	0.00
	RE046-55	Y	3	N/A	0	0.00
	RE046-62A	Y	0	0	0	0.00
	RE046-90	Y	1	N/A	0	0.00
	RE046-100		6	0.04	4	0.16
	RE046-105		1	0.03	4	0.07
	RE046-381	Y	2	N/A	2	0.14
	RE046-192	Y	0	0	1	0.02
Back Bay Fens						
BOS046 [(4)]	Boston Gatehouse #1		N/A	N/A	4	0.29

(1) Flow volumes are estimates based on information available. Direct measurements in the outfall pipe, weir equation, scattergraphs and other methods were used to estimate volumes. Where activations occurred and volume is reported as 0.00 MG, volumes were less than 0.01 MG. In locations where these methods were not applicable (N/A), such as the sites with level-only sensors, no volume was approximated.

(2) A metered activation occurred, however the total measured volume of the activations was less than 0.005 MG.

(3) Metered activation frequency and volume were revised from the previous reported values as a result of the detailed assessments at this location (see Appendix A: Detailed Assessments into Meter/Model, BOS060: RE060-7)

(4) Boston Gatehouse 1 is primarily a stormwater discharge but may contain CSO if the upstream regulators overflow. The upstream regulators are monitored directly. The gatehouse is normally closed but may be opened for flood mitigation. Flow can discharge at the Gatehouse if either the gate is opened or if water overtops the gate. Based on model tracer studies, when a discharge occurs during model simulations at BOS046 it was estimated that 25% of the CSO from the upstream regulators discharges at the MWR023 outfall (Charles River) and 75% discharges at BOS046 (Back Bay Fens). The reported volumes for the model at BOS046 are based on 75% of the predicted CSO volume upstream.

4. Typical Year CSO Discharges: Current Performance and Comparison with LTCP Levels of Control

4.1 MWRA's Current (2019) System Conditions Model and LTCP Levels of Control

As mentioned earlier, MWRA completed recalibration of its hydraulic model using extensive meter data it collected in 2018. MWRA then updated the model to 2019 system conditions, including regulator adjustments at outfalls SOM01A and CAM002 on the Alewife Brook, maintenance work by BWSC at regulator RE003-12 in East Boston and other information from ongoing investigations. MWRA compared the updated 2019 model's CSO predictions for storms in 2019 against meter data to evaluate the calibration and model results. MWRA used the 2019 model to simulate current system performance under Typical Year rainfall, to then compare the results with the Long-Term Control Plan's (LTCP) Typical Year levels of control. The 2019 model's Typical Year results provide an interim assessment of system performance against the LTCP levels of control. MWRA will continue to evaluate modeled CSO discharges across a range of rainfall characteristics by comparing the model results to validated meter data.

The Typical Year and the Court mandated LTCP levels of control are described in Section 1.3. The Court Order - specifically Exhibit B to the Second Stipulation - defines the LTCP levels of control by outfall and by receiving water segment. The sources of these levels of control are included in the historical MWRA reports that documented the various CSO control planning efforts MWRA conducted from 1992 to 2008. These source documents, all submitted to and accepted by EPA and DEP, are presented in Table 4.1. Table 4.1 is copied from the Court Order's Exhibit A to the Second Stipulation. Many of the outfall by outfall levels of control, date to MWRA's 1997 Final Facilities Plan and Environmental Impact Report, while the source of the latest approved levels of control - for the Prison Point CSO Treatment Facility - is an April 2008 report on proposed facility operation modifications. For each subsequent planning effort and planning document from 1992 through 2008, MWRA had the benefit of improved system understanding, and MWRA was able to utilize advanced planning tools, including improved hydraulic models or updated model versions.

4.2 Closed CSO Outfalls

Table 4-2 presents a full accounting of the status and Typical Year overflow activity for all discharge locations addressed by MWRA's CSO planning efforts and projects since MWRA assumed responsibility for system-wide CSO control in the mid 1980's. A few CSO outfalls listed in Table 4-2 were closed prior to the Federal Court's integration of LTCP levels of control into the Court Order in 2006 and are not listed in Exhibit B to the Second Stipulation. Table 4-2 shows that 35 of the 84 outfalls active in the 1980's are now "closed," i.e., CSO discharges are eliminated.[3] The closed outfalls include all 28 outfalls required to be closed by the approved LTCP and the Court Order and several additional outfalls. These additional closed outfalls include:

- SOM002, SOM002A and SOM003 on the Alewife Brook and SOM006 on the Upper Mystic River, closed by the City of Somerville in the 1980's and 1990's;
- CHE002 on the Inner Harbor, closed by the City of Chelsea in 2014;
- BOS006 and BOS007 in East Boston, closed by BWSC in 2008, and BOS072 on Fort Point Channel, closed by BWSC in 2014;
- BOS083 on the South Boston beaches, closed by MWRA in 2008 with construction of the South Boston CSO storage tunnel; and
- CAM009 and CAM011 on the Charles River, which are tentatively closed by the City of Cambridge pending additional hydraulic evaluations to ensure no upstream risk of flooding.

[3] MWRA confirmed that CSO are eliminated at outfalls that are "closed" as a key objective of its CSO inspections in 2018. Some of the outfalls closed to CSO are now utilized by the community for the discharge of separate stormwater.

Table 4-1. MWRA Long-Term CSO Control Plan Facilities Planning Documentation (1 of 2)

Planning Document	Project	Receiving Water
Final Combined Sewer Overflow Facilities Plan and Environmental Impact Report, July 31, 1997	Hydraulic Relief for CAM005	Upper and Lower Charles River Basin
	Stony Brook Sewer Separation	
	Floatables Control at CAM007, CAM009, CAM011 and CAM017	
	Baffle Manhole Separation at SOM 001 and SOM 006-007	Alewife Brook/Upper Mystic River
	Hydraulic Relief for BOS 017[(1)]	Mystic/Chelsea Confluence
	Chelsea Branch Relief Sewer	
Minor modifications were addressed in Notice of Project Change, March 1999	Trunk Sewer Relief for CHE 002-004	
	Outfall Repairs and Floatables Control at CHE 008	
	Storage Conduit for BOS 019	Upper Inner Harbor
	Detention/Treatment Facility at Union Park Pump Station	Fort Point Channel
	South Dorchester Bay Sewer Separation	South Dorchester Bay
	Constitution Beach Sewer Separation	Constitution Beach
	Neponset River Sewer Separation	Neponset River
The following reports <u>supplement</u> information in the Final CSO Facilities Plan and Environmental Impact Report, July 31, 1997		
Upgrades to Existing CSO Facilities, Supplemental Environmental Impact Report, September 30, 1998	Cottage Farm Facility Upgrade	Upper Charles River Basin
	Prison Point Facility Upgrade [(2)]	Upper Inner Harbor
	Somerville Marginal Facility Upgrade	Upper Mystic River; Mystic/Chelsea Confluence
	Commercial Point Facility Upgrade	South Dorchester Bay
Upgrades to the Fox Point CSO Treatment Facility, Supplemental Environmental Impact Report, December 31, 1998	Fox Point Facility Upgrade	South Dorchester Bay
Fort Point Channel CSO Storage Conduit Notice of Project Change, June 2003, and MWRA Long Term CSO Control Plan, Fort Point Channel Sewer Separation and System Optimization Project, Level of Control at CSO Outfalls BOS072 and BOS073, June 7, 2004.	Sewer Separation for BOS072 and BOS073	Fort Point Channel
Re-Assessing Long Term Floatables Control for Outfalls MWR018, 019 and 020, February 2001 Report on Re-Assessment of CSO Activation Frequency and Volume for Outfall MWR010, April 2001, and supplemental letter report (Metcalf & Eddy, Inc.), May 31, 2001	Regionwide Floatables Controls and Outfall Closing Projects	Regionwide

Table 4-1 MWRA Long-Term CSO Control Plan Facilities Planning Documentation (2 of 2)

Planning Document	Project	Receiving Water
Final Variance Report for Alewife Brook and the Upper Mystic River, July 2003, and supplemental letter report (Metcalf & Eddy, Inc.), July 8, 2003	Sewer Separation at CAM004 and CAM400	Alewife Brook
	Interceptor Connection Relief and Floatables Control at CAM002, CAM401B and SOM01A, and Floatables Control at CAM001 and CAM401A	
	Control Gate/Floatables Control at Outfall MWR003 and MWRA Rindge Avenue Siphon Relief	
East Boston Branch Sewer Relief Project Reevaluation Report, February 2004 Recommendations and Proposed Schedule for Long-Term CSO Control for the Charles River, Alewife Brook and East Boston, August 2, 2005	Interceptor Relief for BOS003-014	Mystic/Chelsea Confluence; Upper and Lower Inner Harbor
Supplemental Facilities Plan and Environmental Impact Report on the Long-term CSO Control Plan for North Dorchester Bay and Reserved Channel, April 27, 2004	North Dorchester Bay Storage Tunnel and Related Facilities	North Dorchester Bay
	Pleasure Bay Storm Drain Improvements	
	Morrissey Boulevard Storm Drain	
	Reserved Channel Sewer Separation	Reserved Channel
Recommendations and Proposed Schedule for Long-Term CSO Control for the Charles River, Alewife Brook and East Boston, August 2, 2005, and MWRA Revised Recommended CSO Control Plan for the Charles River, Typical Year CSO Discharge Activations and Volumes, November 15, 2005	Brookline Connection, Cottage Farm Overflow Chamber Interconnection and Cottage Farm Gate Control	Upper and Lower Charles River Basin
	Brookline Sewer Separation	
	Bulfinch Triangle Sewer Separation	
	Charles River Valley/South Charles Relief Sewer Gate Controls	
	Evaluation of Additional Charles River Interceptor Interconnection Alternatives	
Prison Point Optimization Study, April 30, 2007 Proposed Modification of Long-Term Level of Control for the Prison Point CSO Facility, April 2008	Prison Point CSO Facility Optimization	Upper Inner Harbor

[(1)] Also “MWRA Long-Term CSO Control Plan Target CSO Activation Frequency and Volume by Outfall,” letter dated December 9, 2005.

[(2)] Also “Additional Technical Information Regarding Prison Point Flows,” December 23, 2005 (email); “MWRA Long-term CSO Control Plan Prison Point Facility Discharges,” December 30, 2005; “MWRA Long-Term CSO Control Plan Response to Additional EPA Questions Regarding Prison Point Discharges,” January 9, 2005 (2006); “MWRA Long-Term CSO Control Plan Second Response to Additional EPA Questions Regarding Prison Point Discharges,” January 13, 2006; “MWRA Long-Term CSO Control Plan Response to Additional Question About Modeled Prison Point Discharges,” February 7, 2006.

Table 4-2. Typical Year Performance: Baseline 1992, Current (2019) and LTCP (1 of 3)

Outfall	1992 SYSTEM CONDITIONS (1)		2019 SYSTEM CONDITIONS		LONG TERM CONTROL PLAN (2)	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
ALEWIFE BROOK						
CAM001	5	0.15	1	0.02	5	0.19
CAM002	11	2.73	0	0.00	4	0.69
MWR003	6	0.67	3 (3)	1.60 (3)	5	0.98
CAM004	20	8.19	Closed	N/A	Closed	N/A
CAM400	13	0.93	Closed	N/A	Closed	N/A
CAM401A	18	2.12	10	3.59	5	1.61
CAM401B			5	0.73	7	2.15
SOM001A	10	11.93	6	3.60	3	1.67
SOM001	0	0.00	Closed	N/A	Closed	N/A
SOM002	0	0.00	Closed	N/A	N/I (4)	N/I (4)
SOM002A	0	0.00	Closed	N/A	Closed	N/A
SOM003	0	0.00	Closed	N/A	Closed	N/A
SOM004	5	0.09	Closed	N/A	Closed	N/A
TOTAL		**26.81**		**9.54**		**7.29**
UPPER MYSTIC RIVER						
SOM007A/MWR205A	9	7.61	6	4.95	3	3.48
SOM006(4)	0	0.00	Closed	N/A	N/I (4)	N/I (4)
SOM007	3	0.06	Closed	N/A	Closed	N/A
TOTAL		**7.67**		**4.95**		**3.48**
MYSTIC/CHELSEA CONFLUENCE						
MWR205 (Somerville Marginal Facility)	33	120.37	39	109.63	39	60.58
BOS013	36	4.40	10	0.74	4	0.54
BOS014	20	4.91	8	1.45	0	0.00
BOS015	76	2.76	Closed	N/A	Closed	N/A
BOS017	49	7.16	6	0.32	1	0.02
CHE002	49	2.51	Closed	N/A	4	0.22
CHE003	39	3.39	0	0	3	0.04
CHE004	44	18.11	7	1.01	3	0.32
CHE008	35	22.35	11	3.81	0	0.00
TOTAL		**185.96**		**116.96**		**61.72**
UPPER INNER HARBOR						
BOS009	34	3.60	10	0.70	5	0.59
BOS010	48	11.83	7	0.77	4	0.72
BOS012	41	7.90	13	1.34	5	0.72
BOS019	107	4.48	1	0.09	2	0.58
BOS050	No Data		Closed	N/A	Closed	N/A
BOS052	0	0.00	Closed	N/A	Closed	N/A
BOS057	33	14.71	2	1.37	1	0.43
BOS058	17	0.29	Closed	N/A	Closed	N/A
BOS060	64	2.90	2	0.17	0	0.00
MWR203 (Prison Point)	28	261.85	17	241.71	17	243.00
TOTAL		**307.56**		**246.15**		**246.04**

Table 4-2. Typical Year Performance: Baseline 1992, Current (2019) and LTCP (2 of 3)

Outfall	1992 SYSTEM CONDITIONS (1)		2019 SYSTEM CONDITIONS		LONG TERM CONTROL PLAN (2)	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
LOWER INNER HARBOR						
BOS003	28	18.09	9	6.13	4	2.87
BOS004	34	3.43	2	0.06	5	1.84
BOS005	4	10.23	0	0.00	1	0.01
BOS006	17	1.21	Closed	N/A	4	0.24
BOS007	34	3.93	Closed	N/A	6	1.05
TOTAL		**36.89**		**6.19**		**6.01**
CONSTITUTION BEACH						
MWR207	24	4.00	Closed	N/A	Closed	N/A
TOTAL		**4.00**		**N/A**		**N/A**
FORT POINT CHANNEL						
BOS062	8	4.15	4	0.97	1	0.01
BOS064	14	0.99	0	0.00	0	0.00
BOS065	11	3.08	3	0.71	1	0.06
BOS068	4	0.62	0	0.00	0	0.00
BOS070	4	281.62				
BOS070/DBC			7	6.21	3	2.19
MWR215 (Union Park)			10	26.66	17	71.37
BOS070/RCC			0	0.00	2	0.26
BOS072	21	3.62	Closed	N/A	0	0.00
BOS073	23	4.73	0	0.00	0	0.00
TOTAL		**298.81**		**34.55**		**73.89**
RESERVED CHANNEL						
BOS076	65	65.94	2	0.22	3	0.91
BOS078	41	14.84	0	0.00	3	0.28
BOS079	18	2.10	0	0.00	1	0.04
BOS080	33	6.21	0	0.00	3	0.25
TOTAL		**89.09**		**0.22**		**1.48**
NORTHERN DORCHESTER BAY						
BOS081	13	0.32	0 / 25 year	N/A	0 / 25 year	N/A
BOS082	28	3.75	0 / 25 year	N/A	0 / 25 year	N/A
BOS083	14	1.05	Closed	N/A	0 / 25 year	N/A
BOS084	15	3.22	0 / 25 year	N/A	0 / 25 year	N/A
BOS085	12	1.31	0 / 25 year	N/A	0 / 25 year	N/A
BOS086	80	3.31	0 / 25 year	N/A	0 / 25 year	N/A
BOS087	9	1.27	Closed	N/A	Closed	N/A
TOTAL		**14.23**		**0.00**		**0.00**
SOUTHERN DORCHESTER BAY						
BOS088	0	0.00	Closed	N/A	Closed	N/A
BOS089 (Fox Pt.)	31	87.11	Closed	N/A	Closed	N/A
BOS090 (Commercial Pt.)	19	10.16	Closed	N/A	Closed	N/A
TOTAL		**97.27**		**0.00**		**0.00**

Table 4-2. Typical Year Performance: Baseline 1992, Current (2019) and LTCP (3 of 3)

Outfall	1992 SYSTEM CONDITIONS (1)		2019 SYSTEM CONDITIONS		LONG TERM CONTROL PLAN (2)	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
UPPER CHARLES						
BOS032	4	3.17	Closed	N/A	Closed	N/A
BOS033	7	0.26	Closed	N/A	Closed	N/A
CAM005	6	41.56	8	0.73	3	0.84
CAM007	1	0.81	1	0.82	1	0.03
CAM009	19	0.19	Closed	N/A	2	0.01
CAM011	1	0.07	Closed	N/A	0	0.00
TOTAL		**46.06**		**1.55**		**0.88**
LOWER CHARLES						
BOS028	4	0.02	Closed	N/A	Closed	N/A
BOS042	0	0.00	Closed	N/A	Closed	N/A
BOS049	1	0.01	Closed	N/A	Closed	N/A
CAM017	6	4.72	0	0.00	1	0.45
MWR010	16	0.08	0	0.00	0	0.00
MWR018	2	3.18	2	1.92	0	0.00
MWR019	2	1.32	2	0.56	0	0.00
MWR020	2	0.64	2	0.32	0	0.00
MWR021	2	0.50	Closed	N/A	Closed	N/A
MWR022	2	0.43	Closed	N/A	Closed	N/A
MWR201 (Cottage Farm)	18	214.10	4	12.36	2	6.30
MWR023	39	114.60	1	0.14	2	0.13
SOM010	18	3.38	Closed	N/A	Closed	N/A
TOTAL		**342.98**		**15.30**		**6.88**
NEPONSET RIVER						
BOS093	72	1.61	Closed	N/A	Closed	N/A
BOS095	11	5.37	Closed	N/A	Closed	N/A
TOTAL		**6.98**		**0.00**		**0.00**
BACK BAY FENS						
BOS046	2	5.25	0	0.00	2	5.38
TOTAL		**5.25**		**0.00**		**5.38**
Total Treated		**698**		**390**		**381**
Total Untreated		**759**		**40**		**23**
GRAND TOTAL		**1457**		**430**		**404**

(1) 1992 System Conditions include completion of Deer Island Fast-Track Improvements, upgrades to headworks and new Caruso and DeLauri pumping stations.
(2) From Exhibit B to Second Stipulation of the United States and the Massachusetts Water Resources Authority on Responsibility and Legal Liability for Combined Sewer Overflows, as amended by the Federal District Court on May 7, 2008 (the "Second CSO Stipulation").
(3) Value may change pending ongoing review of model calibration for Outfall MWR003.
(4) N/I: Outfall was closed by prior to 2006 and is not included in Exhibit B to the Second CSO Stipulation.

4.3 Outfalls along the South Boston Beaches

MWRA has "effectively eliminated" CSO discharges at the remaining five outfalls along the South Boston beaches: BOS081, BOS082, BOS084, BOS085 and BOS086.[4] Since May 2011 when MWRA brought the South Boston CSO Storage Tunnel and Related facilities on-line, there has been no CSO discharge to the beaches, compared with an average of 20 CSO discharges per year prior to tunnel completion. The tunnel also captures separate stormwater that prior to tunnel completion discharged to the beaches through the CSO outfalls every time it rained - 90 to 100 storms a year. Over the nine years of tunnel operation, stormwater has discharged to the beaches in only three large storms, including Hurricane Irene in August 2011 and the March 2, 2018 storm surge and coastal flooding event. The tunnel has prevented nearly 2 billion gallons of CSO and stormwater from discharging to the beaches since May 2011.

4.4 Discharge Locations that Remain Active in the LTCP

For each of the discharge locations that remain active - in accordance with the approved LTCP - Table 4-2 compares current activation frequency and volume as predicted by MWRA's 2019 system conditions model to the respective LTCP levels of control. The outfalls and regulators where Typical Year activations or volumes are currently predicted to exceed LTCP levels are the subject of continuing investigations by MWRA and the CSO communities. Part of these investigations involves identifying the system conditions that contribute to the higher discharges and evaluating and potentially recommending CSO regulator or other system adjustments that may help to attain the LTCP goals. These investigations and evaluations are discussed in Section 5.

Notwithstanding the need for and value of the ongoing site-specific investigations, the 2019 Typical Year model results validate the accomplishments of MWRA and its member communities in their CSO control efforts and investments over the past three decades. The Typical Year results show that region-wide average annual CSO discharge volume has been reduced from 1.5 billion gallons in 1992 (and from 3.3 billion gallons in the late 1980's prior to Fast Track pumping and reliability improvements at the Deer Island Treatment Plant) to 428 million gallons today. CSO discharges have been permanently eliminated at all of the outfalls required to be closed in the LTCP, and several more outfalls have also been closed; and MWRA's South Boston CSO storage tunnel has prevented any CSO discharge to the beaches since it was brought on-line nine years ago.

MWRA is confident that it will continue to make and show further improvement as its CSO performance assessment and related mitigation efforts continue.

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[4] MWRA is currently reviewing a draft report from its CSO Performance Assessment consultant that documents the analysis of data collected since the tunnel was brought on-line in May 2011.

5. Site-Specific Overflow Activity Investigations

5.1 Addressing Higher Activations and Volumes

MWRA, in consultation with BWSC, Cambridge, Chelsea and Somerville, has been carefully studying the locations where the current model predicts higher Typical Year activations and/or volume compared with the LTCP. Efforts are underway to assess measures that may improve CSO performance. For example, MWRA will perform additional model investigations to determine whether CSO performance will improve with ongoing maintenance activities (e.g., sediment removal) and planned changes to the collection system (e.g., sewer separation and partial sewer separation projects). For instance, BWSC is nearing completion of an extensive sediment cleaning contract involving the South Boston Interceptor - North Branch (SBI-NB) and tributary connecting sewers. Once complete, MWRA will use post-cleaning meter data and the hydraulic model to evaluate how removal of the sediments has affected CSO discharges from the SBI-NB system to the Dorchester Brook Conduit, which discharges to the Fort Point Channel at Outfall BOS070 (see Section 5.5, below).

Further modeling analyses will also be performed to determine if raising weir elevations can improve CSO performance without causing adverse impacts to the upstream systems. In advance of submitting the December 2021 final report on the performance assessment, MWRA intends to implement additional system adjustments (potentially, weir changes, flow shifting, modifications to facility operations, etc.) aimed at improving CSO performance. More information on general investigation approaches can be found in Semiannual Progress Report No. 3, October 31, 2019.

Areas of particular immediate focus include East Boston (Inner Harbor and Chelsea Creek), the Cottage Farm Facility (Lower Charles River) and the Somerville Marginal Facility (Upper Mystic River and Mystic/Chelsea Confluence).

5.2 East Boston Outfalls

Outfall BOS003 receives flow from BWSC regulators RE003-2, RE003-7, and RE003-12. Metering data collected in 2018 and 2019 suggested that discharges at Outfall BOS003 were not meeting the LTCP frequency and volume targets, with Regulator RE003-12 contributing the highest activations and volumes of CSO. At this and other East Boston regulators, discussed below, BWSC record drawings indicate that nozzle restrictions exist in the dry weather flow connections (see Figure 5-1). The nozzles restrict flow entering the MWRA's East Boston Branch Sewer and contribute to higher overflows and CSO discharges. Field investigations found that the most restrictive nozzle is located at RE003-12, and the restriction can cause materials to plug the connection, resulting in the risk of higher wastewater levels in the upstream BWSC sewer system and dry weather overflows, in addition to higher wet weather overflows.
In response, BWSC spends significant maintenance time and resources on a regular basis to keep this nozzle clear and minimize the risks of dry weather overflows and upstream system flooding.

BWSC crew cleaned the connection on three occasions in 2019: in March, in July, and in October.
The East Boston subsystem was the first model subsystem (sub-model) to be recalibrated by MWRA, and with 2018 meter data, when the connection likely was significantly plugged. To match the model results to the meter data, MWRA had significantly increased the friction factor to increase the head loss through the connection. Comparison of the calibrated model results to meter data collected after the 2019 cleaning showed that the modeled discharges were significantly greater than the metered discharges. MWRA then significantly lowered the friction factor, and this brought the model results and metered discharges close together.

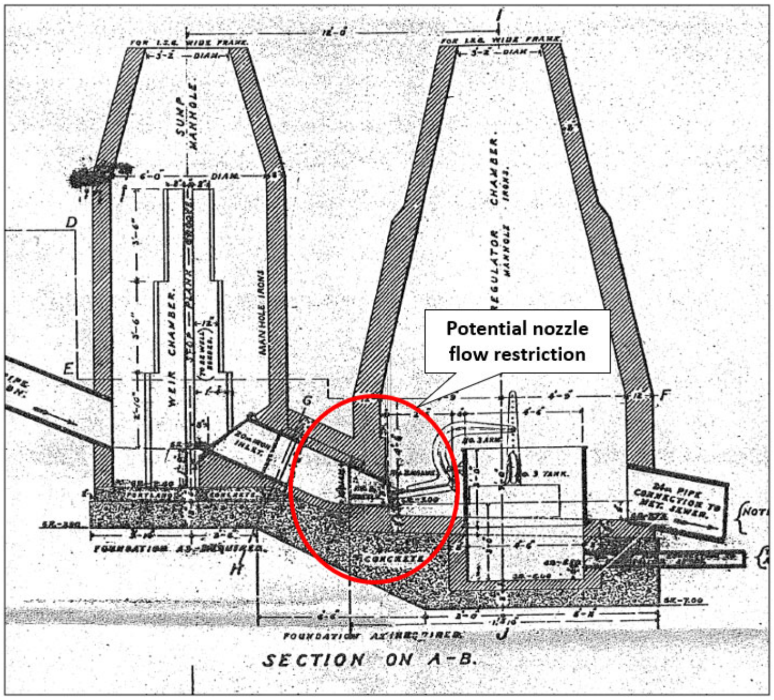


Figure 5-1. BWSC Record Drawing of Nozzle Restriction

Typical year model results using the earlier calibrated model showed 25 activations and 17.41 MG. With the lower friction factor at the RE003-12 connection, the Typical Year model results dropped to 9 activations and 6.13 MG, a significant improvement but still higher than the LTCP levels of control of 4 activations and 2.87 MG.

In 2019, in response to the overflow activity measured in 2018 and early 2019, MWRA performed model runs that simulated the effects of replacing the existing dry weather flow connection and nozzle restriction at RE003-12 with a new pipe of various sizes, but did this using the originally calibrated model that represented the plugged condition. The model results indicated that opening the RE003-12 dry weather flow connection could significantly reduce the activation frequency and volume of overflows at this regulator without causing significant impacts at the other East Boston regulators. However, the model results also showed that the additional flow entering the East Boston Branch Sewer would increase hydraulic grades in the MWRA interceptor.

Planned additional model runs, using the updated model, will determine whether a new pipe connection can improve upon the performance of a clean nozzle connection, as well as reduce or eliminate plugging of the nozzle and reduce maintenance needs. In the meantime, BWSC is conducting monthly inspections of the regulators and is revising its inspection approach to better determine whether the RE003-12 nozzle and other nozzle connections in East Boston are compromised with partial plugging and in need of cleaning.

Outfalls BOS009, BOS010, BOS012, BOS013 and BOS014 are the other outfalls in East Boston. Outfalls BOS009, BOS010 and BOS012 discharge to the Upper Inner Harbor, and outfalls BOS013 and BOS014 discharge to Chelsea Creek. These outfalls receive overflow from BWSC regulators RE009-2, RE010-2, RE012-2, RE013-1 and RE014-2, respectively. Metering data collected in 2018 and 2019 showed relatively high overflow activity, and Typical Year model results show higher CSO activation frequency and volume than the LTCP levels of control at all five outfalls.

Based on the 2018 metering data, MWRA conducted an initial assessment that indicated that the Caruso Pumping Station, which collects flows from the combined sewer areas of East Boston, as well as flows in MWRA's Chelsea Branch Sewer, is not causing backwater that is a contributing factor to these overflows. This suggests that there may be capacity in MWRA's interceptor and pumping system to accept more flow from BWSC's East Boston systems. BWSC historical record drawings indicate that restrictive nozzles may exist within the dry weather flow connections at most of these regulators (see further discussion of the East Boston nozzle restrictions and Figure 5-1, above). The hydraulic impacts of the nozzles are accounted for in the ongoing calibration of MWRA's hydraulic model using the 2018 meter data.

BWSC has embarked on a long-term program to separate its combined sewers throughout East Boston through a sequence of phased design and construction contracts. BWSC has nearly completed the first construction contract, in certain subareas tributary to CSO outfalls BOS012 and BOS013 in 2019, though the last portion of work has been delayed due to COVID-19. The second construction contract is underway (though also currently suspended due to COVID-19) in certain subareas tributary to CSO outfalls BOS005 and BOS010. BWSC is currently designing a third construction contract, which will separate subareas tributary to CSO outfalls BOS003, BOS009 and BOS012. BWSC has provided MWRA with the plans and estimated stormwater removal amounts for these three contracts, as well as the concept plans for separating the rest of East Boston.

As part of its ongoing CSO performance assessment, MWRA will model sewer system performance improvement with these sewer separation contracts to determine how they affect CSO discharges at the East Boston outfalls and where future separation work can best support attainment of the LTCP levels of control. MWRA will also evaluate other potential CSO reduction measures, including the removal of nozzle restrictions, adjustments to weir elevations, and possible optimization of interceptor capacities.

5.3 Somerville Marginal CSO Facility Discharges

Outfall MWR205A/SOM007A is the only CSO outfall discharging to the Upper Mystic River. It discharges treated CSO from MWRA's Somerville-Marginal CSO Facility and City of Somerville separate stormwater to the Mystic River Basin upstream of Amelia Earhart Dam when the primary discharge to the tidal portion of the Mystic River, through the Somerville-Marginal Conduit to Outfall MWR205, is limited by rising tide. The 2018 metering data showed tidal impacts in the level measurements, suggesting a leaking tide gate. This remained true for the 2019 metering period. While the MWRA does not suspect that this measured tidal influence significantly affects CSO discharges at MWR205A/SOM007A, MWRA is developing a project scope to inspect the gate and design repairs or a replacement. The City of Somerville provided its hydraulic model to MWRA, and a portion of the area tributary to the MWR205A/SOM007A system was incorporated into the MWRA's model, providing more detailed information on the stormwater subcatchments that may be contributing to the higher volume, if not frequency, of CSO and stormwater discharges.

Typical Year model results show both higher frequency and higher volume of discharges than the LTCP levels of control at this outfall. The frequency and volume of discharges are related to the frequency and volume of treated discharges from MWRA's Somerville-Marginal Facility, the volume of the City's stormwater flows that drain to the Somerville-Marginal Conduit, storm sizes, and tide. Lowering discharges at this outfall involves lowering the frequency and volume of discharges from the Somerville-Marginal Facility and/or removing stormwater flows from the outfall pipe downstream of the Somerville-Marginal CSO Facility (the Somerville-Marginal Conduit) that contribute to this overflow under high tide conditions. Approaches to accomplish the former are discussed below, for Outfall MWR205. The latter would involve the construction of a major new stormwater outfall to the Mystic River.

Outfall MWR205 (Somerville Marginal Conduit) is located immediately downstream of the Amelia Earhart Dam and discharges CSO that passes through the treatment works at the Somerville Marginal Facility, along with separate stormwater from nearby drainage areas in Somerville that enters the Somerville Marginal Conduit, to tidal waters. Typical Year model results show that the facility's activation frequency is in line with the LTCP level of control, though the treated discharge volume (110 MG) is nearly twice the

LTCP level (61 MG). Meter data collected in 2018 and 2019 indicate that stormwater flows entering the combined sewer system upstream of the facility are higher than in the past.

MWRA and the City of Somerville have been coordinating investigations into potential reasons for higher flows, including a review of the ongoing construction of the MBTA's Green Line Extension (GLX). MWRA has incorporated portions of the City of Somerville's recently developed hydraulic model into the MWRA model, which will help improve the characterization and quantification of stormwater flow contributions to the Somerville Marginal Facility and the Somerville Marginal Conduit.

The amount of flow entering the Somerville-Marginal Facility is controlled by upstream weirs, facility influent stop logs and facility influent gates, all set at elevations to direct flow through an 18-inch connection into MWRA's Somerville-Medford Branch Sewer for conveyance to the Deer Island treatment plant. In the early 2000's, MWRA elevated the stop logs and modified gate operations to take advantage of upstream in-system storage and send more flow into the Branch Sewer prior to having to open the facility gates. MWRA recently performed hydraulic model runs of incrementally higher stop log settings. The model results showed little benefit in reducing Somerville-Marginal facility activations and volumes, and was deemed by MWRA not to be worth any potential upstream flooding risk.

In accordance with a condition in the Alewife Brook/Upper Mystic River CSO Variance, MWRA will commence, by December 2020, evaluations of specific projects that may reduce overflows to the Somerville Marginal Facility and discharges from outfalls MWR205 and MWR205A/SOM007A. These evaluations include 1) the benefit and feasibility of removing MassDOT I-93 stormwater flows that enter the combined sewer system immediately upstream of the Somerville-Marginal Facility and redirecting the stormwater downstream of the Facility, and 2) the benefit and feasibility of increasing the capacity of the connection to the Somerville-Medford Branch Sewer.

5.4 Cottage Farm Facility (Outfall MWR201)

Metering data collected in 2018 suggested that the LTCP Typical Year activation frequency of treated CSO discharges from the Cottage Farm CSO Facility may not be met, but 2018 saw heavier rainfall than the Typical Year. In contrast, meter data from the first half of 2019 indicated that the LTCP Typical Year activation frequency could be met, but the Typical Year volume of CSO discharge may not be met.

Results of investigations into the activation volume suggested that the flow in some of the sewer interceptors tributary to Cottage Farm may have a strong seasonal infiltration component (groundwater entering the sewers), which may contribute to the higher-than-expected CSO volumes. MWRA's calibrated model incorporates the metered groundwater infiltration, as well as metered flow levels in MWRA interceptors that convey flows to the Ward Street Headworks, which directly influences flows and flow levels at Cottage Farm. As a result of this calibration, model predicted discharges from Cottage Farm in 2019 are very close to the measured discharges at the facility. Typical Year simulation with the calibrated model shows higher frequency and higher volume (4 activations and 12.40 MG) than the LTCP levels of control for Cottage Farm (2 activations and 6.30 MG).

The City of Cambridge completed the separation of sewers in the Cambridgeport area, as assumed when the LTCP levels of control for Cottage Farm and other Charles River Basin outfalls were established and approved in 2006. However, the separated Cambridgeport stormwater continues to enter the combined sewer system at two connections pending Cambridge's development of plans for getting some of the stormwater to the Charles River Basin and plans for meeting phosphorus discharge limits. MWRA recently approved, on a trial basis, Cambridge's proposal for "partial sewer separation," whereby Cambridge would significantly reduce these separated stormwater inflows by installing orifice plates on the sewer connections to restrict flows into the sewers and send a portion of the stormwater to the Charles River Basin. Most of the separated stormwater would be discharged to the Charles River during storms that contribute to CSO discharges, but a fraction of the stormwater flow would remain tributary to the combined sewer system. This approach is necessary to attain the LTCP levels of control while limiting the stormwater's phosphorus loading to the river.

Given construction issues and final turnover to the City of a new Talbot St stormwater outfall, as well as delay due to Covid-19, the orifice plate has not yet been installed on the 18-inch Talbot St connection. In addition, at the Pacific and Albany St. stormwater connection to the sewer system, Cambridge has decided to relocate the connection a few blocks further into the Cambridge collection system given the difficulty working and maintaining the connection in the busy Pacific and Albany St. intersection. Cambridge completed this new connection at Pacific and Landsdowne St. (constructing a 6-inch PVC pipe within a 10-inch sleeve),but has sandbagged off this new connection until the existing 10-inch connection can be sealed and abandoned. Cambridge had provided meter data to MWRA measuring the stormwater entering the sewer system prior to the installation of the orifices, and will continue to provide data after the new stormwater outfall on Talbot St. is activated and the 6-inch orifice plate is installed, and after the existing 10-inch connection at Pacific and Albany St. is abandoned and the new 6-inch connection at Pacific and Landsdowne St. is activated by removing the sand bags. Cambridge and MWRA will analyze the data to quantify predicted stormwater inflow reductions and to update their models and evaluate the impact of the partial sewer separation measures in reducing CSO discharge at Cottage Farm relative to the LTCP levels of control.

5.5 Outfall BOS070 (Fort Point Channel)

<u>Outfall BOS070</u> receives overflows from multiple regulators, four of which (RE070/8-3, RE070/8-7, RE070/9-4, and RE070/7-2), based on metering data collected in 2018, overflowed more frequently than expected. The 2019 metering data showed relatively high CSO activity at regulators RE070/8-3, RE070/8-7, RE070/9-4, and RE070/7-2, as well as RE070/8-13. Regulators RE070/8-3, RE070/8-7, and RE070/9-4 are located along Dorchester Avenue in South Boston. Discussions with BWSC revealed that a maintenance weir was located in the South Boston Interceptor on Dorchester Avenue, as shown in Figure 5-2, during the metering period, and that a significant depth of sediment had accumulated in the interceptor upstream of the weir. An ongoing BWSC maintenance contract has removed the weir and much of the sediment. BWSC is documenting the locations and amounts of sediment removed. MWRA will review this information in conjunction with more recent meter data to assess the parts of the model that may be impacted by the cleaning operation and may warrant recalibration.

Figure 5-2. Weir Restriction on Dorchester Ave.

Regulator RE070/7-2 is located on BWSC's Dorchester Brook Sewer and was reconstructed as part of BWSC's Lower Dorchester Brook Sewer separation project. During dry weather, the flow enters BWSC's Boston Main Interceptor (BMI) where it is conveyed to MWRA's Columbus Park Headworks. During larger storms, the regulator overflows to BWSC's Dorchester Brook Conduit (DBC), a large storm drain and overflow conduit that discharges to Fort Point Channel. Flow monitoring data indicated a large number of small-volume activations, suggesting that flow in the Dorchester Brook Sewer may be "sloshing" over the weir. Additional investigation is planned to better understand the cause of the higher activation frequency and to develop mitigation measures.

MWRA's calibrated model includes measured head loss in the South Boston Interceptor likely due to the maintenance weir and sediment that existed during the 2018 metering period. Typical year model results show higher activation frequency and volume from the BOS070 DBC regulators (7 activations and 6.21 MG) than the LTCP levels of control (3 activations and 2.19 MG). The temporary overflow meters are still in place at the 070 regulators, and BWSC and MWRA are reviewing and evaluating meter data to determine the effect of the continuing cleaning operation on overflows to the Dorchester Brook Conduit and Outfall BOS070.

6. Receiving Water Quality Models: Charles River and Alewife Brook/Mystic River

6.1 Progress with the Development of the Models

Models are being developed to assess the impact of CSOs, stormwater and boundary conditions on water quality in the Charles River and Alewife Brook/Mystic River. Specifically, the models will predict resulting *Enterococcus* and *E. coli* counts during the 3-month and 1-year storms as well as the typical year developed for the CSO project. The models that will be used and their coverages are as follows:

- The Charles River model will be implemented with the Delft3D model in two-dimensional mode. The model will extend from the locks between the river and the Upper Inner Harbor to the Watertown Dam (see Figure 6.1).
- The Alewife Brook/Upper Mystic River model will use the one-dimensional InfoWorks ICM software and extend from the Amelia Earhart Dam to the Lower Mystic Lake outlet and will include the entirety of Alewife Brook (see Figure 6.1).

The models will calculate time-varying bacterial count distributions as a function of rainfall hyetographs (rainfall as a function of time). As an intermediate step, the rainfall data will be input to other models to assess the CSO, stormwater, and stream boundary flowrates as a function of time. The models will use bacterial counts in CSOs, stormwater and at upstream boundaries derived from monitoring and adjusted during model calibration.

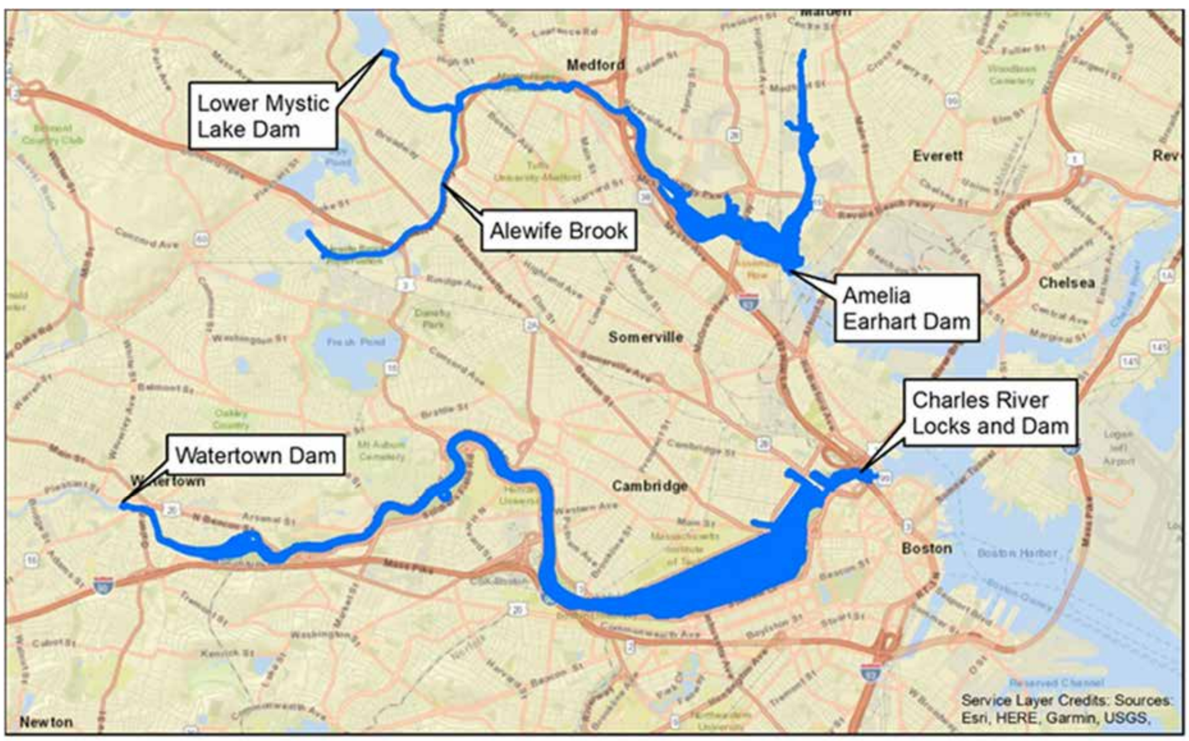


Figure 6-1. Extent of the Charles River and Alewife Brook/Upper Mystic River Models

6.1.1 Review of Monitoring Data Report

The Review of Monitoring Data report was submitted to MWRA in revised form on March 6, 2020 accounting for the MWRA comments received on the first draft. This report describes the monitoring data that will be used to specify the CSO and stormwater flows and water quality (*Enterococcus* and *E. coli* counts), as well as the boundary conditions for the water quality models of the Charles River and Alewife Brook/Upper Mystic River.

The Review of Monitoring Data Report is the first in a series to document, support, and explain the receiving water quality modeling effort. The report reviews monitoring and other relevant data, and also lays the foundation of the modeling process in explaining how the different data will be used and for what purpose. The next report will address the development and calibration of the models and will provide additional details on the approach used for calibration including sensitivity analyses for the main calibration parameters.

The Review of Monitoring Data Report was submitted to MWRA by its consultant, in revised form to explore available monitoring and other relevant data, and to explore how the different data will be used and for what purpose. This information will be summarized in an upcoming report that will address the development and calibration of the models, describing the approach used for calibration including sensitivity analyses for the main calibration parameters.

6.1.2 Charles River Model

The Charles River model grid has been developed, as shown in Figure 6-2 with bathymetry based on measurements conducted by MIT in 2015-2017. The model will calculate *Enterococcus* and *E. coli* counts in each of the 4,400 cells. Stormwater and CSO inputs will be specified at 85 outfalls shown in Figure 6-3 as a function of time based on several models: The Cambridge stormwater model, the BWSC stormwater model and a model developed by the USGS. Inputs from these models have been developed for the design storms and typical year.

An important input to the model is the upstream boundary condition because, during and after storms, the flows discharging at the Watertown dam have high bacteria counts. A model has been developed to estimate these counts based on flow measurements at the USGS Waltham gauge and calibrated to measurements conducted by MWRA at their monitoring Station 012.

As of this writing, the model water quality component is being calibrated using the extensive MWRA monitoring data, in particular the storm-centered monitoring that MWRA initiated in 2017 with sampling at the historical monitoring stations during and for several days after storms.

6.1.3 Alewife Brook / Upper Mystic River Model

This model is based on a previously developed FEMA model of the entire Mystic / Aberjona River Basin. The extent of the model is shown in Figure 6-4. The FEMA model was truncated at a point downstream of the Lower Mystic Lake with a flow boundary condition extracted from the overall model. The FEMA model was primarily geared towards the simulation of very large storms, such as the 100-year storm. For the purpose of the current assessment, the hydrology part of the model (the part that produces the stormwater and groundwater discharges to the river system) was recalibrated to yield flows for smaller storms, including dry periods between storms.

At this point, the water quality part of the model is being calibrated relative to the MWRA in-stream monitoring data.

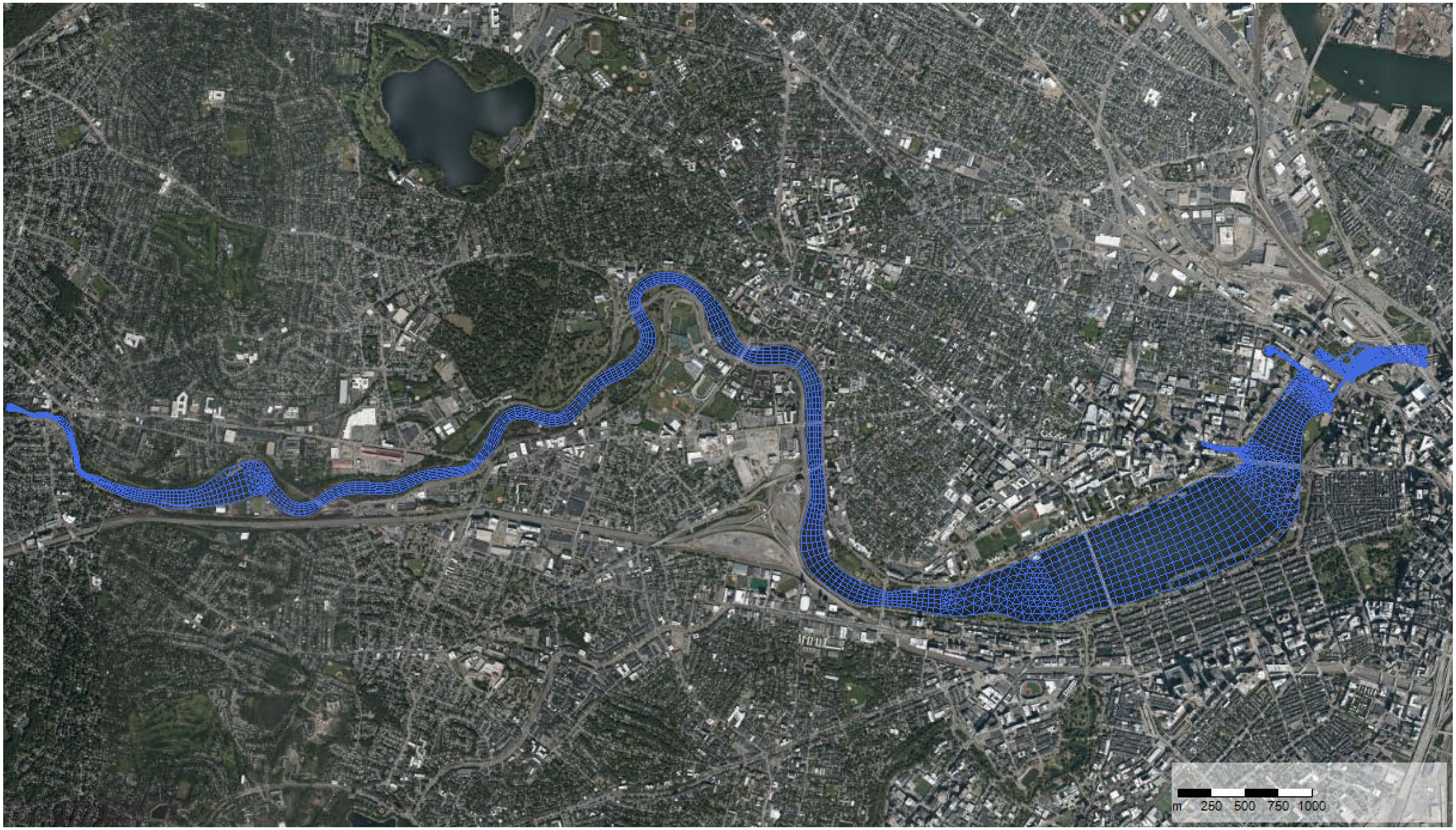


Figure 6-2. Charles River Model Grid

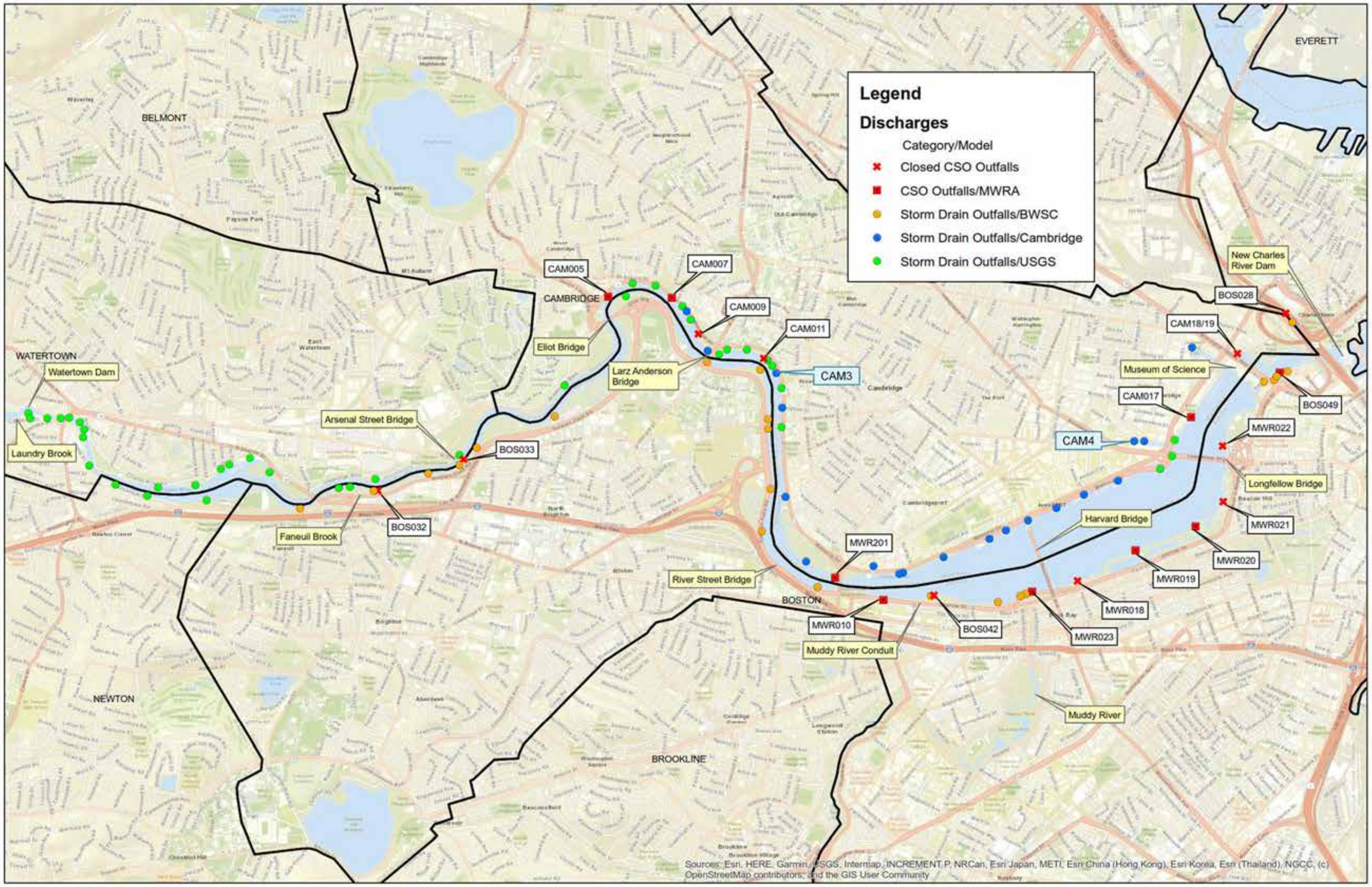


Figure 6-3. CSO and Stormwater Discharge Points to the Charles River Model

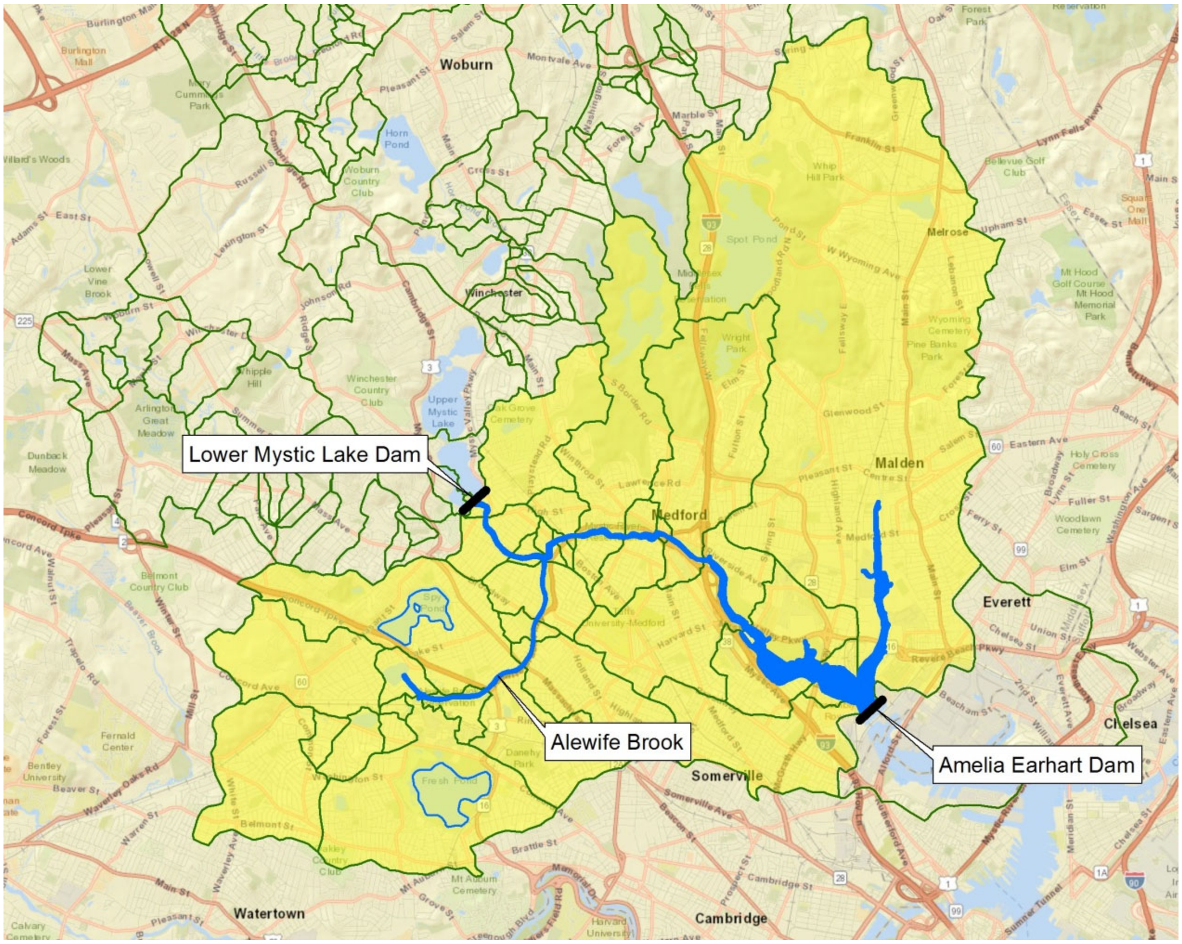


Figure 6-4. Alewife Brook / Upper Mystic River Model showing Stormwater Catchment Areas (in Yellow)

6.2 Water Quality Data

The water quality data that are being used in the modeling includes i) in-stream monitoring data collected by MWRA at numerous stations in the receiving water bodies, ii) untreated CSO effluent and CSO facilities influent data (to characterize untreated CSO discharges), iii) CSO facility effluent quality measurements and iv) stormwater sampling data collected by MWRA, as well as the cities of Cambridge, Somerville and Boston. These data sources are briefly reviewed below.

6.2.1 In-Stream Monitoring Data

MWRA has been conducting water quality monitoring in Boston Harbor and its tributary rivers under several projects since 1989. The Combined Sewer Receiving Water Monitoring Program includes 13 stations in the Charles River and also 13 stations in the Alewife Brook / Mystic River with analyses for several constituents including *Enterococcus* and *E. coli.* Since 2017, the program has included storm driven sampling with samples collected during storms as well as daily for a few days thereafter. These data will be used for the model calibration.

6.2.2 Untreated Combined Sewage Data

Alewife Brook: Untreated CSOs

Because the untreated CSOs discharging to the Alewife Brook are more numerous and discharge more frequently than the untreated CSOs in the Charles, MWRA decided to sample two locations, CAM401A and SOM001A, directly. Both of these CSOs are believed to be among the more frequent discharges on the Alewife Brook. Bacterial water quality of the discharges is believed to be representative of discharges from other CSOs along Alewife Brook.

So far two events have been captured at each location, in August and October of 2019. Samples were taken within 15 minutes of the start of discharge, and then a second sample either as the discharge ended or around an hour after the discharge started, whichever occurs first. These samples were analyzed for *E. coli* and *Enterococcus*, and are presented in Table 6-1. Samples were also collected at selected in-stream locations upstream and downstream of the CAM401A and SOM001A outfalls around the same time as the untreated CSO samples.

Table 6-1. Alewife Brook Untreated CSO Bacterial Counts (2019)

		CAM401A	SOM001A	Combined
	Number of Measurements	16	8	24
	Number of Storms	2	2	2
E. coli (#/100 mL)	Arithmetic Average	55,838	64,775	58,817
	Geometric Mean	41,967	63,065	48,070
Enterococcus (#/100 mL)	Arithmetic Average	36,838	22,050	31,908
	Geometric Mean	32,807	19,958	27,798

Charles River: CSO Treatment Facility Influent

Influent and effluent *Enterococcus* and *E. coli* counts have been measured by the MWRA since 2017 at the Cottage Farm and Prison Point CSO treatment facilities during several facility activations. Influent bacterial counts at these facilities are believed to be representative of other untreated CSOs discharging to the Charles River. Recent data are summarized in Table 6-2. For water quality modeling arithmetic averages should be used. Use of the geometric mean would generally underestimate the loadings.

Table 6-2. Cottage Farm and Prison Point Influent Bacterial Counts

		Cottage Farm (1)	Prison Point (1)
	Number of Measurements	12	8
	Number of Storms	4	4
***E. coli* (#/100 mL)**	Arithmetic Average	2,056,000	171,000
	Geometric Mean	1,177,000	125,000
***Enterococcus* (#/100 mL)**	Arithmetic Average	294,000	57,000
	Geometric Mean	223,000	44,000

(1) Data collected between July 2018 and April 2019 (additional existing data will be reviewed and analyzed. The above data are for initial evaluation)

The results presented in Table 6-2 show that the influent bacterial counts are much higher at Cottage Farm than at Prison Point. This is due to the different sources of flow to each facility and this will be taken into account in the model by using the fraction of stormwater in the combined sewage calculated by the collection system model and assigning different bacterial counts to the sanitary and stormwater fractions. Preliminary calibration shows that this approach adequately simulates the bacterial count variability.

6.2.3 Treated Combined Sewage

Most combined sewage discharged to the Charles River is treated (screened, disinfected, and dechlorinated) at the Cottage Farm Facility. In the Mystic River main stem, the only CSO discharge is from the Somerville Marginal Facility, which discharges above the Amelia Earhart Dam at high tide. Average effluent counts from each of these treatment facilities will be used to represent the bacterial counts input into the Charles River and the Mystic River from these treated CSOs.

6.2.4 Stormwater Sampling

Historical stormwater quality data for discharges to the Charles River and Alewife Brook / Upper Mystic River are available. However, changes in recent years can be expected due to stormwater Best Management Practices that have been implemented in the area. Therefore, new stormwater sampling was by MWRA and the city of Cambridge. (Somerville locations were not able to be sampled due to winter weather and the COVID-19 pandemic.) The locations of the Cambridge monitoring stations on the Charles are shown in Figure 6-2 (Outfalls CAM3 and CAM4 in light blue boxes).

The sampling locations for discharges to the Alewife Brook / Upper Mystic River are shown in Figure 6-5. Land use in the different catchments is summarized in Table 6-2 and monitoring results to date are presented in Table 6-3. These data are being evaluated to identify correlations between bacterial counts and such parameters as land use, catchment area, or storm magnitude. So far, correlations have not been apparent.

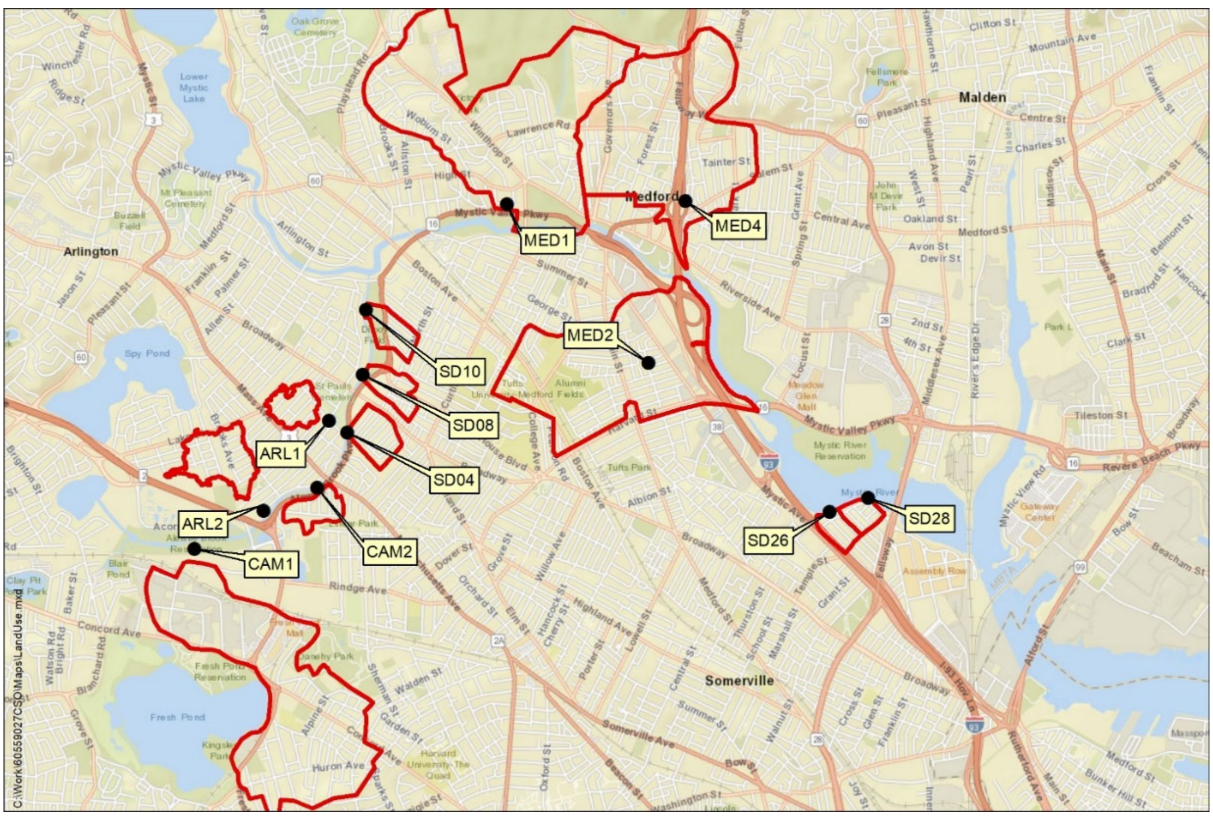


Figure 6-5. Stormwater Monitoring Stations and Associated Catchments for Discharges to the Alewife Brook / Upper Mystic River

Table 6-3. Land Use in the Catchments Tributary to the Alewife Brook/Upper Mystic River Stormwater Monitoring Stations

Monitoring Station	Catchment Area (acres)	Land Use (Percent)			
		Industrial	Commercial	Residential	Undeveloped
ARL1	24	0	0	80	20
ARL2	49	0	5	60	35
CAM1	359	10	32	33	25
CAM2	23	0	35	38	27
MED1	433	0	13	54	33
MED2	317	1	16	31	52
MED4	337	0	5	57	38
SD04	28	0	1	68	31
SD08	23	0	0	44	56
SD10	23	0	2	44	54
SD26	15	0	0	44	56
SD28	14	0	0	55	45

Table 6-4. 2019 Stormwater Sampling Results

Date	10/7/2019	10/27/2019	11/18/2019	11/24/2019	12/13/2019	Average
Rainfall Depth (in) (1)	0.16	1.43	0.24	1.51	1.41	
Duration (hr)	2.5	10.5	6	17	17.25	
Peak Intensity (in/hr) (2)	0.16	0.56	0.12	0.6	.24	
Prior Dry Days	2	3	5	1	2.2	
E. coli						
ARL1	12,376	20,190	6,422	3,018		10,502
ARL2	2,670	4,600		74,980		27,417
CAM1	1,475	20,800		7,200	437	7,478
CAM2	343	142		750	443	420
CAM3	42,000	3,017		4,367	15,650	16,258
CAM4	542	2,308		11,288	54,167	17,076
MED1	3,122	2,632	8,588	520		3,715
MED2	6,578	5,552	8,215	2,063		5,602
MED4	23,984	22,480	41,298	19,658		26,855
Enterococcus						
ARL1	7,376	16,783	3,788	9,282		9,307
ARL2	3,723	4,423		8,223		5,456
CAM1	782	850		4,765	958	1,839
CAM2	970	263		3,745	877	1,464
CAM3	6,017	2,465		5,350	9,650	5,870
CAM4	1,273	1,153		1,603	1,877	1,477
MED1	5,748	3,698	970	834		2,813
MED2	3,310	3,520	2,980	2,002		2,953
MED4	62,818	3,594	8,355	3,060		19,457

(1) Somerville Marginal Data

(2) 15-min peak intensity

7. Progress Toward the Fifth Semiannual Report

MWRA plans to issue the next semiannual report (Semiannual CSO Discharge Report No. 5) in October 2020. The following efforts are underway or are planned to be conducted over the next several months.

- MWRA will continue to investigate system and regulator conditions and work with member CSO communities to better understand the measured CSO discharges.
- MWRA will continue to collect data from rainfall gauges, CSO and sewer system meters, and facility operational records for all rainfall events. MWRA will continue to quantify and validate CSO discharges from the meter data collected at the 36 CSO regulators where meters remain in place.
- Data analyses are being conducted for the period January 1 through June 30, 2020, and findings will be presented in Semiannual Report No. 5. Temporary meters are currently installed at 36 CSO regulators where additional data will support evaluation of changes to system configurations or to support receiving water quality evaluations for the CSO variance waters. The temporary meters will be removed after June 30, 2020.
- MWRA will continue to conduct receiving water quality monitoring in waters potentially impacted by CSO, with a focus on the storm impacts and recovery times in the Variance waters (Lower Charles River/Charles Basin and Alewife Brook/Upper Mystic River).
- The receiving water quality models will continue to be developed.

Appendix A: Detailed Assessments into Meter/Model Differences at Ten Locations

Attachment A

Detailed Assessments into Meter/Model Differences at Ten Locations

*An update has been added following the submittal of Attachment A on February 18, 2020.

BOS070: RE070/7-2

Regulator Information

Regulator RE070/7-2 directs flow from BWSC's Dorchester Brook Sewer to BWSC's Boston Main Interceptor. Overflow from the regulator enters BWSC's Dorchester Brook Conduit for discharge to the head of Fort Point Channel at Outfall BOS070 (Figure 1). This regulator was reconstructed as part of BWSC's Lower Dorchester Brook Sewer Separation project, and it essentially replaces former regulator 070/11-2, which had directed flow to the New Boston Main Interceptor. With the sewer separation work completed, separate stormwater was re-routed from the Dorchester Brook Sewer around RE070/7-2 and into the Dorchester Brook Conduit to reduce CSO discharges at BOS070. The Dorchester Brook Conduit also receives overflows from regulators located along the South Boston Interceptor. Project flow meters were installed in the influent to RE070/7-2, and in the overflow downstream of the regulator weir.

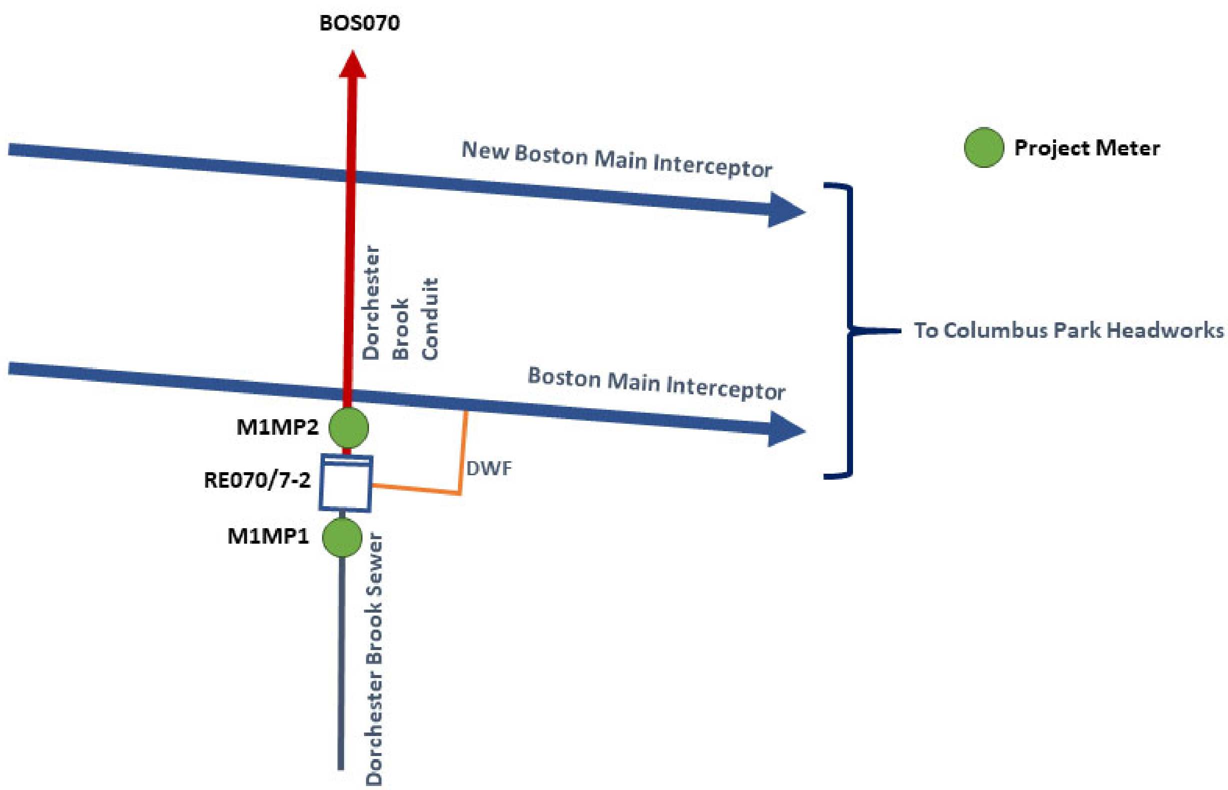


Figure 1. Schematic of Regulator RE070/7-2

Figure 2 presents a schematic detailing the connection between Regulator RE070/7-2 and the Boston Main Interceptor. As indicated in Figure 2, Regulator RE070/7-2 is a complex structure.

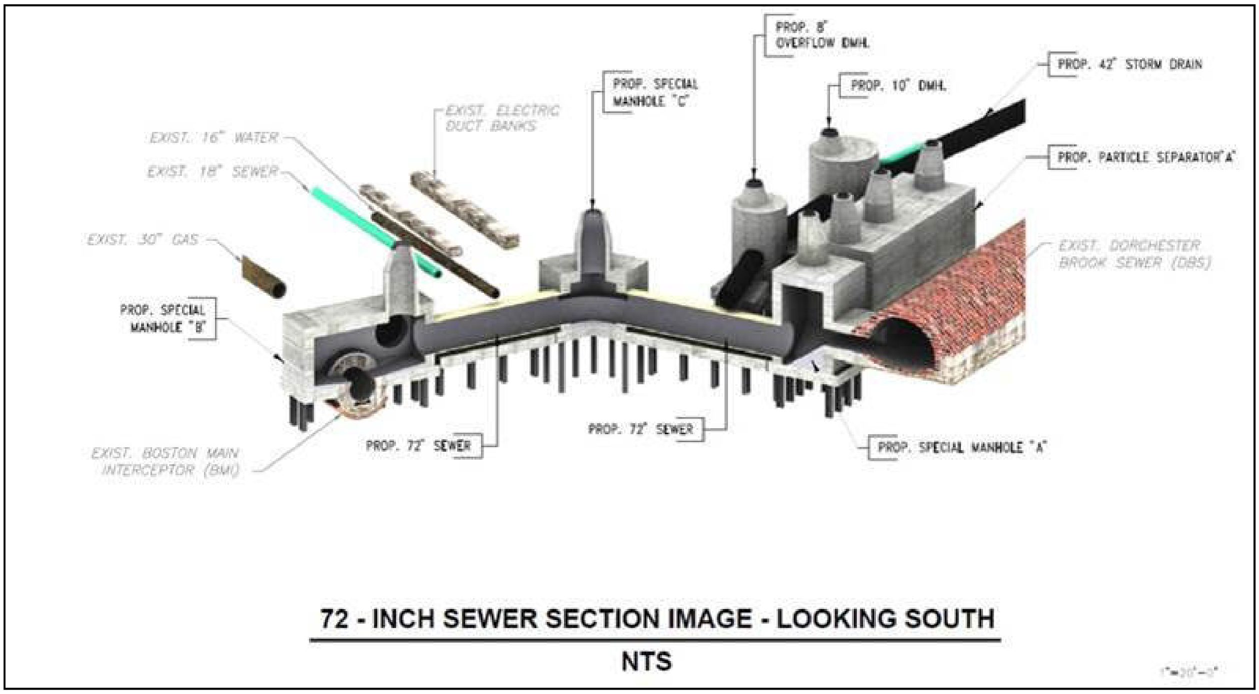


Figure 2. Detail of Connection from RE-070/7-2 to the Boston Main Interceptor

Reason for Further Investigation

After initial calibration, the model over-predicted activation frequency and volume at RE070/7-2 in both the April-December 2018 period and in the January-June 2019 period (Table 1).

Table 1. Comparison of Model vs. Meter for RE070/7-2

April 15-December 31, 2018			
Metered		**Modeled (Original Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
25	1.81	38	6.84
January 1-June 30, 2019			
Metered		**Modeled (Original Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
7	0.04	18	0.77

Regulator Calibration Investigation

The data in Table 1 indicated that for both the model prediction and the meter data, the average volume per activation was relatively small (0.14 MG/activation for the model, and 0.06 MG/activation for the meter). Thus, for the extra activations in the model compared to the meter data, it is likely that the model's depth of flow in the regulator was just barely exceeding the weir elevation for a relatively short period. The largest metered overflow volume for the period of April 2018 to June 2019 was 0.6 MG, and 23 of the 32 metered activations were recorded as "volume too small to measure." Many of these very-low volume activations may be due to turbulence or wave action in the regulator causing the flow to "slosh" over the weir.

Table 2 presents a list of all of the storms that occurred in the April 2018 to June 2019 period. Storms that caused a metered activation are indicated by either a value for the volume of activation, or a "**" symbol, indicating an exceedance of the trigger elevation but metered volume was too small to be quantified.

Table 2. Metered Activations from April 15, 2018 through June 30, 2019

Date	Metered Activations (MG)	Date	Metered Activations (MG)	Date	Metered Activations (MG)
4/16/2018	0.600	9/25/2018	0.580	1/24/2019	**
4/25/2018	**	9/26/2018	**	2/6/2019	
4/27/2018	**	9/28/2018		2/12/2019	
5/15/2018	0.139	10/3/2018		3/4/2019	
6/4/2018		10/11/2018	**	3/22/2019	**
6/18/2018	**	10/23/2018		4/8/2019	
6/28/2018	**	10/27/2018	**	4/15/2019	**
7/6/2018		10/29/2018	**	4/22/2019	0.034
7/11/2018	0.075	11/3/2018	**	4/26/2019	**
7/17/2018	0.299	11/6/2018	**	5/13/2019	
7/26/2018	**	11/9/2018	**	5/26/2019	
8/4/2018	**	11/13/2018		5/31/2019	
8/8/2018	0.051	11/16/2018	**	6/11/2019	
8/11/2018		11/25/2018	**	6/13/2019	
8/12/2018	0.066	11/26/2018		6/20/2019	**
8/13/2018		12/2/2018		6/21/2019	**
8/22/2018		12/16/2018		6/29/2019	0.001
9/10/2018	**	12/31/2018			
9/13/2018		1/5/2019			
9/18/2018	**	1/20/2019			

Calibration plots for this location showed that for several storm events, the modeled flow and depth at the influent to the regulator were higher than the metered flow and depth. A series of model runs was conducted adjusting the percent impervious area (to attempt to increase wet weather flow to the regulator), but these adjustments did not improve the calibration plots. A review of other parameters associated with the upstream tributary areas identified an area where the Horton infiltration rate was different from surrounding areas. The Horton infiltration rate is a factor that addresses the change in rate of soil infiltration over time. Once this rate was adjusted to match the surrounding areas, the model results were much closer to the meter results.

In the model, the Horton Infiltration rate was changed from “1a” to “1e”.

The updated calibration results are presented in comparison to the original calibration and the meter data in Table 3.

Table 3. Comparison of Model vs. Meter for RE070/7-2

April 15- December 31, 2018					
Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration- CAL040)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
25	1.81	38	6.84	25	2.13
January 1-June 30, 2019					
Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration- CAL040)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
7	0.04	18	0.77	11	0.01

As indicated in Table 3, the model matches the metered activations for the April-December 2018 period, and the model is slightly high on the volume. For the January-June 2019 period, the model is slightly high on the activation frequency, but the average volume/activation is less than 0.01 MG.

Investigation Conclusions

Based on the results of this analysis, with the change to the Horton’s infiltration rate, the model is considered to be adequately calibrated for evaluation of CSO performance.

CAM401B

Regulator Information

Outfall CAM401B's sole regulator, RE-401B. directs flow to MWRA's Alewife Brook Conduit (ABC) through an 18-inch dry weather flow (DWF) pipe connection, as shown in Figure 3 below. Project flow meters were installed on the influent sewer and the overflow conduit from the regulator, and Cambridge has a meter on the overflow pipe. Regulator RE01A (Outfall SOM01A) also directs flow to the Alewife Brook Conduit downstream of regulator RE-401B, while regulator RE011 (Outfall CAM001) directs flow to the Alewife Brook Branch Sewer (ABBS) downstream of RE401B. Regulator RE021 (Outfall CAM002) discharges to both the ABC and the ABBS, downstream of RE401B. Regulator RE031 (MWR003) is located on the ABC upstream of the RE401B connection. Regulator RE401A is located along a Cambridge combined sewer that carries flow to RE401B. The ABC and ABBS are interconnected at multiple locations.

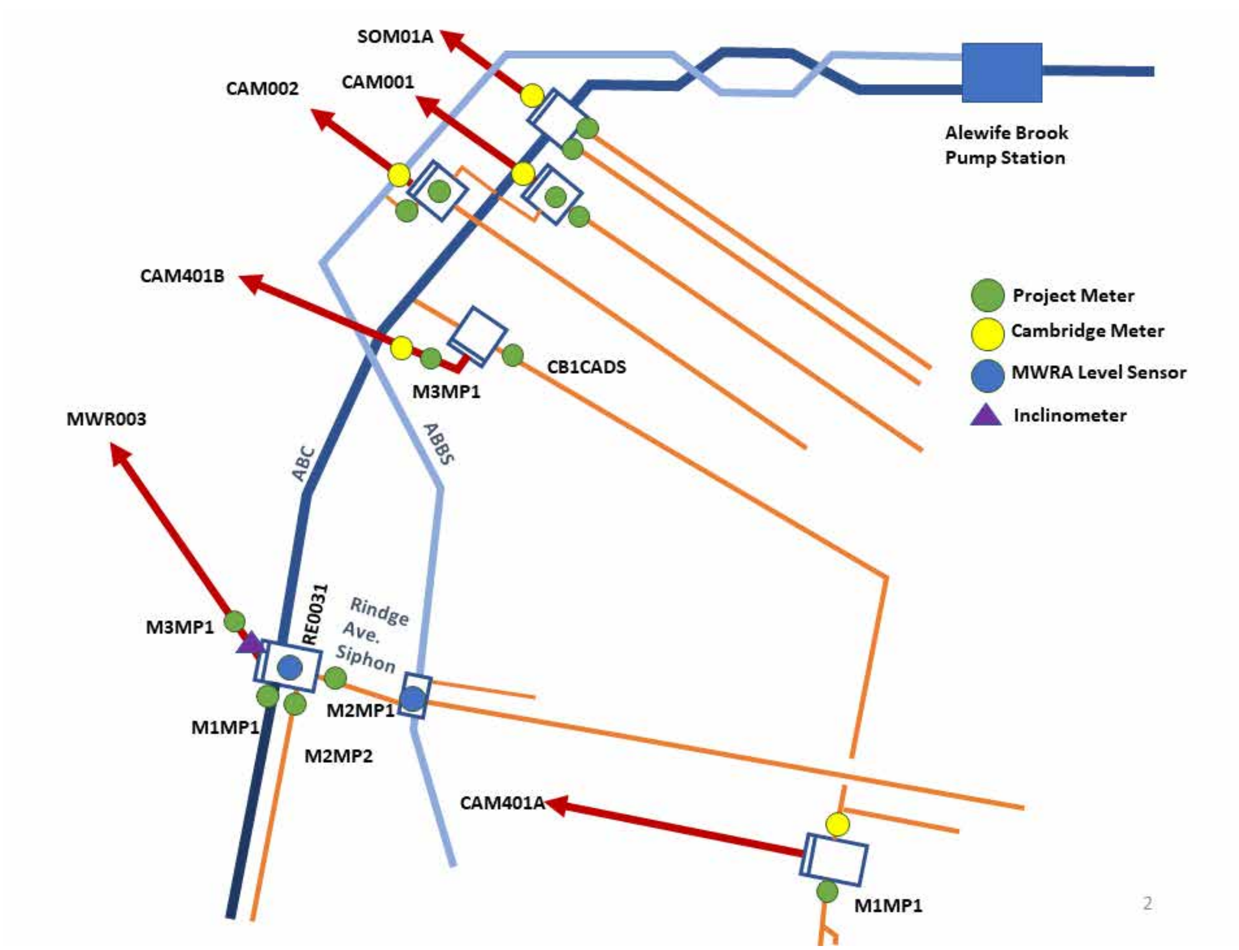


Figure 3. Schematic of Alewife System

Reason for Further Investigation

The initially calibrated model predicted a higher activation frequency and volume than the observed metering data for both the 2018 and 2019 monitoring periods as shown in Table 4 below, and as a result was further reviewed.

Table 4. Comparison of Model vs. Meter for CAM401B

April 15- December 31, 2018			
Modeled (Original Calibration)		**Metered**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
17	0.95	3	0 *

* Metered volume too small to be quantified

January 1-June 30, 2019			
Modeled (Original Calibration)		**Metered**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
2	0.13	0	0

Regulator Calibration Investigation

The City of Cambridge's hydraulic model, which also models CSO activation frequency and volume at CAM401B, was used as a reference in the calibration investigation(1). The Cambridge model predicted 3 activations with a discharge volume of 0.177 MG for all of 2018. Differences between the MWRA and Cambridge models include differences in upstream subcatchment representation as well as variation in rainfall and other model input files. For example, the MWRA model uses Fresh Pond rain gauge data, while Cambridge replaces the Fresh Pond data with data from the Cambridge DPW gauge when those data are available (2). In terms of the configuration of regulator RE401B, the weir elevations in the MWRA and Cambridge models were the same, at 108.75 ft MDC. This overflow elevation was similar to the weir elevation of 108.97 ft MDC measured in the field during this investigation. However, differences were observed in the hydraulic losses through the DWF connection between the MWRA and Cambridge models. The Cambridge model had a relatively low Manning's n on the DWF connection (n= 0.01) while the MWRA model had a higher Manning's n on the DWF connection (n= 0.03). No additional entrance or exit losses were modeled in either the Cambridge of MWRA models.

The MWRA model was overpredicting activations compared to the MWRA meter data and the Cambridge model predictions even though the weir elevation is the same in both models, which suggests that there may be too much headloss in the 18-inch DWF pipe in the MWRA model, restricting flow through the 18-inch DWF pipe to the Alewife Brook Conduit. To assess the losses in the regulator structure, the MWRA model was rerun with lower Manning's n values for the 18-inch DWF pipe.

(1) The Cambridge model was also over predicting CSO activation frequency and volume at this location, however, it was to a lesser extent than MWRA's model and was attributed to a lower baseflow measured during this period. Refer to page 12 of the City of Cambridge CSO NPDES Report 2019 for additional information.
(2) Following the submittal of Attachment A to the court on February 18, 2020, Cambridge provided additional information. Both MWRA and Cambridge use the USGS Fresh Pond rain data, however, MWRA uses USGS Fresh Pond for the entire area tributary to the Alewife, while Cambridge substitutes Cambridge DPW Rainfall data in some areas.

Decreasing the headloss in the DWF connection resulted in anticipated decreases in activation frequency. Table 5 below presents the original model calibration results, as well as the results after lowering the Manning's n value on the DWF connection. As indicated in Table 5, a Manning's n of 0.019 resulted in 3 overflows, with a total volume of 0.22 MG. While the predicted volume is still a little high compared to the meter data, the average per-storm modeled volume is only 0.07 MG.

Table 5. Results of Varying Manning's n in DWF Connection for CAM401B

April 15- December 31, 2018		
Manning's n value on DWF connection	**Modeled Activation Frequency**	**Modeled Discharge Volume (MG)**
Original Calibration		
0.03	13	0.78
Model Iterations		
0.012	2	0.08
0.015	2	0.14
0.017	2	0.18
0.018	2	0.20
0.019	3	0.22
0.020	4	0.25
Target from Meter		
	3	0 *

* Metered volume too small to be quantified

A comparison of the original calibration to the revised calibration and meter data for the April-December 2018 period and the January-June 2019 period is summarized in Table 6. For the January-June 2019 period, the model matches the meter, with no activations predicted or measured.

Table 6. Comparison of Model vs. Meter for CAM401B

	April 15- December 31, 2018					
	Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
CAM401B	3	0.00	17	0.95	3	0.22
	January 1 – June 30, 2019					
	Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
CAM401B	0	0.00	2	0.13	1	<0.01

Investigation Conclusions

Based on the results of this analysis, it is recommended the Manning's n value of 0.019 be used on the RE401B DWF connection to provide a better match to the metered activations. With this change, the model is considered to be adequately calibrated for evaluation of CSO performance.

CHE004

Regulator Information

Outfall CHE004's sole regulator, RE-41, directs flow into the City of Chelsea's Chelsea Trunk Sewer at a location just upstream of its connection to the North Metropolitan Relief Sewer (Figure 4). Project flow meters were installed on each of two influent lines into the regulator, and an inclinometer was installed on the tidegate downstream of the overflow weir. MWRA's permanent meter CH6C is located on the Chelsea Trunk Sewer between the RE-41 connection and the North Metropolitan Relief Sewer. The City of Chelsea maintains a flow meter located directly on the overflow weir in RE-41.

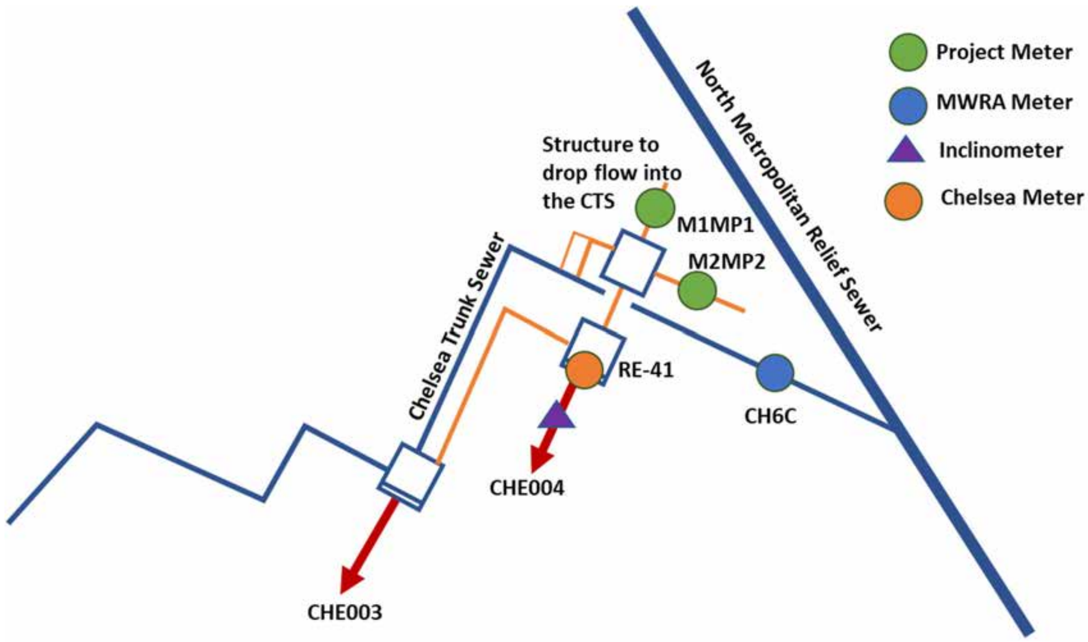


Figure 4. Schematic of CHE004 System

Reason for Further Investigation

The initially calibrated model was predicting a higher activation frequency and volume than the observed metering data for both the 2018 and 2019 monitoring periods as shown in Table 7, and as a result was further reviewed.

Table 7. Comparison of Model vs. Meter for CHE004

April 15- December 31, 2018			
Modeled (Orig. Calib.)		Metered	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
34	9.44	19	1.79
January 1-June 30, 2019			
Modeled (Orig. Calib.)		**Metered**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
11	4.48	13	0.29

Regulator Calibration Investigation

Record drawings of Regulator RE-41 indicate that the DWF connection at the regulator is a 24-inch diameter pipe that splits to an 18-inch drop connection and 24-inch relief connection, both connected to the Chelsea Trunk Sewer. However, during installation of the meter,the inspection crew reported that the size of the DWF connection leaving the regulator was 12-inch diameter. Thus, the original calibration was based on a 12-inch connection, with a Manning's n value of 0.025. The size of the connection leaving the regulator was re-measured in the field, and was confirmed to be 24-inch diameter, matching the record drawing. It is suspected that the original inspection may have measured a different pipe in the regulator that was not the DWF connection. During the more recent field measurement, flow into the dry weather flow connection did not appear to be impeded. To improve the match to the meter data, the size of the opening to the DWF connection was set to 24-inch diameter, and the roughness coefficient was adjusted to n = 0.033. With this adjustment, the modeled activations and volume both dropped to more closely match the meter data (Table 8).

Figure 5 shows a plot of model versus metered depth and flow at MWRA meter CH-6-C on the Chelsea Trunk Sewer downstream of the RE-41 connection for the 7/18/2018 storm. This storm caused an activation (metered and modeled) at CHE004. The model appears to somewhat over-predict the depth and volume at meter CH-6-C, but the metered depth and flow data show plateaus at the peaks, and may not be representing the actual peaks.

Table 8. Summary of Impacts of Calibration Changes to Activations and Volume at CH004, RE-41

April 15- December 31, 2018					
Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
19	1.79	34	9.44	10	1.63
January 1-June 30, 2019					
Metered		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
13	0.29	11	4.48	4	1.09

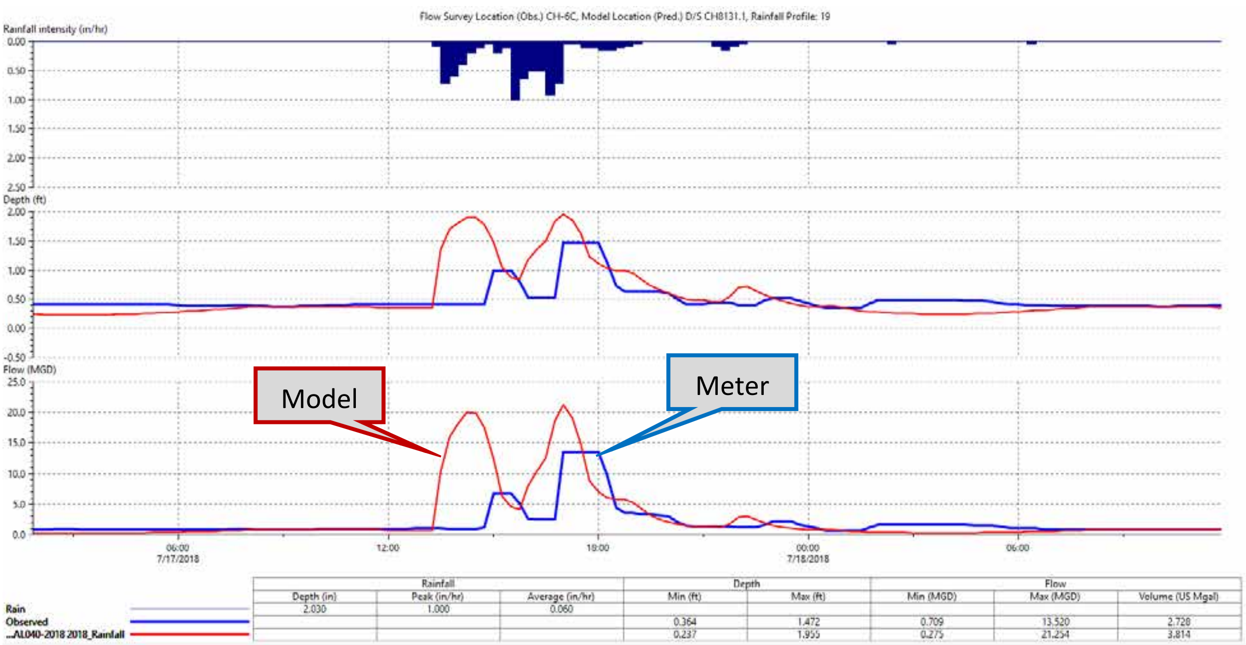


Figure 5. Model vs Metered Plot at MWRA Meter CH-6C

As another point of comparison, it was noted that during the January-June 2019 period, when the project meter (M1MP1, shown in Figure 4) indicated a total of 13 activations, the City of Chelsea's meter on the weir reported only two activations. The project-meter activations were determined when the depth at the project meter on the influent pipe into RE-41 exceeded the weir elevation. Since that influent meter was located approximately 30 feet upstream of the weir (as well as upstream of a drop connection structure), there was some concern that the depth measured at the influent meter might not represent the actual depth at the weir. To assess the potential impact of headlosses between the project meter and the weir on metered activations, the depth at the influent meter was plotted for the January-June 2019 period, with the trigger depth (corresponding to the weir elevation) indicated (Figure 6). The data from Figure 6 are presented in tabular format in Table 9.

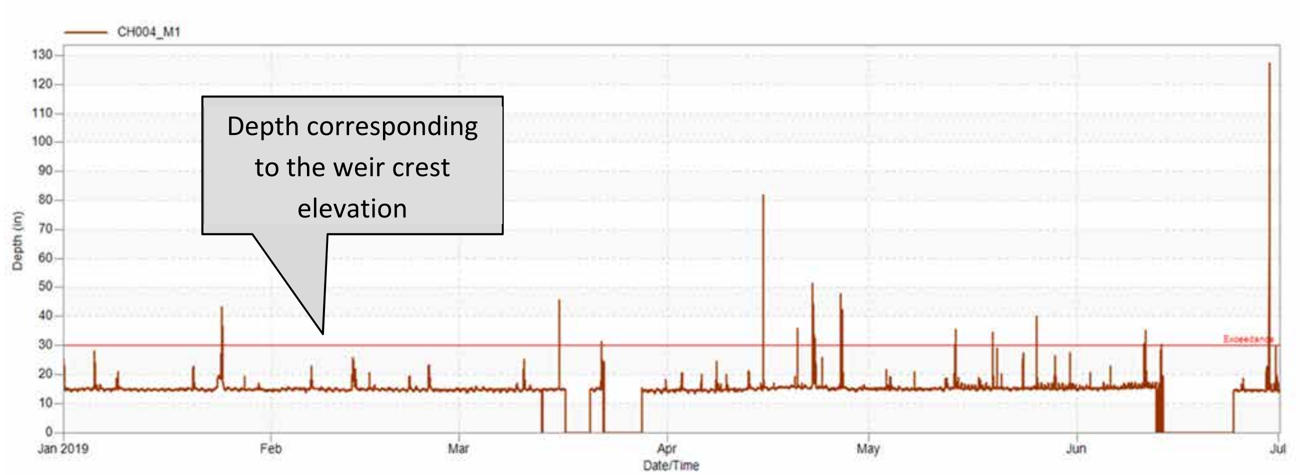


Figure 6. Depth vs. Time at RE-41 Influent Meter for January-June 2019

Table 9. Depth and Duration of Outfall CHE004 Metered Events for Jan-June 2019

Event	Date	Maximum Depth (in)	Depth above Trigger (in)	Duration of Exceedances (min)
1	1/24/2019 15:10	43.4	13.4	97
2	3/15/2019 21:30	45.5	15.5	15
3	3/22/2019 4:30	31.3	1.3	10
4	4/15/2019 6:00	81.9	51.9	59
5	4/20/2019 9:25	35.7	5.7	10
6	4/22/2019 13:10	51.4	21.4	275
7	4/26/2019 19:20	48.0	18.0	113
8	5/13/2019 20:55	35.5	5.5	35
9	5/19/2019 11:45	34.5	4.5	13
10	5/26/2019 0:55	40.1	10.1	13
11	6/11/2019 0:35	35.2	5.2	23
12	6/13/2019 13:15	30.3	0.3	1
13	6/29/2019 15:10	127.3	97.3	51

As indicated in Figure 6 and Table 9, out of the 13 metered activations, the depth at meter M1MP1 was more than 50 inches above the trigger elevation for two events, and the depth was at least 10 inches above the trigger elevation for five other events. For these seven events, at least, it would seem likely that the depth over the weir was also exceeded. When flow first starts to back up against the weir, the velocity between the location of the dry weather flow connection and the weir would tend to be relatively low, as the regulator is filling up “like a bathtub.” Headloss between these points would similarly tend to be low. Once the elevation of the weir is exceeded and flow starts to move over the weir, velocities in the chamber, and headloss, would increase, and there would be a higher likelihood of a difference between the influent depth and the depth at the weir.

Based on the evaluation of the depth data relative to the trigger elevation, it appears that most of the 13 "metered" activations in the January-June 2019 timeframe would be considered legitimate activations. The two storm events where the depth exceeded the weir elevation by less than two inches, and for relatively short durations, are less certain and were not counted as activations.

As noted above, the metered and modeled activations matched best with the Manning's n value of the DWF connection set to n=0.033. The cause of this relatively high headloss was not apparent from inspections conducted in the regulator. It is possible that unusual hydraulic conditions in the regulator during wet weather are causing this high apparent headloss.

Investigation Conclusions

Based on these revised results, with the parameters of the dry weather flow connection adjusted to better reflect actual field conditions, the model is considered to be adequately calibrated for evaluation of CSO performance.

MWR201 (Cottage Farm Facility)

Facility Information

The Cottage Farm CSO Facility receives overflow from the North Charles Metropolitan Sewer, the North Charles Relief Sewer (East and West), and the South Charles Relief Sewer (SCRS) (Figure 7). The Cottage Farm CSO Facility provides relief for interceptors on the north and south sides of the Charles River, and is the primary upstream relief point when Ward Street Headworks capacity is exceeded and the Headworks must choke incoming flow. Overflow enters the Cottage Farm Facility when flow from the interceptors overtops the interconnected NCRS and/or SCRS weir chambers and a high level set point is reached at the facility influent structure, triggering the influent gates to open. A gate on the Brookline Connection (which runs directly from the Cottage Farm Facility to the junction chamber on the other side of the river) is manually operated to maximize flow to Ward Street Headworks in the open position and prevent flow from Ward Street Headworks from backing up into the facility in the closed position.

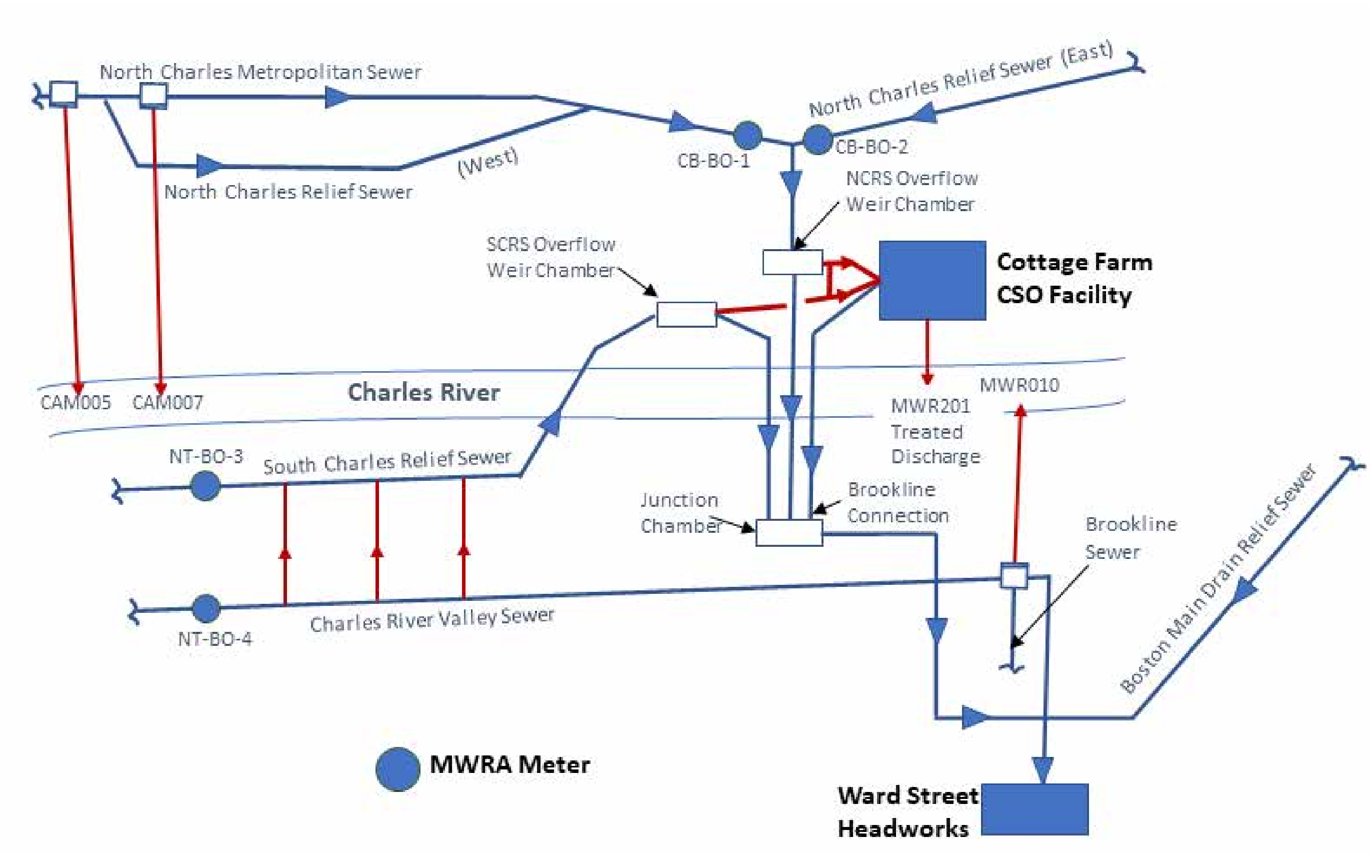


Figure 7. Schematic of System Upstream of Cottage Farm CSO Facility

Reason for Further Investigation

For the April 2018 to June 2019 metering period, the facility data indicated a total of 6 facility activations with 38.58 MG of discharge, and the initially calibrated model predicted a total of 3 activations with 17.4 MG of discharge. Since the model appeared to be under-predicting both activations and volume, further investigation was conducted.

Calibration Investigation

Table 10 presents a storm-by-storm comparison of modeled vs. metered activations at Cottage Farm for the April 2018 to June 2019 period. As indicated in Table 10, the model missed the activations on 9/18/18, 11/10/18, and 4/15/19. The model predicted a discharge for the storm on 4/16/2018; however, the predicted discharge volume was less than half of the measured discharge volume. For the 4/22/2019 storm, the predicted discharge volume was only 0.13 MG as compared to a measured volume of 5.01 MG. The 7/17/2018 storm was the only storm where the model reasonably matched the measured discharge volume.

Table 10. Metered vs Measured Activation Volumes in Original Model for Cottage Farm

Date	Metered Activations (MG)	Original Calibration Modeled Activations (MG)	Updated Calibration Modeled Activations (MG)
4/16/2018	8.5	3.54	4.92
7/17/2018	11.19	13.87	14.87
9/18/2018	4.28		3.04
11/10/2018	6.17		4.42
4/15/2019	3.43		
4/22/2019	5.01	0.13	3.60

Facility operations for each storm event were reviewed, and it was found that the facility activation for the 04/22/2019 storm was missed due to a gate being closed too early in the model. Correcting this led to an overflow of 3.6 MG in the model for the 4/22/18 storm, compared to the 5.01 MG measured volume. To address the other activations not predicted by the model, the amount of flow coming into the facility was investigated. It was noted that the missed storms tended to occur during periods of high groundwater. The interceptor meter data showed evidence of the influence of groundwater on the flow, and groundwater had previously been incorporated into some of the runoff areas upstream of the facility. However, an area without the groundwater component was identified adjacent to other areas that had the groundwater component. To be consistent, groundwater was added to this area. In addition, the model was found to be under-predicting the wet weather flow at MWRA interceptor flow meter CB-BO-1, which measures flows from the North Charles Metropolitan Sewer and the North

Charles Relief Sewer (West). Runoff parameters were adjusted to increase the wet weather flow to better match this meter.

With the increase in flow due to the added groundwater, and the increase in flows from CB-BO-1, the model predicted activations for the 9/18/2018 and the 11/10/2018 storms. The model, however, still did not predict a facility activation for the 4/15/2019 storm. The characteristics and rainfall distribution for that storm were reviewed, but rainfall variation did not seem to be a contributing factor for this storm event. The facility operations during this storm also appeared to be normal, so the facility activation could not be attributed to unique operating conditions. It is not entirely clear why the model did not predict an activation for the 4/15/19 storm. However, since the model predicted the other five events during this period, and the predicted activation volumes were reasonably close, the model was considered to be sufficiently calibrated.

Investigation Conclusions

With the additional groundwater and adjustment of flows to meter CB-BO-1, the model is sufficiently calibrated for use in post-monitoring evaluations. Table 11 presents the meter and revised model activation frequency and volume for the 2018 and 2019 period.

Table 11. Comparison of Model vs. Meter for Cottage Farm

April 15-December 31, 2018					
Metered		Modeled (Original Calibration)		Modeled (Revised Calibration- CAL034)	
Activation Frequency	Activation Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
4	30.14	2	17.41	4	27.26

January 1-June 30, 2019					
Metered		Modeled (Original Calibration)		Modeled (Revised Calibration- CAL034)	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
2	8.44	1	0.13	1	3.60

MWR018, MWR019 and MWR020

Regulator Information

Outfalls MWR018, MWR019 and MWR020 can discharge overflows from MWRA's Boston Marginal Conduit (BMC) to the Charles River Basin in large storms. Otherwise, the BMC conveys combined sewer flows to MWRA's Prison Point CSO treatment facility (Figure 8). MWRA identifies the overflow events at these outfalls using measurements at level sensors in the BMC upstream of MWR018 and downstream of MWR020. Discharge volumes are not measured. During the 2018 calibration period, the level data at the MWRA meter downstream of MWR020 was determined to be faulty, and those data were not used for identifying overflow activations at MWR018 to MWR020, nor were they used in the calibration.

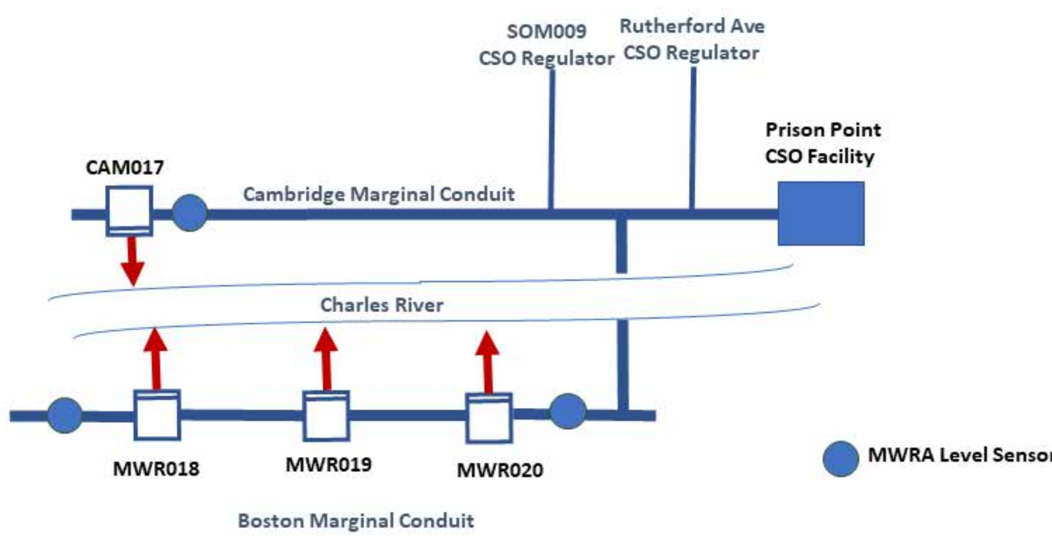


Figure 8. Schematic of Boston Marginal Conduit System

Justification for Further Investigation

The initially calibrated model was predicting a higher activation frequency than the meter data for the 2018 monitoring period as shown in Table 12, and as a result was further reviewed. No measured or model predicted CSO activations occurred for the January 1 through June 30, 2019 period.

Table 12. Comparison of Meter vs. Model for MWR018/019/020

	April 15- December 31, 2018			
	Modeled (Orig. Calib.)		Metered	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
018	4	5.72	2	Not Measured
019	4	2.33	2	Not Measured
020	4	1.71	2	Not Measured
	January 1-June 30, 2019			
	Modeled (Orig. Calib.)		Metered	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
018	0	0	0	Not Measured
019	0	0	0	Not Measured
020	0	0	0	Not Measured

Regulator Calibration Investigation

Calibration adjustments related to Prison Point resulted in elimination of one of the modeled 2018 overflows. Previously, the model predicted no activation of Prison Point for the 11/03/2018 storm, while the facility data indicated an activation. When the Prison Point influent gate closing time for the 11/03/2018 storm was adjusted, the model predicted the Prison Point facility to activate, consistent with the measured data. The modeled activation of the Prison Point facility reduced the peak hydraulic grade line in the Boston Marginal Conduit for the 11/03/2018 storm, eliminating the modeled overflow at outfalls MWR018/019/020 for that storm, and improving the match between modeled and metered depth at the MWRA level sensor upstream of MWR018.

Calibration plots were then created for each remaining storm where the model indicated an activation, as well as for three storms where the model did not predict an activation. The peak elevations in the BMC at the MWRA meter upstream of MWR018 for each of these storms is shown in Table 13. Plots of modeled vs. metered elevations in the BMC at the meter upstream of MWR018 are shown in Figures 9 to 14.

Table 13. Summary of Modeled and Metered Activations

	MWR018 Metered Activations @ MWR018			Modeled Activation	
Date	Storm Report Activations (2018 NPDES reported)	Max. Level	Activation Indicated >108.85 for MWR018, >109.1 for MWR019/020	Max. Level	Modeled Activation?
7/17/2018	✔	110.4	✔	112	✔
8/12/2018	✔	110.7	✔	111.2	✔
9/18/2018		106.4		110.2	✔
11/3/2018		106.8		107.1	
2/13/2019		101.9		104.7	
6/20/2019		107.3		107.1	

The plots in Figures 9 to 14 indicate that the model and meter match reasonably well for each of the storms except for the 9/18/2018 storm, where the model over-predicts the depth by about four feet, resulting in a modeled activation at MWR018/019/020. Investigating the 9/18/2018 storm further, it was determined that this storm had highly variable rainfall over the large area that contributes flows to the BMC. The description of calibration for the Prison Point CSO Facility, presented below, includes examples of the impacts of variable rainfall on the Prison Point tributary area, and the MWR018/019/020 tributary area overlaps with the Prison Point tributary area up through the Stony Brook system.

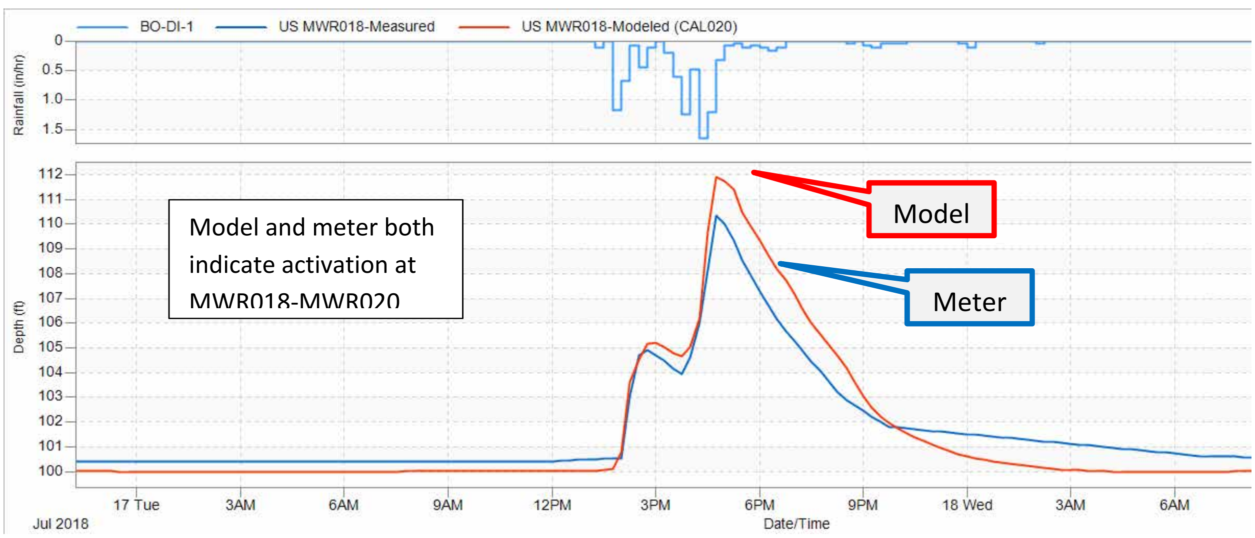


Figure 9. July 17, 2018 Storm

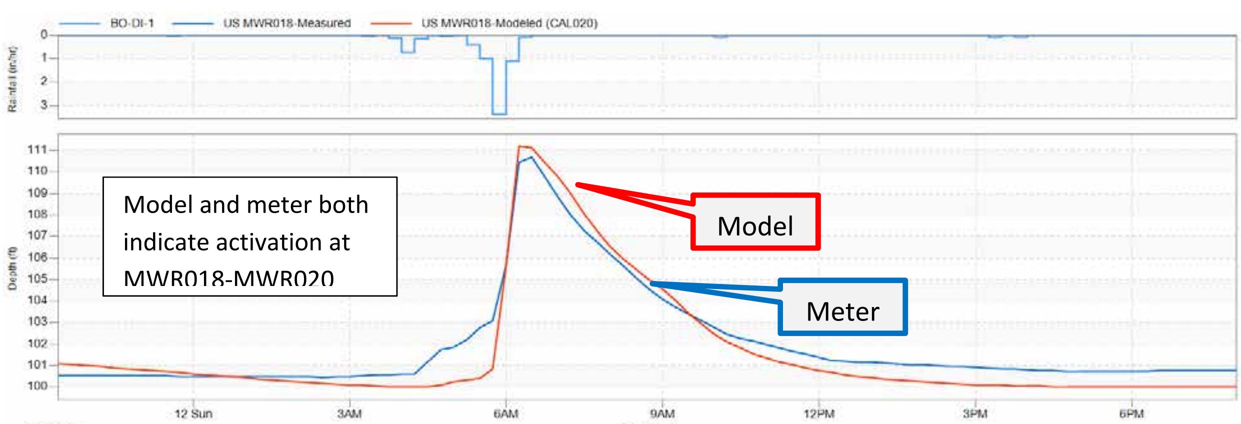


Figure 10. August 12, 2018 Storm

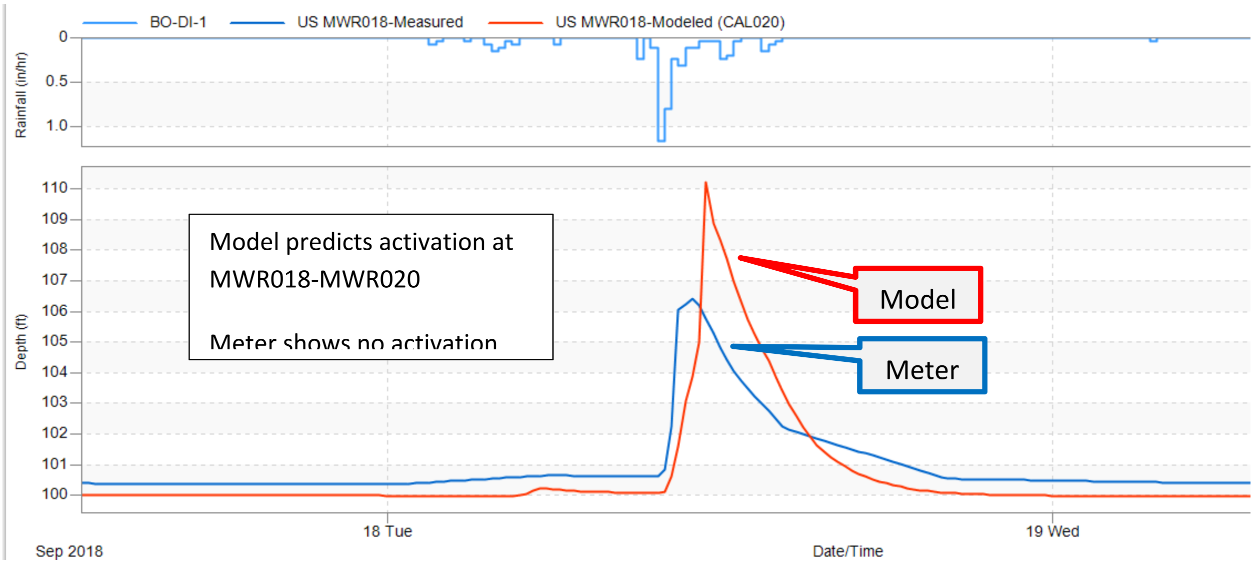


Figure 11. September 18, 2018 Storm

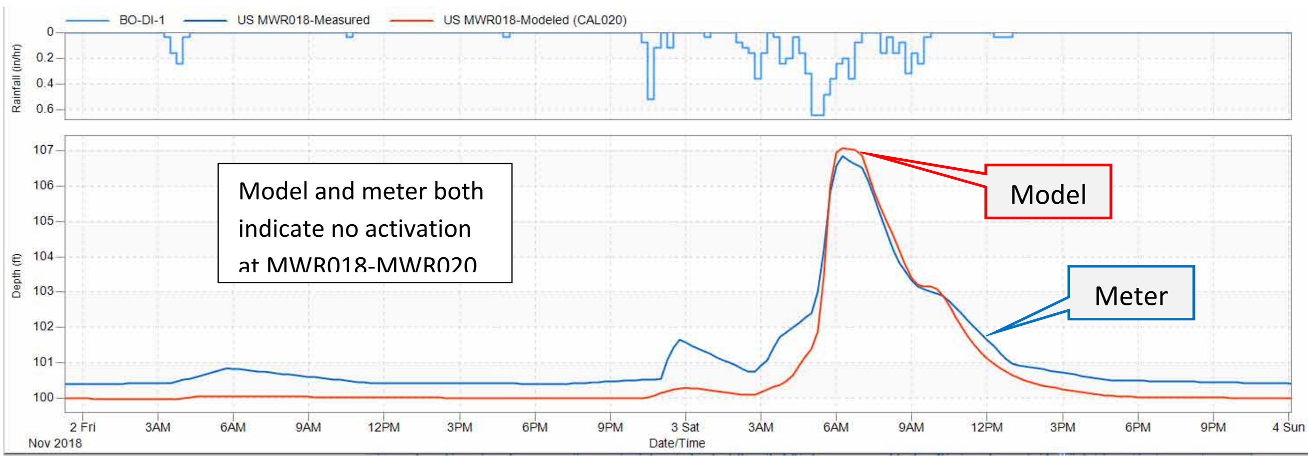


Figure 12. November 3, 2018 Storm

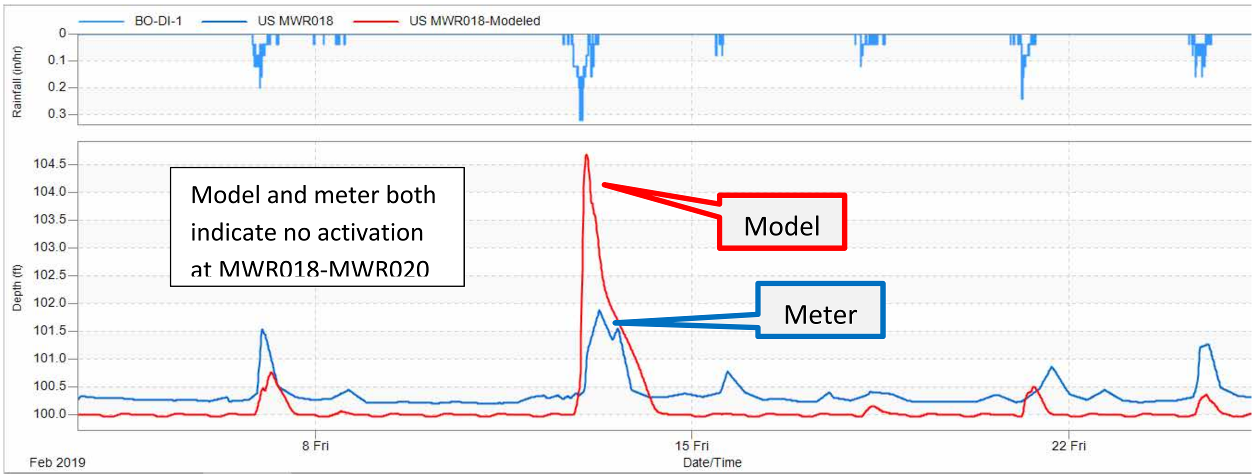


Figure 13. February 7-22, 2019 Storm

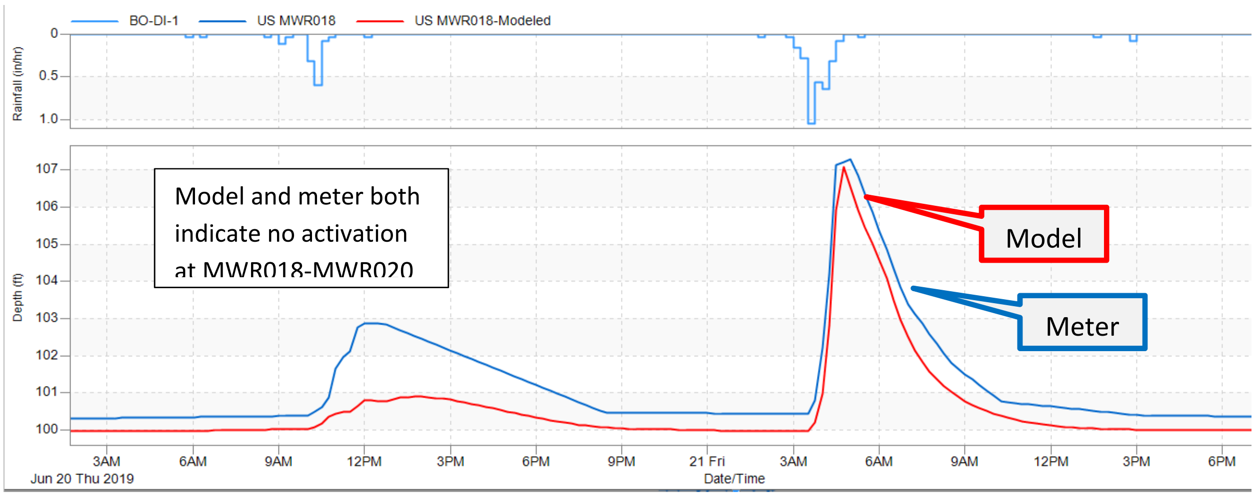


Figure 14. June 20, 2019 Storm

Figure 15 presents a screen shot of radar imagery from the 9/18/2018 storm. As indicated in Figure 15, a band of intense rainfall moved through the tributary area. The rain gage data used as input to the model would not fully represent the spatial variability of this type of rainfall pattern. Therefore, the calibration for MWR018/019/020 is now considered to be good, since the model does replicate the meter data for storms where the rain gage data represents the actual rainfall that fell throughout the tributary area (i.e., storms with less spatially variable rainfall). The model therefore can adequately predict Typical Year flows and discharges, because Typical Year rainfall is uniform over the MWRA service area.

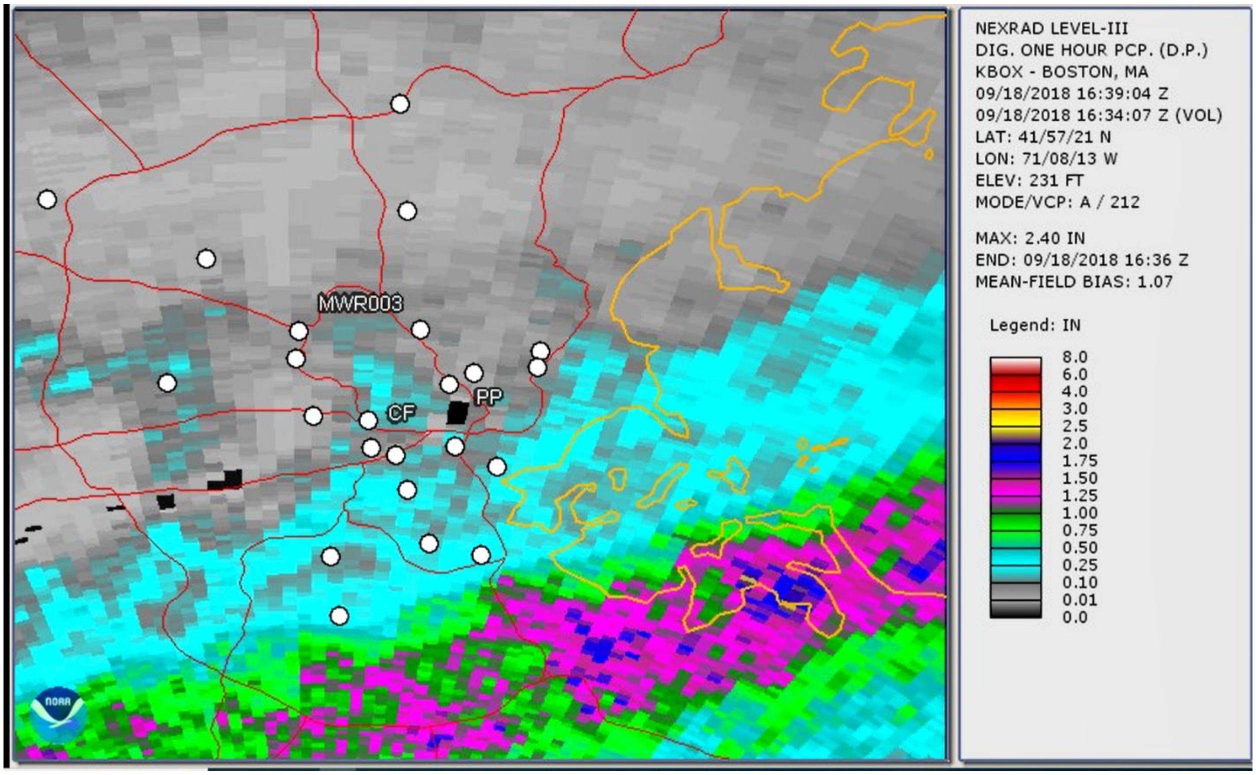


Figure 15. Rainfall Variation during the 9/18/2018 Storm

A comparison of the original calibration to the revised calibration and meter data for the April-December 2018 period and the January-June 2019 period is summarized in Table 14. For the January-June 2019 period, the model matches the meter, with no activations predicted or measured.

Table 14. Comparison of Model vs. Meter for MWR018/MWR019/MWR020

	April 15- December 31, 2018					
	Measured		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
018	2	Not Measured	4	5.72	3	4.30
019	2	Not Measured	4	2.33	3	1.68
020	2	Not Measured	4	1.71	3	1.14
	January 1-June 30, 2019					
	Metered		**Modeled**		**Modeled (Revised Calibration)**	
Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)

Table 14. Comparison of Model vs. Meter for MWR018/MWR019/MWR020

018	0	Not Measured	0	Not Measured	0	0.00
019	0	Not Measured	0	Not Measured	0	0.00
020	0	Not Measured	0	Not Measured	0	0.00

Investigation Conclusions

Based on the results of this analysis, no further changes to the calibration for outfalls MWR018/019/020 is needed, beyond the adjustment that was made at Prison Point for the 11/03/2018 storm. The model is considered to be adequately calibrated for evaluation of CSO performance.

Prison Point

Facility Information

The Prison Point CSO Facility receives flow from the Cambridge Marginal Conduit and the Boston Marginal Conduit, as well as from the SOM009 and Rutherford Ave. regulators on the Cambridge Branch Sewer in Somerville and the Charlestown Branch Sewer in Charlestown, respectively (see Figure 16). In dry weather, flows are pumped to the Rutherford Avenue sewer. In wet weather, the gates to the wet weather tanks open on high level in the influent chamber. For storms in the flow metering periods, available facility data included the discharge volume, and the timing and influent chamber level associated with the opening and closing of the wet weather influent gates.

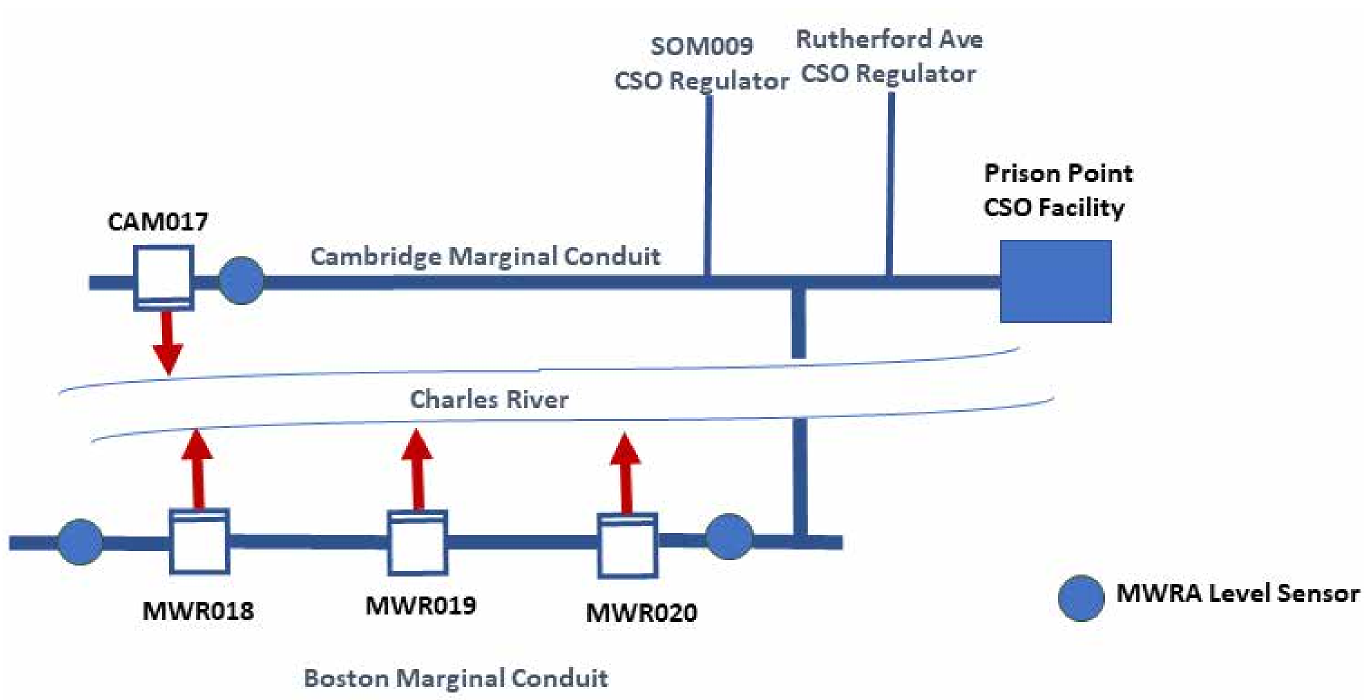


Figure 16. Schematic of System Upstream of Prison Point CSO Facility

Reason for Further Investigation

For the April 2018 to June 2019 metering period, the facility data indicated a total of 25 facility activations with 461 MG of discharge, and the model predicted a total of 19 activations with 334 MG of discharge. Since the model appeared to be under-predicting both activations and volume, further investigation was conducted.

Calibration Investigation

A storm-by-storm comparison of modeled vs. metered activations at Prison Point showed that for many storms, the model was reasonably close to the facility data on activation volume (Table 15). The storms where the model missed an actual activation were then investigated further.

Table 15. Metered vs Measured Activations in Original Model for Prison Point

Date	Metered Activations (MG)	Metered Open Elevation (ft)	Modeled Activations (MG)
4/16/2018	38.13	104	30.09
5/15/2018	17.52	98	16.17
6/25/2018	0.42	101	
6/28/2018	13.38	101	13.15
7/17/2018	29.46	98.5	46.26
7/26/2018	5.72	102.5	2.29
8/4/2018	3.26	102.5	4.04
8/11/2018	3.95	102	
8/12/2018	28.52	103	24.11
9/18/2018	12.46	95.5	23.69
9/25/2018	11.5	103	18.74
10/27/2018	16.96	104	11.14
10/29/2018	*5.91*	*103*	
11/3/2018	*24.2*	*103.7*	
11/9/2018	23.59	104	24.40
11/13/2018	4.31	104	3.58
11/16/2018	14.03	104	10.65
11/27/2018	18.48	104	4.77
1/24/2019	23	102.7	
4/15/2019	8.15	104	7.49
4/22/2019	41.21	104	39.66
4/27/2019	19.91	104/104.98	10.35
6/21/2019	11.74	93.3	6.65
6/29/2019	9.53	98	8.00
6/30/2019	4.72	99	

The 11/03/2018 storm was missed due to a gate being closed too early in the model, compared to the actual gate operation. Correcting this led to an overflow of 23.16 MG in the model, compared to the 23.2 MG metered volume. For the remaining storms, facility activations and overflow volumes the model missed were due to rainfall variation not being captured by the rain gage network (see the MWR018, MWR019 and MWR020 discussion, above). Figure 17 shows the portion of the modeled system that can contribute flow to Prison Point. The area in red represents a large portion of the MWRA system. Large tributary areas such as this are more sensitive to the exact spatial distribution of rainfall.

For example, Figure 18 shows rainfall at two gages for the 10/29/18 storm, which is a storm where activation of Prison Point was missed by the model. While the BO-DI-1 gage shows a peak intensity of around 0.5 in/hr, the rainfall recorded at the Fresh Pond gage had a peak intensity of 1 in/hr. The timing of rainfall peaks was also different at the two gages. Radar imagery during this storm also showed wide variation. Figure 19 shows a radar image of the rainfall during the 10/29/18 storm. This image shows a band of rainfall, with relatively little rainfall at Cottage Farm, but extensive rainfall north and west of Prison Point. This is an example of rainfall hitting the tributary area in real life, but the modeled rainfall for the tributary area represented by the Cottage Farm gage showed much less rainfall.

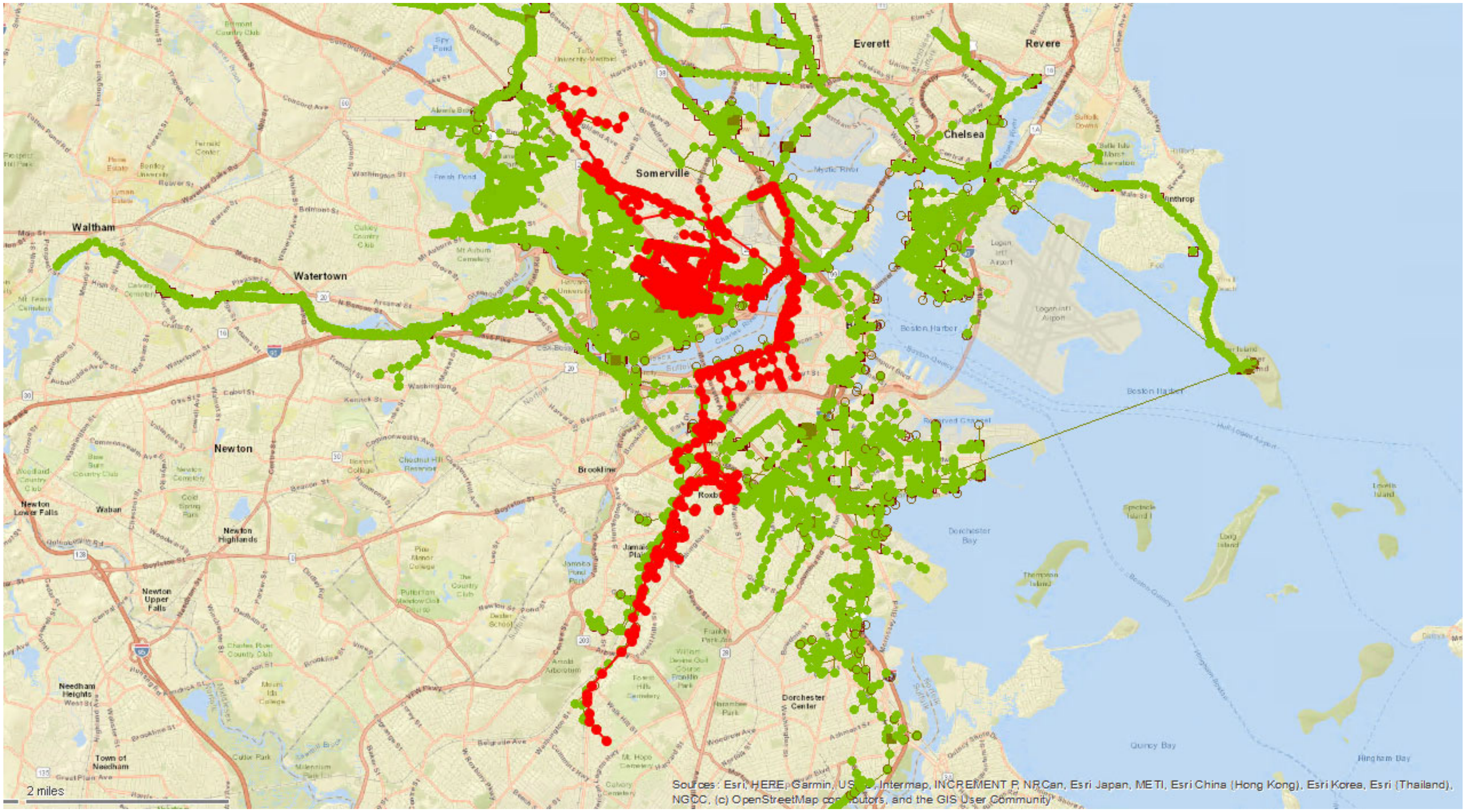


Figure 17. Model Schematic of System Tributary to Prison Point

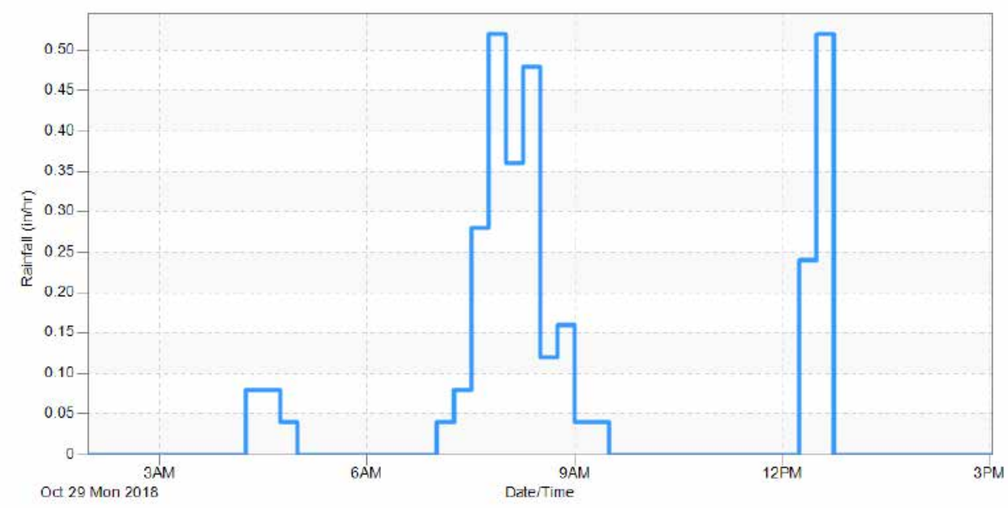


Figure 26. BO-DI-1 October 29, 2018

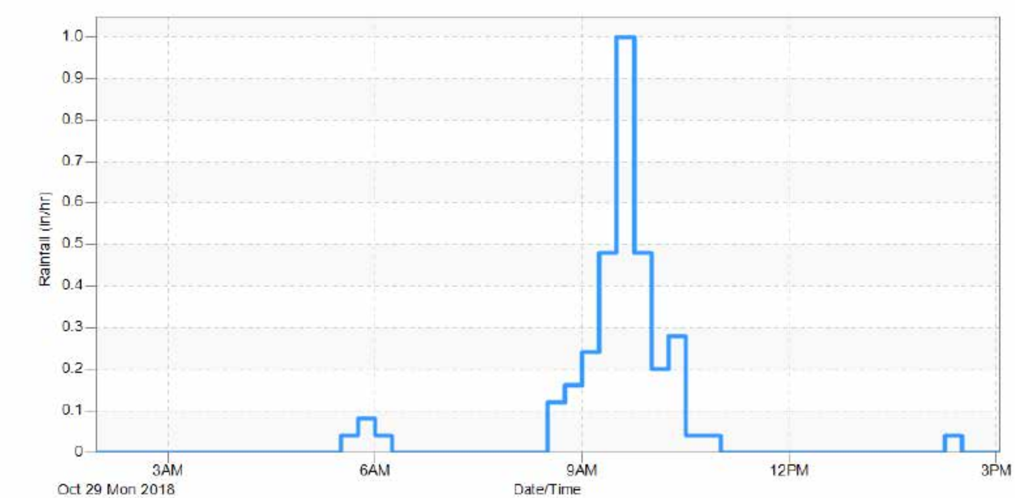


Figure 27. USGS Fresh Pond October 29, 2018

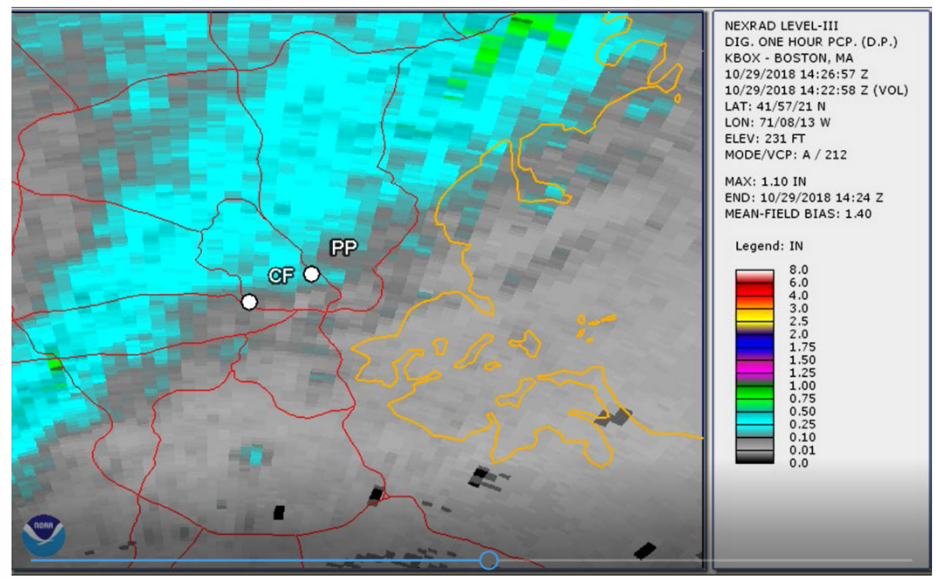


Figure 19. NEXRAD Radar during 10/29/19 storm.

Figure 18. Rainfall Variation – 10/29/2018 Storm (Meter = 5.91 MG, Model = 0 MG at Prison Point)

Figure 20 shows rainfall data at two gages for the 11/9/2018 storm, where the model closely matched the metered volume (24.4 MG model vs. 23.6 MG meter). As indicated in Figure 20, the hyetographs at the two gage locations are fairly similar in terms of shape and peak intensity. Figure 21 shows a radar image from the 11/9/2018 storm, confirming the relatively uniform rainfall over a large area, compared to the distribution shown for the 10/29/18 storm in Figure 19.

Radar imagery from the other storms where the model missed a measured activation at Prison Point showed similar variability in the distribution of rainfall over the Prison Point tributary area. As a sensitivity test, a model run was conducted that modified the rainfall for certain storms. From Table 15, the model missed activations for six storms, but the missed activation on 11/3/18 was resolved by adjusting the gate opening time. For the remaining five storms, rather than apply rainfall from the closest gage to a location, the largest recorded rainfall that fell at any one gage was applied for all locations. The resulting overflows are not a true estimate of overflow, but rather show the potential impact rainfall variation can have on overflow volumes. As a check, the rainfall for three other storms where the model had closely predicted the metered volume were similarly adjusted, to provide a sense of the impact of this rainfall adjustment during more uniform rainfall events. The results of this sensitivity analysis are presented in Table 16.

Table 16: Sensitivity Test with Adjusted Rainfall at Prison Point

Date of Storms with Modified Rainfall	Volume from Metered Activations (MG)	Volume from Original Modeled Activations (MG)	Volume from Model Activations with adjusted rainfall (MG)
6/25/2018	0.42	0 (no activation)	12.82
8/11-12/2018	32.5	0 (no activation)	41.31
10/29/2018	5.91	0 (no activation)	9.89
11/9/2018	23.59	24.4	32.92
1/24/2019	23	0 (no activation)	--
4/22/2019	41.21	39.7	38.68
4/27/2019	19.91	10.35	9.63
6/30/2019	4.72	0 (no activation)	0.004

As indicated in Table 16, adjusting the rainfall caused modeled activations for four of the five storms where the model had previously missed the activation. For the three storms in Table 16 that the model had previously predicted an activation (11/9/18, 4/22/19 and 4/27/19), the rainfall adjustment had a relatively modest impact on the predicted volume. This finding is consistent with a more uniform rainfall pattern throughout the tributary area for those storms.

For the 1/24/19 storm, where no activation was predicted with the adjusted rainfall, and for the 6/30/19 storm, where the predicted volume was only 0.004 MG, rainfall variation is still believed to be a factor in the difference between the modeled and metered values. For example, Figure 22 shows a radar rainfall image at the peak of the 06/30/2019 storm. In addition to the location of both Cottage Farm and Prison Point, this figure shows all rain gages used for the study. As represented by the radar image, none of the available gages are capturing the pockets of peak rainfall intensities indicated in the pink color. Similar rainfall variation was also present during the 01/24/2019 storm.

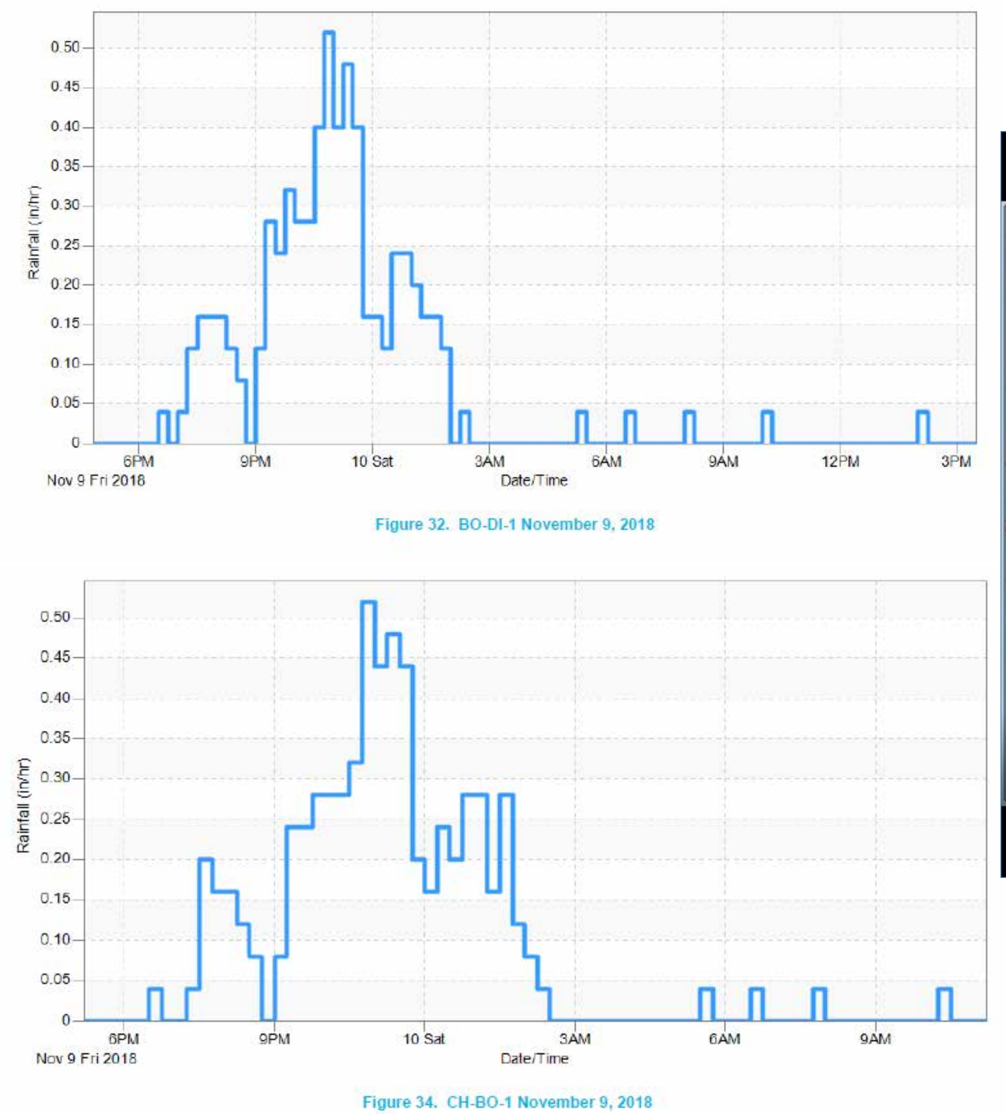


Figure 20. Rainfall Variation – 11/9/2018 Storm (Meter = 23.59 MG, Model = 24.40)

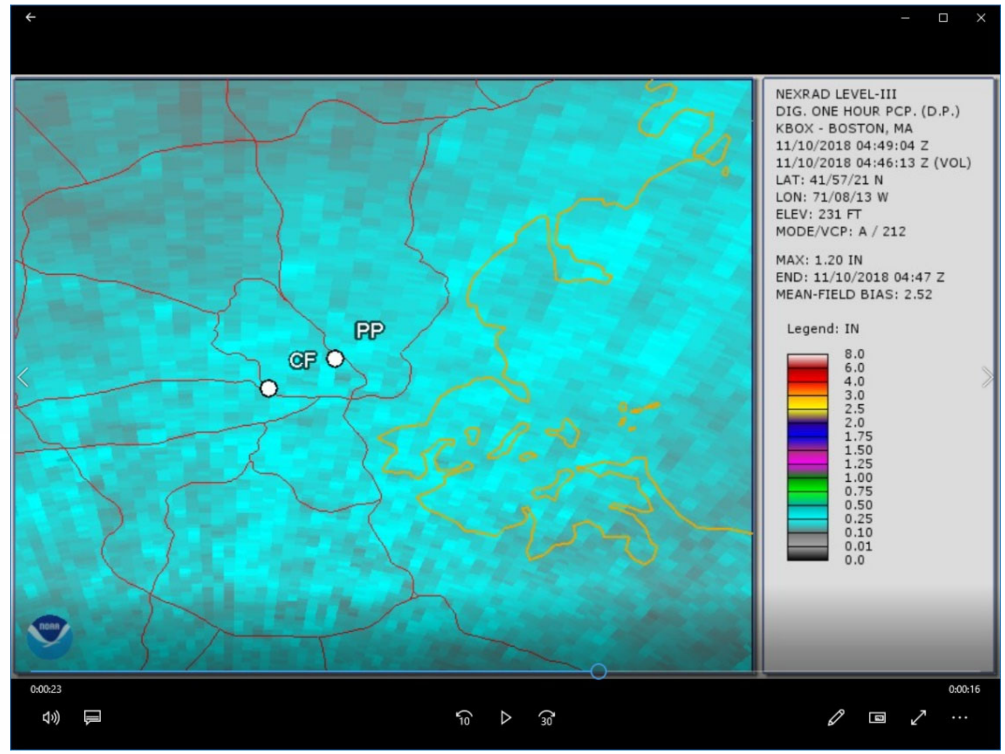


Figure 21. NEXRAD Radar during approximate peak of 11/09/19 storm.

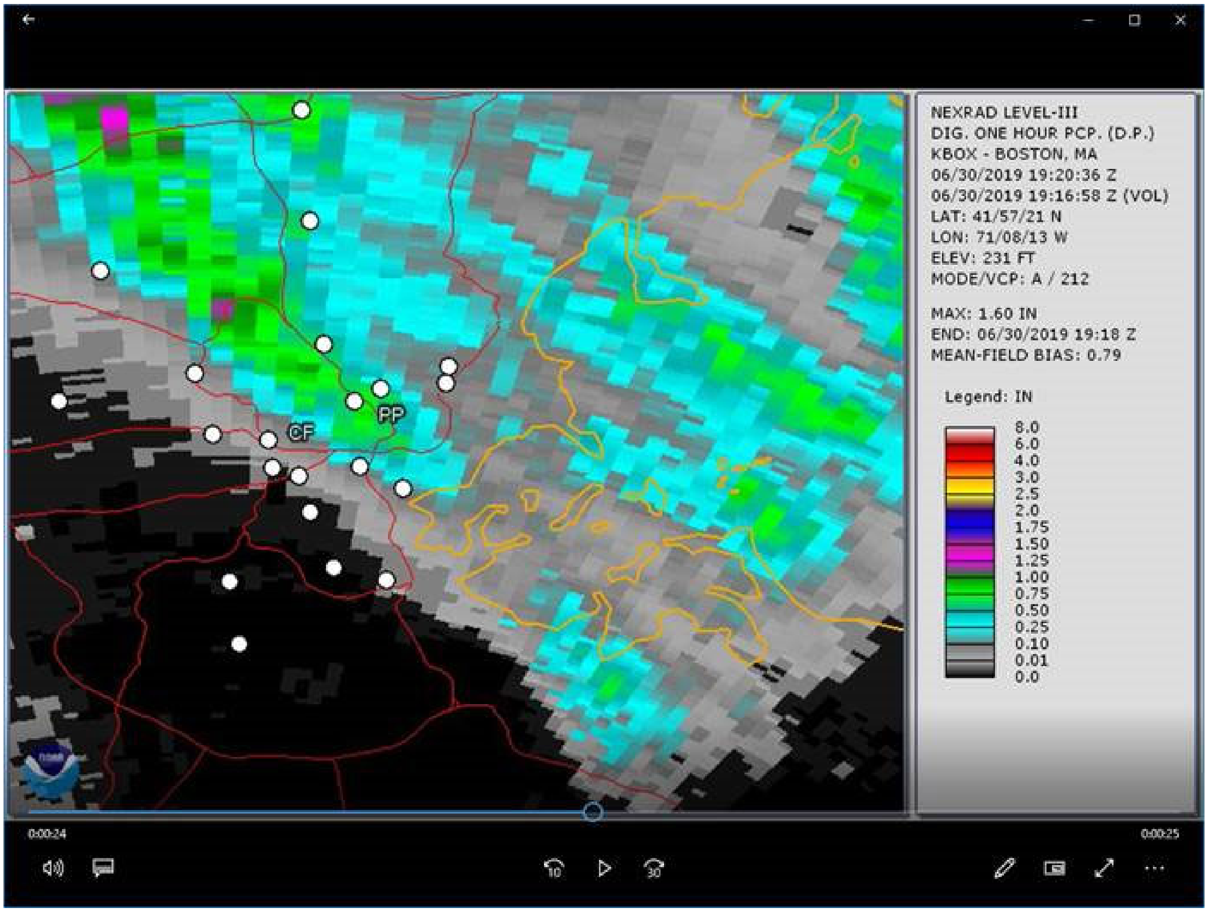


Figure 22. Rainfall Variation at Peak of 06/30/2019 Storm

Investigation Conclusions

Based on the analysis presented above, it is concluded the model can accurately reflect the performance at Prison Point when the rain gages used to represent rainfall in the model accurately reflect actual rainfall that fell throughout the tributary area. The calibration of the model tributary to Prison Point is therefore considered to be good. Where actual rainfall is highly variable spatially, and may not be accurately reflected by the available rain gage data, the model may not represent performance at Prison Point as well. However, CSO activations are being evaluated against the Typical Year that is applied uniformly across the system. CSO activations match well for storms where the rainfall was uniform throughout the system. Therefore the model is adequately calibrated for use in post-monitoring evaluations.

BOS060: RE060-7

Regulator Information

Regulator RE060-7 is located at the upstream end of the New East Side Interceptor (Figure 23). This regulator receives combined sewer flow from the DWF connection from regulator RE060-20. Outfall BOS060 receives overflows from both RE060-7 and RE060-20. Project flow meters were installed on the influent line to RE060-20, and on the influent line to RE060-7 from RE060-20. An inclinometer was installed on the tidegate immediately downstream of RE060-7.

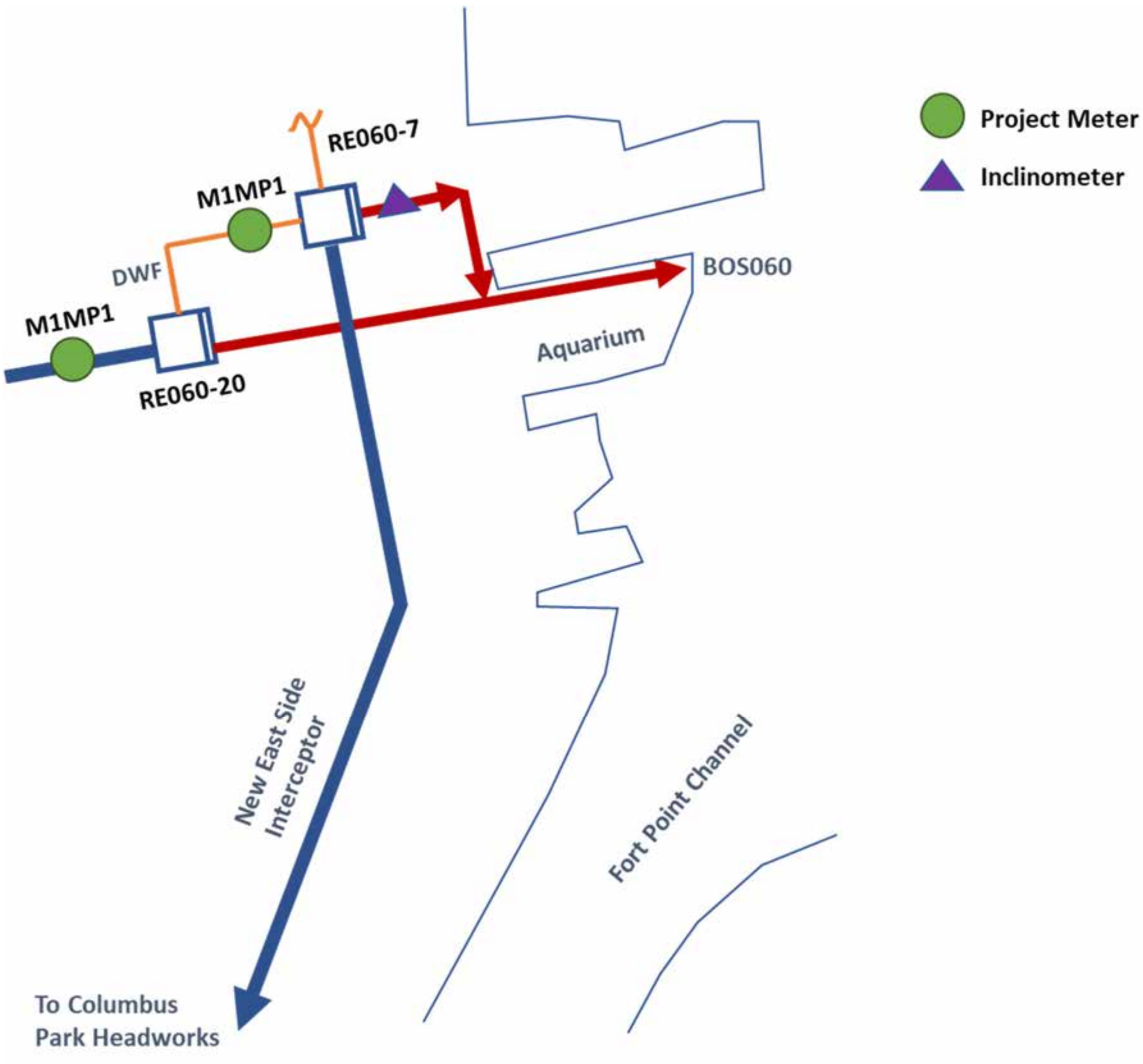


Figure 23. Schematic of Regulator 060-7

Reason for Further Investigation

The model was thought to be under predicting volume and activation frequency for the April-December, 2018 calibration period, and under predicting volume for the January-June 2019 period, as shown in Table 17.

Table 17. Comparison of Model vs. Meter for RE060-7

	April 15- December 31, 2018			
	Modeled (Orig. Calib.)		**Metered**	
Regulator	**Activation Frequency**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**
060-7	5	0.28	9	4.22
	January 1-June 30, 2019			
	Modeled (Orig. Calib.)		**Metered**	
Regulator	**Activation Frequency**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**
060-7	2	0.08	2	0.32

Regulator-Calibration Investigation

As shown in Table 17, during the initial calibration process, the metered volume for RE060-7 was reported to be 4.22 MG for the April-December 2018 period, and thus it appeared that the modeled volume was noticeably under-predicted. However, upon further review of the meter data, an issue was discovered with both the methodology of the overflow volume calculation, and the trigger elevation. When those issues were resolved, the metered activations and volumes for the April to December 2018 and January to June 2019 period went down, as shown in Table 18.

To further improve the calibration at RE060-7, the configuration of the connection between the regulator and the interceptor was revised to better reflect the physical configuration of the regulator. The model had previously represented the interceptor connection as a pipe, but the actual connection is through an opening in the wall of the regulator. This opening functions as an orifice, so the model was revised to remove the old pipe connection and replace it with an orifice. With this change, the revised model predictions relative to the meter data are shown in Table 18.

Table 18. Summary of Impacts of Calibration Changes to Activations and Volume at RE060-7

April 15- December 31, 2018					
Metered (Updated)		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
4	0.98	5	0.28	6	0.68
January 1-June 30, 2019					
Metered (Updated)		**Modeled (Original Calibration)**		**Modeled (Revised Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
1	0.09	2	0.08	1	0.49

As a separate issue for RE060-7, the meter data for the influent flow into RE060-7 showed a recurring pattern of flow and depth spikes during dry weather. These spikes were not clearly apparent during wet weather, but they may have been masked by the wet weather flows. The specific pattern of the spikes is irregular, and is suspected to be related to the discharge of localized dewatering pumps. Figure 24 shows an example of the spikes occurring during a dry weather period.

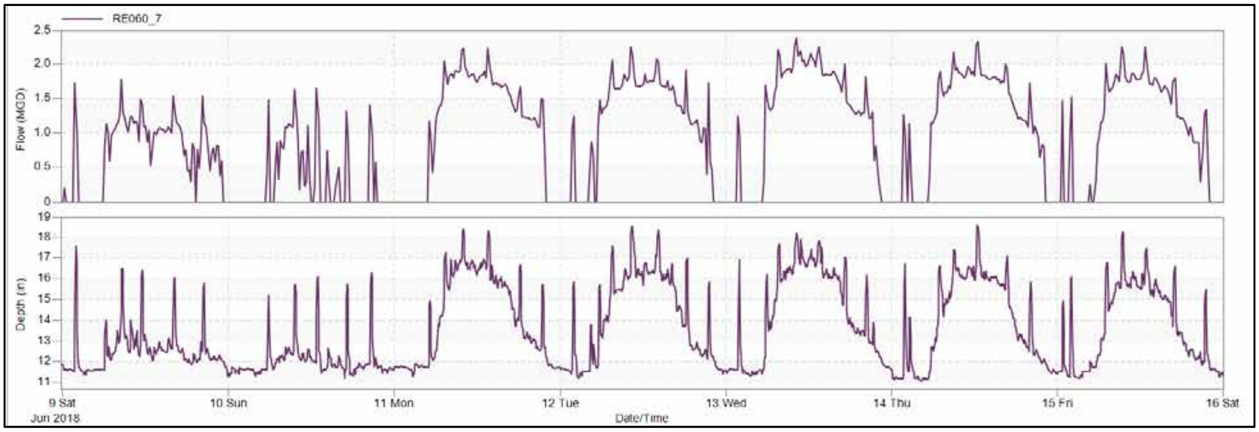


Figure 24. Metered Dry Weather Flow at RE060-7 Influent

As indicated in Figure 24, during periods of low dry weather flow (weekends, evenings), the magnitude of the flow spikes is about 1.5 MGD, and the depth spike is about 4-5 inches. During peak dry weather flow periods, the magnitude of the flow spike is about 0.5 MGD and the depth spike about 2 inches. Based on the meter depth versus time plots for storms where the meter indicated an overflow occurred, the measured water surface was generally high enough over the trigger elevation that the impact of these flow spikes was not likely significant in terms of causing the overflow. MWRA has obtained dewatering pump discharge data that may shed more light on the location, capacity and timing of the dewatering flows. However, it is not anticipated that this flow data would significantly affect the wet weather calibration at RE060-7.

Investigation Conclusions

Based on the revised configuration of the regulator in the model and the revised metered volumes, the model now slightly over-predicts activations and volumes in the April-December 2018 calibration period, while slightly overpredicting the volume in the January-June 2019 period. Given the relatively small differences in activations and volumes, the model is considered to be adequately calibrated for evaluation of CSO performance.

<u>**MWR003**</u>

Regulator Information

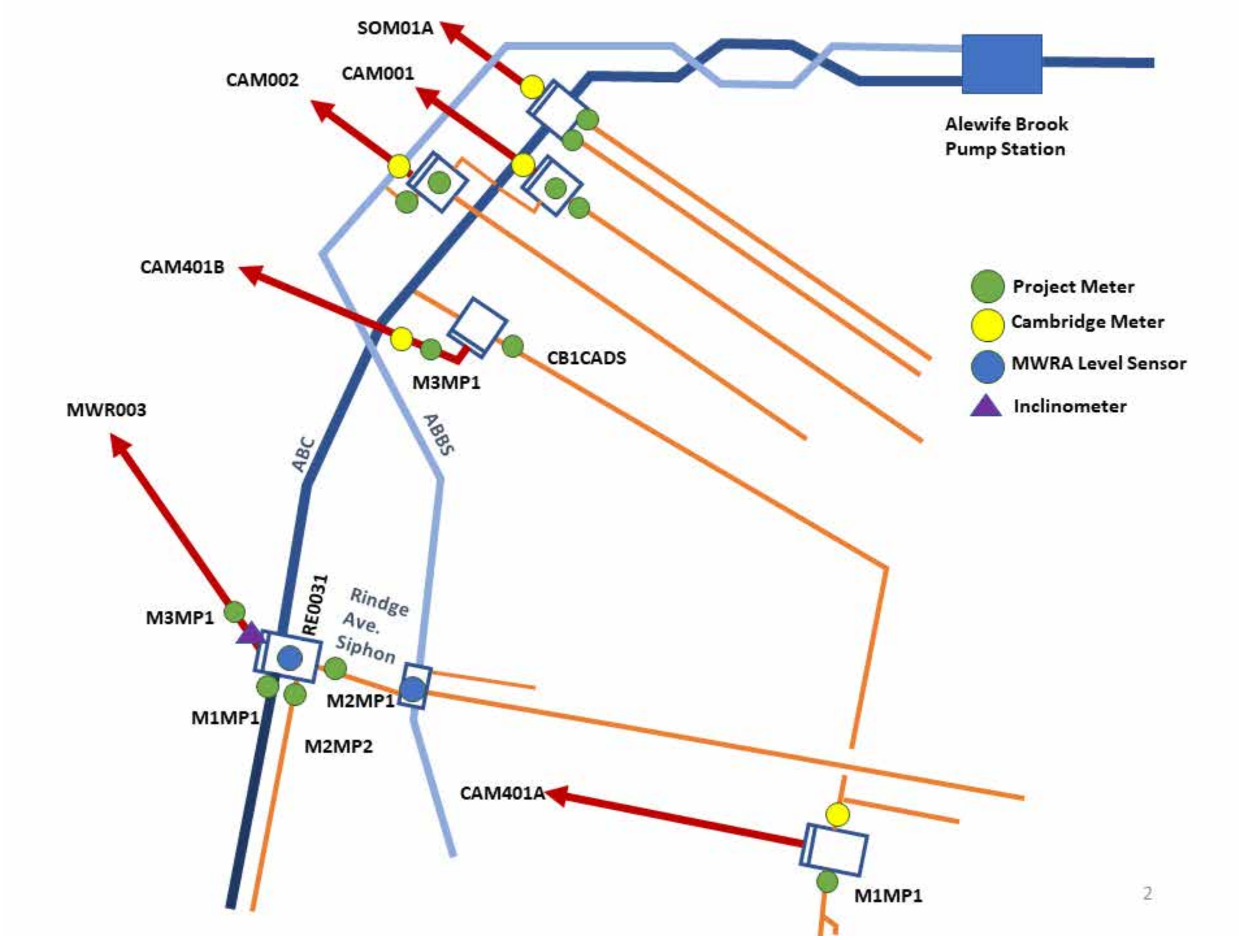
The MWR003 regulator structure (RE031) is situated directly on the MWRA's Alewife Brook Conduit (ABC). It receives flow collected from parts of Cambridge and Belmont by the ABC, as well as overflow from MWRA's Rindge Avenue Siphon, which provides relief for MWRA's Alewife Brook Branch Sewer (ABBS) and City of Cambridge's Rindge Avenue Sewer at MWRA internal regulator RE032 (Figure 25). Dry weather flow is carried by the ABC to the Alewife Brook Pump station. When the hydraulic grade line in regulator RE031 exceeds the elevation of the top of the weir gate, excess flow is discharged to Alewife Brook. Project flow meters were installed in the three influent lines into the regulator, and in the overflow pipe downstream of the weir gate. An inclinometer was installed on the flap gate on the outfall. The MWRA maintains level elements in the MWR003 regulator, and in the Rindge Avenue siphon chamber. These MWRA level elements are in part used to automatically lower the weir gate for greater system relief in extreme storms.

Reason for Further Investigation

The model was predicting a higher activation frequency and volume than the observed metering data for the 2018 monitoring period (Table 19), and as a result was further reviewed. For the January-June 2019 period, activations were not measured by the meter or predicted by the model

Table 19. Comparison of Model vs. Meter for MWR003

April 15- December 31, 2018			
Metered		**Modeled (Original Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
0	0	2	0.36
January 1-June 30, 2019			
Metered		**Modeled (Original Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
0	0	0	0.00



Regulator Calibration Investigation

Figure 25. Schematic of Alewife System

MWR003 is hydraulically interconnected to outfalls SOM01A and CAM002 through the ABC. In early 2019, physical changes were implemented at the regulators associated with these outfalls which could affect flows in the ABC and the hydraulics at MWR003. At SOM01A, a structure that could potentially impede flow into the orifice connection to the ABC was removed, and a plate restricting the size of the orifice was also removed. At CAM002, a plate blocking a connection between the regulator and the ABC was removed. These actions would allow more flow into the ABC from the SOM01A and the CAM002 regulators.

The model calibration for the April-December 2018 period, prior to the implementation of the changes at SOM01A and CAM002, overpredicted the activation frequency and volume at MWR003. No activations at MWR003 were measured by the meters or predicted by the model for the January 1 to June 30, 2019 period. Since no activations were predicted or modeled after the period when the changes were made at SOM01A and CAM002, the calibration of meter to model discharges after those changes cannot be confirmed at this time. Preliminary meter data indicate that two activations occurred at MWR003 in the late summer and early fall of 2019, but the model has not yet been set up to run for that period. Rainfall, SCADA and tide data have recently been obtained for the July-December 2019 period, so the next step for the MWR003 model calibration is to run the model for that period and evaluate the results.

Analysis of the data from the April-December 2018 period showed that the model was overpredicting the hydraulic grade line in the ABC at the MWR003 regulator structure. Potential causes of the higher hydraulic grade line would include either too much flow into the regulator, too much headloss in the interceptor downstream, incorrect representation of the operation of the Alewife Brook Pump Station, or a combination of these issues. The operation of the Alewife Brook Pump station was reviewed for the two storm events where the model predicted activations at MWR003. The facility operations were found to be consistent with the model representation, so variations in the operations of Alewife Brook Pump Station did not appear to be causing the two modeled activations.

In reviewing modeled versus metered flows into the MWR003 regulator, the model did not appear to be consistently over-predicting the flows. Reducing the upstream flows caused the model to under-predict the influent flows compared to the meters. The next step was to investigate the modeled roughness of the downstream sections of the ABC. The model had Manning's n values ranging from 0.015 to 0.020 for the ABC, and from 0.013 to 0.020 for the ABBS. As a sensitivity test, the model was run with the Manning's n for both the ABC and ABBS decreased to a uniform 0.015, and again with the Manning's n reduced to a uniform 0.013. The model still predicted two activations with the Manning's n at 0.015, but only one activation with the Manning's n of 0.013.

Although lowering the Manning's n of the interceptors appeared to improve the calibration at MWR003 for the April-December 2018 period, it is unclear what the effect would be on the 2019 period after the physical changes at SOM01A and CAM002 were implemented. In particular, it is unclear whether the model would still predict the two metered activations that occurred after July 2019. Because of the physical changes to the system that occurred in early 2019, the calibration of MWR003 cannot be considered complete until the model can be assessed for the late summer/early fall 2019 period where the meter indicated that activations occurred.

Investigation Conclusions

The model needs to be assessed against meter data from late summer/early fall 2019 in order to check the calibration of the physical changes that were implemented in early 2019.

<u>Further Investigation at MWR003</u>

Following the submittal of Attachment A to the court on February 18, 2020 additional investigation was conducted into the model's ability to replicate metered CSO activations at MWR003. While the previous investigations found that the model was slightly conservative for the 2018 calibration period, it was unknown how the implemented modifications at SOM001A and CAM002 would impact the overflow frequencies and volumes at MWR003. The investigation following the submittal of the court report focused on the activations that occurred in the late summer/early fall of 2019.

The modeled and metered activation frequency for July 1 to December 31, 2019 matched, as shown in Table 20. The model conservatively predicts the overflow volume for the period, with the volume over predicted for two storm events and under predicted for one storm event. The difference in modeled and metered volumes, as shown in Table 21 could be attributed to rainfall variation, the capacity of the Alewife Brook Conduit, and/or groundwater impacts to the regulator.

Table 20. Comparison of Model vs. Meter for MWR003

July 1-December 31, 2019			
Metered		**Modeled (Original Calibration)**	
Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
3	2.99	3	5.62

Table 21. Storm-by-Storm Comparison of Model vs. Meter for MWR003

Date of Activation	Meter Volume (MG)	Model Volume (MG)	Difference Between Model and Revised Model (MG)
8/7/2019	2.35	4.12	1.77
9/2/2019	0.26	1.34	1.08
10/16/2019	0.38	0.16	-0.22

Further Investigation Conclusions

Based on the July 1 to December 31, 2019 results, the model is adequately calibrated for evaluation of CSO performance, matching the activation frequency and slightly over predicting the volume. The model over predicts the activation frequencies for the 2018 calibration period, however, the model more closely replicates the current 2019 conditions with the modifications at SOM001A and CAM002.

Appendix B: Rainfall Data for July 1 through December 31, 2019

Appendix C: Rainfall Summary Tables

Rain Gauge 1: Allston

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
1	7/8/2019 11:00	0.5	0.02	0.04	0.02	0.00	0.02	<3m	<3m	N/A
2	7/11/2019 23:45	21.25	0.7	0.03	0.27	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 16:30	16.75	0.53	0.03	0.33	0.02	0.01	<3m	<3m	N/A
4	7/22/2019 12:15	22.25	1.88	0.08	0.32	0.08	0.04	<3m	3m	N/A
5	7/24/2019 4:00	0.25	0.01	0.04	0.00	0.03	0.04	<3m	<3m	N/A
6	7/31/2019 14:30	1.75	0.25	0.14	0.22	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:30	12.75	2.9	0.23	1.56	0.12	0.06	5.5 yr	1 yr	N/A
8	8/9/2019 18:30	0.25	0.01	0.04	0.01	0.00	0.06	<3m	<3m	N/A
9	8/18/2019 15:45	0.25	0.21	0.84	0.21	0.01	0.00	<3m	<3m	N/A
10	8/19/2019 15:45	0.25	0.02	0.08	0.02	0.01	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 15:00	10.25	1.39	0.14	0.64	0.06	0.03	3-6m	<3m	N/A
14	9/2/2019 15:45	10.75	1.09	0.10	0.99	0.05	0.02	1 yr	<3m	N/A
15	9/4/2019 17:45	0.25	0.08	0.32	0.08	0.00	0.01	<3m	<3m	N/A
16	9/7/2019 0:45	2.75	0.07	0.03	0.03	0.00	0.00	<3m	<3m	N/A
17	9/12/2019 6:45	2.25	0.06	0.03	0.04	0.00	0.00	<3m	<3m	N/A
18	9/13/2019 4:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
19	9/14/2019 12:45	11	0.19	0.02	0.11	0.01	0.00	<3m	<3m	N/A
20	9/23/2019 22:45	3	0.15	0.05	0.13	0.01	0.00	<3m	<3m	N/A
21	9/26/2019 16:00	2.25	0.32	0.14	0.18	0.01	0.01	<3m	<3m	N/A
22	10/1/2019 5:00	0.75	0.02	0.03	0.02	0.00	0.00	<3m	<3m	N/A
23	10/2/2019 13:45	3.5	0.25	0.07	0.16	0.01	0.00	<3m	<3m	N/A
24	10/3/2019 22:30	5.25	0.1	0.02	0.04	0.00	0.01	<3m	<3m	N/A
25	10/7/2019 19:30	11.25	0.31	0.03	0.19	0.01	0.01	<3m	<3m	N/A
26	10/9/2019 11:15	22.75	0.12	0.01	0.05	0.01	0.01	<3m	<3m	N/A
27	10/11/2019 11:30	21	0.75	0.04	0.2	0.03	0.02	<3m	<3m	N/A
28	10/16/2019 20:15	9	2.3	0.26	1.07	0.10	0.05	1.5 yr	3-6m	N/A
29	10/22/2019 18:45	12.5	0.42	0.03	0.09	0.02	0.01	<3m	<3m	N/A
30	10/25/2019 23:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
31	10/27/2019 9:00	10.75	1.65	0.15	0.54	0.07	0.03	3m	<3m	N/A
32	10/28/2019 19:30	8.25	0.05	0.01	0.01	0.00	0.04	<3m	<3m	N/A
33	10/30/2019 17:30	29.25	0.16	0.01	0.03	0.00	0.00	<3m	<3m	N/A
34	11/1/2019 0:15	4.25	0.08	0.02	0.05	0.00	0.00	<3m	<3m	N/A
35	11/5/2019 11:00	4.75	0.42	0.09	0.29	0.02	0.01	<3m	<3m	N/A
36	11/7/2019 16:15	6.5	0.28	0.04	0.1	0.01	0.01	<3m	<3m	N/A
37	11/12/2019 10:45	2.5	0.08	0.03	0.04	0.00	0.00	<3m	<3m	N/A
38	11/18/2019 12:45	5	0.3	0.06	0.08	0.01	0.01	<3m	<3m	N/A
39	11/19/2019 5:45	5	0.21	0.04	0.1	0.02	0.01	<3m	<3m	N/A
40	11/20/2019 2:30	18	0.18	0.01	0.04	0.01	0.01	<3m	<3m	N/A
41	11/22/2019 13:45	1.75	0.07	0.04	0.05	0.00	0.00	<3m	<3m	N/A
42	11/24/2019 3:15	18	1.34	0.07	0.35	0.06	0.03	<3m	<3m	N/A
43	11/27/2019 17:15	19	0.28	0.01	0.11	0.01	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/2/2019 0:45	15	1.43	0.10	0.22	0.06	0.00	<3m	<3m	N/A
45	12/4/2019 9:45	3.25	0.13	0.04	0.07	0.01	0.00	<3m	<3m	N/A
46	12/9/2019 7:45	17.75	0.51	0.03	0.16	0.02	0.01	<3m	<3m	N/A
47	12/10/2019 14:00	23.75	0.39	0.02	0.13	0.02	0.02	<3m	<3m	N/A
48	12/13/2019 18:00	24.75	1.41	0.06	0.19	0.06	0.03	<3m	<3m	N/A
49	12/17/2019 16:30	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
50	12/18/2019 9:15	5.75	0.23	0.04	0.07	0.01	0.01	<3m	<3m	N/A
51	12/22/2019 10:15	5.5	0.19	0.03	0.05	0.01	0.00	<3m	<3m	N/A
52	12/29/2019 20:45	36.25	2.09	0.06	0.17	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 2: BO-DI-1

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.5	1.13	0.32	0.84	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.25	0.71	0.03	0.19	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 16:30	17	1.07	0.06	0.46	0.04	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	22.25	2	0.09	0.41	0.08	0.04	<3m	3m	N/A
5	7/24/2019 2:15	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/31/2019 14:15	1.75	0.29	0.17	0.24	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:30	12.75	2.45	0.19	1.26	0.10	0.05	2.5 yr	6m	N/A
8	8/18/2019 0:15	0.5	0.12	0.24	0.12	0.01	0.00	<3m	<3m	N/A
9	8/18/2019 15:45	0.5	0.05	0.10	0.05	0.01	0.00	<3m	<3m	N/A
10	8/19/2019 15:30	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 15:00	11.75	1.2	0.10	0.61	0.05	0.03	3-6m	<3m	N/A
14	9/2/2019 16:15	2	0.74	0.37	0.67	0.03	0.00	3-6m	<3m	N/A
15	9/4/2019 17:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
16	9/7/2019 0:45	3	0.11	0.04	0.05	0.00	0.00	<3m	<3m	N/A
17	9/12/2019 6:45	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
18	9/14/2019 12:45	12.25	0.31	0.03	0.21	0.01	0.01	<3m	<3m	N/A
19	9/23/2019 22:45	2.5	0.23	0.09	0.22	0.01	0.00	<3m	<3m	N/A
20	9/26/2019 16:00	2.5	0.36	0.14	0.17	0.02	0.01	<3m	<3m	N/A
21	10/1/2019 5:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
22	10/2/2019 13:45	3	0.28	0.09	0.15	0.01	0.00	<3m	<3m	N/A
23	10/3/2019 22:00	9.75	0.13	0.01	0.05	0.01	0.01	<3m	<3m	N/A
24	10/7/2019 20:00	11	0.22	0.02	0.12	0.01	0.00	<3m	<3m	N/A
25	10/9/2019 16:00	17	0.12	0.01	0.06	0.01	0.01	<3m	<3m	N/A
26	10/11/2019 11:45	21.75	0.62	0.03	0.17	0.03	0.01	<3m	<3m	N/A
27	10/16/2019 20:30	11.75	1.85	0.16	0.7	0.08	0.04	6m	3m	N/A
28	10/22/2019 18:45	13	0.43	0.03	0.13	0.02	0.01	<3m	<3m	N/A
29	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
30	10/27/2019 9:00	10.75	1.69	0.16	0.54	0.07	0.04	3m	<3m	N/A
31	10/28/2019 10:00	16	0.06	0.00	0.02	0.07	0.04	<3m	<3m	N/A
32	10/29/2019 20:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
33	10/30/2019 17:30	30.25	0.2	0.01	0.01	0.00	0.00	<3m	<3m	N/A
34	11/1/2019 2:00	3	0.05	0.02	0.02	0.00	0.00	<3m	<3m	N/A
35	11/5/2019 11:15	10.75	0.45	0.04	0.3	0.02	0.01	<3m	<3m	N/A
36	11/7/2019 17:00	17.5	0.29	0.02	0.09	0.01	0.01	<3m	<3m	N/A
37	11/12/2019 11:00	2.5	0.1	0.04	0.05	0.00	0.00	<3m	<3m	N/A
38	11/18/2019 12:30	5	0.3	0.06	0.09	0.01	0.01	<3m	<3m	N/A
39	11/19/2019 5:30	2.75	0.21	0.08	0.11	0.02	0.01	<3m	<3m	N/A
40	11/20/2019 2:15	17.5	0.21	0.01	0.05	0.01	0.01	<3m	<3m	N/A
41	11/22/2019 13:45	1.75	0.08	0.05	0.06	0.00	0.00	<3m	<3m	N/A
42	11/24/2019 3:15	17.5	1.38	0.08	0.3	0.06	0.03	<3m	<3m	N/A
43	11/27/2019 17:15	19	0.32	0.02	0.14	0.01	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/1/2019 22:45	42	0.99	0.02	0.12	0.02	0.02	<3m	<3m	N/A
45	12/6/2019 15:30	1.25	0.02	0.02	0.01	0.00	0.00	<3m	<3m	N/A
46	12/9/2019 7:30	18.5	0.56	0.03	0.18	0.02	0.01	<3m	<3m	N/A
47	12/10/2019 14:15	20.5	0.47	0.02	0.07	0.02	0.02	<3m	<3m	N/A
48	12/13/2019 18:15	17.5	1.54	0.09	0.26	0.06	0.03	<3m	<3m	N/A
49	12/15/2019 12:45	0.25	0.01	0.04	0.01	0.00	0.03	<3m	<3m	N/A
50	12/17/2019 6:30	14.75	0.66	0.04	0.17	0.03	0.01	<3m	<3m	N/A
51	12/29/2019 21:30	35.75	1.91	0.05	0.16	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 3: BO-DI-2

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.5	1.42	0.41	1.14	0.06	0.03	2 yr	<3m	N/A
2	7/11/2019 23:30	21.75	0.9	0.04	0.3	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 15:00	18.5	1.28	0.07	0.52	0.05	0.03	<3m	<3m	N/A
4	7/22/2019 12:15	23.75	2.34	0.10	0.55	0.10	0.05	3m	6m	N/A
5	7/31/2019 14:00	2.25	1.69	0.75	1.61	0.07	0.04	6 yr	<3m	N/A
6	8/7/2019 13:45	13.25	2.05	0.15	0.87	0.09	0.04	6m-1yr	3-6m	N/A
7	8/18/2019 0:00	1.25	0.15	0.12	0.14	0.01	0.00	<3m	<3m	N/A
8	8/19/2019 16:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
9	8/21/2019 15:15	1	0.08	0.08	0.08	0.00	0.00	<3m	<3m	N/A
10	8/28/2019 15:15	10.5	1.26	0.12	0.48	0.05	0.03	<3m	<3m	N/A
11	9/2/2019 16:45	1.5	0.58	0.39	0.53	0.02	0.00	3m	<3m	N/A
12	9/3/2019 6:15	0.25	0.01	0.04	0.01	0.02	0.01	<3m	<3m	N/A
13	9/7/2019 0:30	3.5	0.1	0.03	0.05	0.00	0.00	<3m	<3m	N/A
14	9/12/2019 7:00	2	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
15	9/14/2019 13:00	11	0.36	0.03	0.28	0.02	0.01	<3m	<3m	N/A
16	9/23/2019 23:00	1.5	0.1	0.07	0.09	0.00	0.00	<3m	<3m	N/A
17	9/26/2019 16:15	3.25	0.29	0.09	0.13	0.01	0.01	<3m	<3m	N/A
18	10/1/2019 5:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
19	10/2/2019 10:15	6.5	0.32	0.05	0.19	0.01	0.00	<3m	<3m	N/A
20	10/3/2019 22:00	5.75	0.13	0.02	0.06	0.01	0.01	<3m	<3m	N/A
21	10/7/2019 20:15	3.25	0.18	0.06	0.12	0.01	0.00	<3m	<3m	N/A
22	10/9/2019 16:00	17.75	0.14	0.01	0.06	0.01	0.01	<3m	<3m	N/A
23	10/11/2019 10:45	23.5	0.73	0.03	0.22	0.03	0.02	<3m	<3m	N/A
24	10/16/2019 20:30	8.5	1.91	0.22	0.84	0.08	0.04	6m-1yr	3m	N/A
25	10/22/2019 18:30	13	0.54	0.04	0.24	0.02	0.01	<3m	<3m	N/A
26	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27	10/27/2019 9:00	11.75	1.48	0.13	0.48	0.06	0.03	<3m	<3m	N/A
28	10/28/2019 23:45	3	0.02	0.01	0.01	0.00	0.03	<3m	<3m	N/A
29	10/30/2019 17:15	29.25	0.17	0.01	0.05	0.00	0.00	<3m	<3m	N/A
30	11/1/2019 0:30	4.25	0.04	0.01	0.02	0.00	0.00	<3m	<3m	N/A
31	11/5/2019 13:00	3	0.37	0.12	0.28	0.02	0.01	<3m	<3m	N/A
32	11/7/2019 16:15	7	0.26	0.04	0.08	0.01	0.01	<3m	<3m	N/A
33	11/12/2019 11:30	2.5	0.07	0.03	0.04	0.00	0.00	<3m	<3m	N/A
34	11/18/2019 5:00	12.75	0.36	0.03	0.09	0.02	0.01	<3m	<3m	N/A
35	11/19/2019 5:45	6.75	0.26	0.04	0.13	0.02	0.01	<3m	<3m	N/A
36	11/20/2019 2:30	18.5	0.29	0.02	0.06	0.01	0.01	<3m	<3m	N/A
37	11/22/2019 14:00	1	0.04	0.04	0.04	0.00	0.00	<3m	<3m	N/A
38	11/24/2019 3:15	17.5	1.84	0.11	0.53	0.08	0.04	3m	3m	N/A
39	11/27/2019 17:15	18.5	0.29	0.02	0.18	0.01	0.01	<3m	<3m	N/A
40	12/1/2019 22:45	19.25	0.87	0.05	0.12	0.04	0.00	<3m	<3m	N/A
41	12/4/2019 17:30	18	0.36	0.02	0.08	0.02	0.01	<3m	<3m	N/A
42	12/6/2019 20:15	0.5	0.02	0.04	0.02	0.00	0.01	<3m	<3m	N/A
43	12/9/2019 7:15	18.5	0.51	0.03	0.16	0.02	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/10/2019 14:15	35.25	0.39	0.01	0.11	0.02	0.02	<3m	<3m	N/A
45	12/13/2019 9:45	25.75	1.5	0.06	0.27	0.06	0.03	<3m	<3m	N/A
46	12/14/2019 23:30	0.25	0.01	0.04	0.01	0.06	0.03	<3m	<3m	N/A
47	12/17/2019 17:30	2.25	0.2	0.09	0.14	0.01	0.00	<3m	<3m	N/A
48	12/18/2019 10:00	5	0.17	0.03	0.05	0.02	0.01	<3m	<3m	N/A
49	12/22/2019 11:00	7.25	0.16	0.02	0.04	0.01	0.00	<3m	<3m	N/A
50	12/23/2019 9:45	0.75	0.03	0.04	0.12	0.01	0.00	<3m	<3m	N/A
51	12/29/2019 20:30	36.75	2	0.05	0.12	0.07	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 4: Charlestown

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:00	3.5	1.49	0.43	1.08	0.06	0.03	1.5 yr	<3m	N/A
2	7/11/2019 23:45	21.25	0.61	0.03	0.17	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 13:45	17.75	0.75	0.04	0.7	0.03	0.02	6m	<3m	N/A
4	7/22/2019 12:30	22	1.77	0.08	0.34	0.07	0.04	<3m	3m	N/A
5	7/24/2019 3:45	0.25	0.01	0.04	0.01	0.03	0.04	<3m	<3m	N/A
6	7/31/2019 14:45	1.5	0.31	0.21	0.28	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:00	13.25	2.16	0.16	0.94	0.09	0.05	1 yr	3-6m	N/A
8	8/18/2019 0:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
9	8/21/2019 15:15	5.5	0.08	0.01	0.07	0.00	0.00	<3m	<3m	N/A
10	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	8/28/2019 15:15	11.75	1.13	0.10	0.6	0.05	0.02	3m	<3m	N/A
12	9/2/2019 16:00	2.25	1.14	0.51	0.96	0.05	0.00	1 yr	<3m	N/A
13	9/4/2019 17:45	0.5	0.39	0.78	0.39	0.02	0.02	<3m	<3m	N/A
14	9/7/2019 1:30	2.25	0.03	0.01	0.02	0.00	0.00	<3m	<3m	N/A
15	9/12/2019 6:45	2.5	0.09	0.04	0.07	0.00	0.00	<3m	<3m	N/A
16	9/14/2019 12:45	9.75	0.26	0.03	0.12	0.01	0.01	<3m	<3m	N/A
17	9/23/2019 23:00	2.25	0.17	0.08	0.15	0.01	0.00	<3m	<3m	N/A
18	9/26/2019 16:15	2.25	0.34	0.15	0.17	0.01	0.01	<3m	<3m	N/A
19	10/1/2019 5:00	0.75	0.03	0.04	0.03	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 12:45	3.75	0.24	0.06	0.09	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:45	5	0.12	0.02	0.05	0.01	0.01	<3m	<3m	N/A
22	10/7/2019 19:45	11.25	0.21	0.02	0.11	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 16:00	2	0.07	0.04	0.05	0.00	0.01	<3m	<3m	N/A
24	10/11/2019 11:45	14	0.5	0.04	0.11	0.02	0.01	<3m	<3m	N/A
25	10/16/2019 20:30	9	1.5	0.17	0.64	0.06	0.03	3-6m	<3m	N/A
26	10/22/2019 18:30	13	0.46	0.04	0.16	0.02	0.01	<3m	<3m	N/A
27	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 9:15	10.5	1.61	0.15	0.52	0.07	0.03	<3m	<3m	N/A
29	10/28/2019 19:00	8.75	0.1	0.01	0.04	0.00	0.04	<3m	<3m	N/A
30	10/30/2019 17:30	29.25	0.15	0.01	0.04	0.00	0.00	<3m	<3m	N/A
31	11/1/2019 0:15	4.5	0.09	0.02	0.06	0.00	0.00	<3m	<3m	N/A
32	11/5/2019 11:15	4.75	0.4	0.08	0.3	0.02	0.01	<3m	<3m	N/A
33	11/7/2019 16:15	6.75	0.28	0.04	0.1	0.01	0.01	<3m	<3m	N/A
34	11/12/2019 11:00	2.75	0.1	0.04	0.04	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 12:30	5	0.29	0.06	0.08	0.01	0.01	<3m	<3m	N/A
36	11/19/2019 5:30	7.5	0.25	0.03	0.11	0.02	0.01	<3m	<3m	N/A
37	11/20/2019 10:15	10	0.21	0.02	0.05	0.01	0.01	<3m	<3m	N/A
38	11/22/2019 13:45	1.5	0.12	0.08	0.09	0.01	0.00	<3m	<3m	N/A
39	11/24/2019 3:15	17.5	1.42	0.08	0.39	0.06	0.03	<3m	<3m	N/A
40	11/27/2019 17:15	17.5	0.3	0.02	0.12	0.01	0.01	<3m	<3m	N/A
41	12/1/2019 22:45	17.25	0.59	0.03	0.08	0.02	0.00	<3m	<3m	N/A
42	12/3/2019 12:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
43	12/4/2019 9:00	5	0.02	0.00	0.01	0.00	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/9/2019 8:15	18	0.52	0.03	0.17	0.02	0.01	<3m	<3m	N/A
45	12/10/2019 14:15	25	0.37	0.01	0.06	0.01	0.02	<3m	<3m	N/A
46	12/13/2019 18:15	22	1.4	0.06	0.22	0.06	0.03	<3m	<3m	N/A
47	12/17/2019 17:15	3	0.17	0.06	0.13	0.01	0.00	<3m	<3m	N/A
48	12/18/2019 9:30	5.5	0.23	0.04	0.07	0.02	0.01	<3m	<3m	N/A
49	12/21/2019 13:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
50	12/22/2019 10:30	1.75	0.07	0.04	0.05	0.00	0.00	<3m	<3m	N/A
51	12/29/2019 20:45	36.25	1.64	0.05	0.14	0.05	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 5: CH-BO-1

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:00	4	1.69	0.42	1.26	0.07	0.04	2.5 yr	<3m	N/A
2	7/12/2019 0:00	20.75	0.74	0.04	0.19	0.03	0.02	<3m	<3m	N/A
3	7/16/2019 11:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
4	7/17/2019 13:45	5.75	0.71	0.12	0.63	0.03	0.02	3-6m	<3m	N/A
5	7/22/2019 12:30	22.75	1.85	0.08	0.39	0.08	0.04	<3m	3m	N/A
6	7/31/2019 14:30	2	0.31	0.16	0.28	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:00	13.5	1.92	0.14	0.88	0.08	0.04	6m-1yr	3m	N/A
8	8/18/2019 0:45	0.25	0.02	0.08	0.02	0.00	0.00	<3m	<3m	N/A
9	8/21/2019 15:30	0.75	0.07	0.09	0.07	0.00	0.00	<3m	<3m	N/A
10	8/23/2019 6:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	8/28/2019 15:15	13	1.02	0.08	0.42	0.04	0.02	<3m	<3m	N/A
12	9/2/2019 16:30	1.75	0.93	0.53	0.8	0.04	0.00	6m-1yr	<3m	N/A
13	9/4/2019 17:45	0.5	0.35	0.70	0.35	0.01	0.02	<3m	<3m	N/A
14	9/7/2019 2:45	1.75	0.05	0.03	0.03	0.00	0.00	<3m	<3m	N/A
15	9/12/2019 6:45	2.5	0.12	0.05	0.11	0.01	0.00	<3m	<3m	N/A
16	9/14/2019 12:45	9.75	0.27	0.03	0.11	0.01	0.01	<3m	<3m	N/A
17	9/23/2019 23:00	2.25	0.2	0.09	0.17	0.01	0.00	<3m	<3m	N/A
18	9/26/2019 16:15	2.25	0.34	0.15	0.17	0.01	0.01	<3m	<3m	N/A
19	10/1/2019 5:00	0.75	0.04	0.05	0.04	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 12:45	3.75	0.29	0.08	0.13	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:45	5.5	0.17	0.03	0.07	0.01	0.01	<3m	<3m	N/A
22	10/7/2019 20:00	11.25	0.2	0.02	0.1	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 16:15	1.5	0.06	0.04	0.05	0.00	0.01	<3m	<3m	N/A
24	10/11/2019 11:45	20.25	0.46	0.02	0.11	0.02	0.01	<3m	<3m	N/A
25	10/16/2019 20:30	9	1.62	0.18	0.69	0.07	0.03	6m	<3m	N/A
26	10/22/2019 20:00	11.75	0.55	0.05	0.25	0.02	0.01	<3m	<3m	N/A
27	10/25/2019 23:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 9:15	11.75	1.34	0.11	0.47	0.06	0.03	<3m	<3m	N/A
29	10/28/2019 9:15	18.5	0.1	0.01	0.03	0.06	0.03	<3m	<3m	N/A
30	10/30/2019 17:30	27	0.11	0.00	0.04	0.00	0.00	<3m	<3m	N/A
31	11/1/2019 3:45	1	0.05	0.05	0.05	0.00	0.00	<3m	<3m	N/A
32	11/5/2019 11:15	5	0.39	0.08	0.26	0.02	0.01	<3m	<3m	N/A
33	11/7/2019 17:00	6	0.28	0.05	0.11	0.01	0.01	<3m	<3m	N/A
34	11/12/2019 11:00	2.5	0.09	0.04	0.05	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 12:15	5.25	0.29	0.06	0.08	0.01	0.01	<3m	<3m	N/A
36	11/19/2019 5:45	7.5	0.22	0.03	0.1	0.02	0.01	<3m	<3m	N/A
37	11/20/2019 9:45	9.5	0.24	0.03	0.06	0.01	0.01	<3m	<3m	N/A
38	11/22/2019 13:45	2.5	0.11	0.04	0.08	0.00	0.00	<3m	<3m	N/A
39	11/24/2019 3:30	17.25	1.54	0.09	0.44	0.06	0.03	<3m	<3m	N/A
40	11/27/2019 17:30	19	0.36	0.02	0.15	0.02	0.01	<3m	<3m	N/A
41	12/1/2019 22:45	44.75	0.89	0.02	0.07	0.02	0.02	<3m	<3m	N/A
42	12/4/2019 11:30	2.75	0.06	0.02	0.02	0.01	0.01	<3m	<3m	N/A
43	12/6/2019 15:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
44	12/9/2019 8:00	55	1.05	0.02	0.17	0.02	0.02	<3m	<3m	N/A
45	12/13/2019 8:45	27.25	1.41	0.05	0.24	0.06	0.03	<3m	<3m	N/A
46	12/17/2019 17:30	3	0.29	0.10	0.13	0.01	0.01	<3m	<3m	N/A
47	12/18/2019 9:45	4.25	0.13	0.03	0.05	0.02	0.01	<3m	<3m	N/A
48	12/22/2019 10:45	2	0.09	0.05	0.06	0.00	0.00	<3m	<3m	N/A
49	12/29/2019 21:00	36.5	1.91	0.05	0.16	0.06	0.03	<3m	<3m	N/A

Rain Gauge 6: Dorchester-Adams

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.75	1.13	0.30	0.87	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.5	0.98	0.05	0.22	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 15:00	18.5	1.11	0.06	0.44	0.05	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	23	2	0.09	0.46	0.08	0.04	<3m	3m	N/A
5	7/24/2019 4:30	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/29/2019 15:15	0.25	0.03	0.12	0.03	0.00	0.00	<3m	<3m	N/A
7	7/31/2019 14:00	2.25	0.46	0.20	0.43	0.02	0.01	<3m	<3m	N/A
8	8/7/2019 11:45	15.25	1.97	0.13	1.02	0.08	0.04	1.5 yr	3m	N/A
9	8/18/2019 0:15	2	0.11	0.06	0.1	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:15	0.75	0.1	0.13	0.1	0.00	0.00	<3m	<3m	N/A
11	8/23/2019 6:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
12	8/28/2019 15:00	11.75	1.15	0.10	0.47	0.05	0.02	<3m	<3m	N/A
13	9/2/2019 16:30	2.75	0.49	0.18	0.44	0.02	0.00	<3m	<3m	N/A
14	9/7/2019 0:30	10.5	0.15	0.01	0.06	0.01	0.00	<3m	<3m	N/A
15	9/12/2019 6:45	2.25	0.05	0.02	0.03	0.00	0.00	<3m	<3m	N/A
16	9/14/2019 13:00	10.75	0.28	0.03	0.2	0.01	0.01	<3m	<3m	N/A
17	9/23/2019 23:00	2.25	0.08	0.04	0.07	0.00	0.00	<3m	<3m	N/A
18	9/26/2019 16:15	2.25	0.31	0.14	0.15	0.01	0.01	<3m	<3m	N/A
19	10/1/2019 5:00	0.5	0.03	0.06	0.03	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 13:45	5.5	0.25	0.05	0.12	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:00	6.25	0.11	0.02	0.04	0.00	0.01	<3m	<3m	N/A
22	10/7/2019 20:00	10.75	0.2	0.02	0.12	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 11:30	22.25	0.15	0.01	0.04	0.01	0.01	<3m	<3m	N/A
24	10/11/2019 10:45	22.75	0.74	0.03	0.19	0.03	0.02	<3m	<3m	N/A
25	10/16/2019 20:15	8.75	2.02	0.23	0.85	0.08	0.04	6m-1yr	3m	N/A
26	10/22/2019 18:45	12.75	0.42	0.03	0.13	0.02	0.01	<3m	<3m	N/A
27	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 8:45	12	1.6	0.13	0.5	0.07	0.03	<3m	<3m	N/A
29	10/28/2019 10:45	14.75	0.03	0.00	0.01	0.06	0.03	<3m	<3m	N/A
30	10/30/2019 9:00	38.5	0.22	0.01	0.05	0.00	0.00	<3m	<3m	N/A
31	11/1/2019 0:15	4.75	0.09	0.02	0.03	0.00	0.00	<3m	<3m	N/A
32	11/5/2019 13:00	3	0.4	0.13	0.28	0.02	0.01	<3m	<3m	N/A
33	11/7/2019 16:15	7.5	0.28	0.04	0.08	0.01	0.01	<3m	<3m	N/A
34	11/12/2019 11:15	3.75	0.09	0.02	0.04	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 5:30	26.75	0.54	0.02	0.1	0.02	0.01	<3m	<3m	N/A
36	11/20/2019 2:00	17.25	0.24	0.01	0.04	0.01	0.01	<3m	<3m	N/A
37	11/22/2019 7:45	7.5	0.08	0.01	0.05	0.00	0.00	<3m	<3m	N/A
38	11/24/2019 3:00	17.75	1.54	0.09	0.36	0.06	0.03	<3m	<3m	N/A
39	11/27/2019 17:15	21	0.37	0.02	0.18	0.02	0.01	<3m	<3m	N/A
40	12/1/2019 22:45	17.5	1.22	0.07	0.14	0.05	0.00	<3m	<3m	N/A
41	12/4/2019 13:45	7.25	0.22	0.03	0.11	0.01	0.00	<3m	<3m	N/A
42	12/5/2019 9:45	2.25	0.1	0.04	0.06	0.01	0.01	<3m	<3m	N/A
43	12/9/2019 6:45	19.5	0.61	0.03	0.16	0.03	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/10/2019 14:15	23.75	0.38	0.02	0.08	0.02	0.02	<3m	<3m	N/A
45	12/13/2019 9:45	25.75	1.44	0.06	0.25	0.06	0.03	<3m	<3m	N/A
46	12/17/2019 17:30	2.25	0.2	0.09	0.14	0.01	0.00	<3m	<3m	N/A
47	12/18/2019 10:00	5	0.17	0.03	0.05	0.02	0.01	<3m	<3m	N/A
48	12/22/2019 11:00	7.25	0.16	0.02	0.04	0.01	0.00	<3m	<3m	N/A
49	12/23/2019 9:45	0.75	0.03	0.04	0.03	0.01	0.00	<3m	<3m	N/A
50	12/29/2019 20:30	36.75	2	0.05	0.15	0.07	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 7: Dorchester Talbot

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.75	1.13	0.30	0.87	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.5	0.98	0.05	0.22	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 15:00	18.5	1.11	0.06	0.44	0.05	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	23	2	0.09	0.46	0.08	0.04	<3m	3m	N/A
5	7/24/2019 4:30	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/29/2019 15:15	0.25	0.03	0.12	0.03	0.00	0.00	<3m	<3m	N/A
7	7/31/2019 14:00	2.25	0.46	0.20	0.43	0.02	0.01	<3m	<3m	N/A
8	8/7/2019 11:45	15.25	1.97	0.13	1.02	0.08	0.04	1.5 yr	3m	N/A
9	8/18/2019 0:15	2	0.11	0.06	0.1	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:15	0.75	0.1	0.13	0.1	0.00	0.00	<3m	<3m	N/A
11	8/23/2019 6:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
12	8/28/2019 15:00	11.75	1.15	0.10	0.47	0.05	0.02	<3m	<3m	N/A
13	9/2/2019 16:30	2.75	0.49	0.18	0.44	0.02	0.00	<3m	<3m	N/A
14	9/7/2019 0:30	10.5	0.15	0.01	0.06	0.01	0.00	<3m	<3m	N/A
15	9/12/2019 6:45	2.25	0.05	0.02	0.03	0.00	0.00	<3m	<3m	N/A
16	9/14/2019 13:00	10.75	0.28	0.03	0.2	0.01	0.01	<3m	<3m	N/A
17	9/23/2019 23:00	2.25	0.08	0.04	0.07	0.00	0.00	<3m	<3m	N/A
18	9/26/2019 16:15	2.25	0.31	0.14	0.15	0.01	0.01	<3m	<3m	N/A
19	10/1/2019 5:00	0.5	0.03	0.06	0.03	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 13:45	5.5	0.25	0.05	0.12	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:00	6.25	0.11	0.02	0.04	0.00	0.01	<3m	<3m	N/A
22	10/7/2019 20:00	10.75	0.2	0.02	0.12	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 11:30	22.25	0.15	0.01	0.04	0.01	0.01	<3m	<3m	N/A
24	10/11/2019 10:45	22.75	0.74	0.03	0.19	0.03	0.02	<3m	<3m	N/A
25	10/16/2019 20:15	8.75	2.02	0.23	0.85	0.08	0.04	6m-1yr	3m	N/A
26	10/22/2019 18:45	12.75	0.42	0.03	0.13	0.02	0.01	<3m	<3m	N/A
27	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 8:45	12	1.6	0.13	0.5	0.07	0.03	<3m	<3m	N/A
29	10/28/2019 10:45	14.75	0.03	0.00	0.01	0.06	0.03	<3m	<3m	N/A
30	10/30/2019 9:00	38.5	0.22	0.01	0.05	0.00	0.00	<3m	<3m	N/A
31	11/1/2019 0:15	4.75	0.09	0.02	0.03	0.00	0.00	<3m	<3m	N/A
32	11/5/2019 13:00	3	0.4	0.13	0.28	0.02	0.01	<3m	<3m	N/A
33	11/7/2019 16:15	7.5	0.28	0.04	0.08	0.01	0.01	<3m	<3m	N/A
34	11/12/2019 11:15	3.75	0.09	0.02	0.04	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 5:30	26.75	0.54	0.02	0.1	0.02	0.01	<3m	<3m	N/A
36	11/20/2019 2:00	17.25	0.24	0.01	0.04	0.01	0.01	<3m	<3m	N/A
37	11/22/2019 7:45	7.5	0.08	0.01	0.05	0.00	0.00	<3m	<3m	N/A
38	11/24/2019 3:00	17.75	1.54	0.09	0.36	0.06	0.03	<3m	<3m	N/A
39	11/27/2019 17:15	21	0.37	0.02	0.18	0.02	0.01	<3m	<3m	N/A
40	12/1/2019 22:45	17.5	1.22	0.07	0.14	0.05	0.00	<3m	<3m	N/A
41	12/4/2019 13:45	7.25	0.22	0.03	0.11	0.01	0.00	<3m	<3m	N/A
42	12/5/2019 9:45	2.25	0.1	0.04	0.06	0.01	0.01	<3m	<3m	N/A
43	12/9/2019 6:45	19.5	0.61	0.03	0.16	0.03	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/10/2019 14:15	23.75	0.38	0.02	0.08	0.02	0.02	<3m	<3m	N/A
45	12/13/2019 9:45	25.75	1.44	0.06	0.25	0.06	0.03	<3m	<3m	N/A
46	12/17/2019 17:30	2.25	0.2	0.09	0.14	0.01	0.00	<3m	<3m	N/A
47	12/18/2019 10:00	5	0.17	0.03	0.05	0.02	0.01	<3m	<3m	N/A
48	12/22/2019 11:00	7.25	0.16	0.02	0.04	0.01	0.00	<3m	<3m	N/A
49	12/23/2019 9:45	0.75	0.03	0.04	0.03	0.01	0.00	<3m	<3m	N/A
50	12/29/2019 20:30	36.75	2	0.05	0.15	0.07	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 8: East Boston

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
1	7/6/2019 16:00	3.75	1.68	0.45	1.24	0.07	0.04	2.5 yr	<3m	N/A
2	7/11/2019 23:45	21.25	0.69	0.03	0.2	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 13:45	5.75	0.82	0.14	0.72	0.03	0.02	6m	<3m	N/A
4	7/22/2019 12:30	22.5	1.99	0.09	0.44	0.08	0.04	<3m	3m	N/A
5	7/31/2019 14:30	1.75	0.44	0.25	0.41	0.02	0.01	<3m	<3m	N/A
6	8/7/2019 12:00	13.25	2.04	0.15	0.91	0.09	0.04	1 yr	3m	N/A
7	8/18/2019 0:30	0.5	0.05	0.10	0.05	0.00	0.00	<3m	<3m	N/A
8	8/18/2019 15:15	0.25	0.03	0.12	0.03	0.00	0.00	<3m	<3m	N/A
9	8/19/2019 15:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:30	0.75	0.07	0.09	0.07	0.00	0.00	<3m	<3m	N/A
11	8/23/2019 5:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
12	8/28/2019 15:15	11.75	1.06	0.09	0.46	0.04	0.02	<3m	<3m	N/A
13	9/2/2019 16:30	2	0.98	0.49	0.86	0.04	0.00	6m-1yr	<3m	N/A
14	9/4/2019 17:45	0.5	0.5	1.00	0.5	0.02	0.02	<3m	<3m	N/A
15	9/7/2019 2:45	1.25	0.04	0.03	0.03	0.00	0.00	<3m	<3m	N/A
16	9/12/2019 6:45	3.5	0.12	0.03	0.1	0.01	0.00	<3m	<3m	N/A
17	9/14/2019 12:45	9.75	0.21	0.02	0.12	0.01	0.00	<3m	<3m	N/A
18	9/23/2019 23:00	2.25	0.24	0.11	0.22	0.01	0.01	<3m	<3m	N/A
19	9/26/2019 16:15	2.25	0.33	0.15	0.17	0.01	0.01	<3m	<3m	N/A
20	10/1/2019 5:00	0.75	0.05	0.07	0.05	0.00	0.00	<3m	<3m	N/A
21	10/2/2019 12:45	4	0.28	0.07	0.11	0.01	0.00	<3m	<3m	N/A
22	10/3/2019 22:45	5.25	0.14	0.03	0.05	0.01	0.01	<3m	<3m	N/A
23	10/7/2019 20:00	11	0.2	0.02	0.11	0.01	0.00	<3m	<3m	N/A
24	10/9/2019 16:00	1.5	0.07	0.05	0.05	0.00	0.01	<3m	<3m	N/A
25	10/10/2019 7:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
26	10/11/2019 11:45	15.75	0.6	0.04	0.14	0.03	0.01	<3m	<3m	N/A
27	10/16/2019 20:30	7.75	1.79	0.23	0.76	0.07	0.04	6m-1yr	3m	N/A
28	10/22/2019 18:30	13.25	0.59	0.04	0.24	0.02	0.01	<3m	<3m	N/A
29	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
30	10/27/2019 9:15	10.75	1.65	0.15	0.53	0.07	0.03	3m	<3m	N/A
31	10/28/2019 10:45	17	0.11	0.01	0.03	0.07	0.04	<3m	<3m	N/A
32	10/30/2019 17:30	29.25	0.15	0.01	0.05	0.00	0.00	<3m	<3m	N/A
33	11/1/2019 0:30	4.25	0.07	0.02	0.04	0.00	0.00	<3m	<3m	N/A
34	11/5/2019 11:15	4.75	0.43	0.09	0.29	0.02	0.01	<3m	<3m	N/A
35	11/7/2019 17:00	6	0.26	0.04	0.1	0.01	0.01	<3m	<3m	N/A
36	11/12/2019 11:00	2.75	0.1	0.04	0.05	0.00	0.00	<3m	<3m	N/A
37	11/18/2019 6:30	11	0.3	0.03	0.08	0.01	0.01	<3m	<3m	N/A
38	11/19/2019 5:30	7	0.24	0.03	0.11	0.02	0.01	<3m	<3m	N/A
39	11/20/2019 3:00	17	0.25	0.01	0.05	0.01	0.01	<3m	<3m	N/A
40	11/22/2019 13:45	3.75	0.13	0.03	0.09	0.01	0.00	<3m	<3m	N/A
41	11/24/2019 3:30	17.25	1.78	0.10	0.52	0.07	0.04	<3m	3m	N/A
42	11/27/2019 17:15	18.75	0.37	0.02	0.15	0.02	0.01	<3m	<3m	N/A
43	12/1/2019 22:45	17.75	0.77	0.04	0.12	0.03	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
44	12/3/2019 19:00	0.25	0.01	0.04	0.01	0.00	0.02	<3m	<3m	N/A
45	12/4/2019 11:30	2.5	0.15	0.06	0.07	0.01	0.01	<3m	<3m	N/A
46	12/6/2019 20:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
47	12/9/2019 7:00	18.75	0.54	0.03	0.17	0.02	0.01	<3m	<3m	N/A
48	12/10/2019 14:15	24.75	0.45	0.02	0.1	0.02	0.02	<3m	<3m	N/A
49	12/13/2019 8:45	27.25	1.41	0.05	0.24	0.06	0.03	<3m	<3m	N/A
50	12/17/2019 17:30	3	0.29	0.10	0.13	0.01	0.01	<3m	<3m	N/A
51	12/18/2019 9:45	4.25	0.13	0.03	0.05	0.02	0.01	<3m	<3m	N/A
52	12/22/2019 10:45	2	0.09	0.05	0.06	0.00	0.00	<3m	<3m	N/A
53	12/29/2019 21:00	36.5	1.91	0.05	0.16	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 9: HF-1C

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 15:15	3.75	0.91	0.24	0.31	0.02	0.01	<3m	<3m	N/A
2	7/11/2019 23:30	15.25	1.88	0.12	0.41	0.05	0.02	<3m	<3m	N/A
3	7/17/2019 16:30	0.75	0.12	0.16	0.13	0.01	0.00	<3m	<3m	N/A
4	7/22/2019 17:45	16.25	2.04	0.13	0.41	0.08	0.04	<3m	3m	N/A
5	7/31/2019 16:15	0.25	0.04	0.16	0.03	0.01	0.00	<3m	<3m	N/A
6	8/1/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
7	8/7/2019 12:45	12.25	2.09	0.17	0.88	0.09	0.04	6m-1yr	3-6m	N/A
8	8/17/2019 22:30	1	0.08	0.08	0.08	0.00	0.00	<3m	<3m	N/A
9	8/21/2019 15:15	10.75	0.06	0.01	0.05	0.00	0.00	<3m	<3m	N/A
10	8/28/2019 14:45	15.75	1.41	0.09	0.62	0.06	0.03	3-6m	<3m	N/A
11	9/2/2019 15:30	9.25	1.17	0.13	0.99	0.05	0.02	1 yr	<3m	N/A
12	9/4/2019 17:30	0.5	0.24	0.48	0.24	0.01	0.01	<3m	<3m	N/A
13	9/7/2019 1:00	2.5	0.16	0.06	0.1	0.01	0.00	<3m	<3m	N/A
14	9/12/2019 6:30	6	0.17	0.03	0.12	0.01	0.00	<3m	<3m	N/A
15	9/14/2019 12:30	11.5	0.18	0.02	0.1	0.01	0.00	<3m	<3m	N/A
16	9/23/2019 23:30	2	0.05	0.03	0.04	0.00	0.00	<3m	<3m	N/A
17	9/26/2019 16:00	12.5	0.38	0.03	0.21	0.02	0.01	<3m	<3m	N/A
18	10/1/2019 4:45	1.25	0.04	0.03	0.03	0.00	0.00	<3m	<3m	N/A
19	10/2/2019 13:00	5.5	0.33	0.06	0.13	0.01	0.00	<3m	<3m	N/A
20	10/3/2019 22:00	7.25	0.2	0.03	0.08	0.01	0.01	<3m	<3m	N/A
21	10/7/2019 19:45	11.25	0.21	0.02	0.11	0.01	0.00	<3m	<3m	N/A
22	10/9/2019 16:15	14.5	0.08	0.01	0.03	0.00	0.01	<3m	<3m	N/A
23	10/11/2019 12:00	21.5	0.48	0.02	0.13	0.02	0.01	<3m	<3m	N/A
24	10/16/2019 20:15	9.25	2.49	0.27	1.2	0.10	0.05	2 yr	6m-1yr	N/A
25	10/20/2019 21:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
26	10/22/2019 17:45	13.75	0.66	0.05	0.34	0.03	0.01	<3m	<3m	N/A
27	10/26/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 9:15	12	1.71	0.14	0.51	0.07	0.04	<3m	<3m	N/A
29	10/28/2019 20:30	8	0.12	0.02	0.04	0.01	0.04	<3m	<3m	N/A
30	10/29/2019 19:30	9.75	0.03	0.00	0.01	0.01	0.00	<3m	<3m	N/A
31	10/30/2019 17:30	30.25	0.25	0.01	0.02	0.00	0.00	<3m	<3m	N/A
32	11/1/2019 0:15	5.25	0.13	0.02	0.09	0.00	0.00	<3m	<3m	N/A
33	11/5/2019 12:00	13.25	0.48	0.04	0.34	0.02	0.01	<3m	<3m	N/A
34	11/7/2019 16:15	6.75	0.37	0.05	0.11	0.02	0.01	<3m	<3m	N/A
35	11/12/2019 11:15	2.25	0.09	0.04	0.04	0.00	0.00	<3m	<3m	N/A
36	11/18/2019 13:30	23.25	0.4	0.02	0.11	0.02	0.01	<3m	<3m	N/A
37	11/20/2019 7:15	12.5	0.21	0.02	0.06	0.01	0.01	<3m	<3m	N/A
38	11/21/2019 8:00	0.25	0.01	0.04	0.01	0.01	0.01	<3m	<3m	N/A
39	11/22/2019 0:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
40	11/22/2019 13:45	1.75	0.12	0.07	0.09	0.01	0.00	<3m	<3m	N/A
41	11/24/2019 3:30	17.5	1.32	0.08	0.32	0.06	0.03	<3m	<3m	N/A
42	11/27/2019 17:15	19.75	0.38	0.02	0.12	0.02	0.01	<3m	<3m	N/A
43	12/2/2019 2:45	11.75	0.87	0.07	0.19	0.04	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/3/2019 12:15	2.25	0.07	0.03	0.04	0.00	0.02	<3m	<3m	N/A
45	12/4/2019 9:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
46	12/7/2019 9:00	0.75	0.05	0.07	0.05	0.00	0.00	<3m	<3m	N/A
47	12/9/2019 6:00	18.75	0.62	0.03	0.17	0.03	0.01	<3m	<3m	N/A
48	12/10/2019 14:15	24	0.48	0.02	0.16	0.02	0.02	<3m	<3m	N/A
49	12/13/2019 18:00	24	1.37	0.06	0.23	0.06	0.03	<3m	<3m	N/A
50	12/18/2019 9:30	2.75	0.46	0.17	0.21	0.02	0.01	<3m	<3m	N/A
51	12/29/2019 20:15	37	2.17	0.06	0.13	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 10: Hyde Park

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:30	3	1.31	0.44	1.15	0.05	0.03	2 yr	<3m	N/A
2	7/11/2019 23:15	22.25	1.07	0.05	0.35	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 14:45	4.75	1.02	0.21	0.84	0.04	0.02	6m-1yr	<3m	N/A
4	7/18/2019 7:30	1.75	0.1	0.06	0.09	0.05	0.02	<3m	<3m	N/A
5	7/22/2019 12:15	23	2.65	0.12	0.67	0.11	0.06	3-6m	6m-1yr	N/A
6	7/29/2019 15:15	0.25	0.05	0.20	0.05	0.00	0.00	<3m	<3m	N/A
7	7/31/2019 14:15	1.75	0.51	0.29	0.32	0.02	0.01	<3m	<3m	N/A
8	8/7/2019 13:15	11.75	2.16	0.18	1.24	0.09	0.05	2.5 yr	3-6m	N/A
9	8/19/2019 16:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:00	1	0.12	0.12	0.12	0.01	0.00	<3m	<3m	N/A
11	8/23/2019 5:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
12	8/28/2019 14:45	12	1.17	0.10	0.43	0.05	0.02	<3m	<3m	N/A
13	9/2/2019 17:00	2.5	0.44	0.18	0.42	0.02	0.00	<3m	<3m	N/A
14	9/7/2019 0:00	4.25	0.29	0.07	0.1	0.01	0.01	<3m	<3m	N/A
15	9/12/2019 7:00	1.75	0.06	0.03	0.05	0.00	0.00	<3m	<3m	N/A
16	9/13/2019 4:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
17	9/14/2019 13:15	10.5	0.15	0.01	0.09	0.01	0.00	<3m	<3m	N/A
18	9/24/2019 0:00	1.25	0.02	0.02	0.01	0.00	0.00	<3m	<3m	N/A
19	9/26/2019 16:15	14	0.31	0.02	0.19	0.01	0.01	<3m	<3m	N/A
20	10/1/2019 5:00	0.5	0.03	0.06	0.03	0.00	0.00	<3m	<3m	N/A
21	10/2/2019 13:45	6.75	0.54	0.08	0.39	0.02	0.00	<3m	<3m	N/A
22	10/3/2019 20:45	7.5	0.1	0.01	0.04	0.00	0.01	<3m	<3m	N/A
23	10/7/2019 20:15	10.5	0.19	0.02	0.14	0.01	0.00	<3m	<3m	N/A
24	10/9/2019 11:15	22.5	0.25	0.01	0.05	0.01	0.01	<3m	<3m	N/A
25	10/11/2019 7:45	26.75	1.29	0.05	0.16	0.05	0.03	<3m	<3m	N/A
26	10/16/2019 20:00	8.75	2.06	0.24	0.93	0.09	0.04	1 yr	3-6m	N/A
27	10/20/2019 22:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/22/2019 18:30	13	0.42	0.03	0.11	0.02	0.01	<3m	<3m	N/A
29	10/25/2019 23:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
30	10/27/2019 5:15	15.5	1.52	0.10	0.49	0.06	0.03	<3m	<3m	N/A
31	10/28/2019 17:15	8	0.06	0.01	0.02	0.01	0.03	<3m	<3m	N/A
32	10/29/2019 19:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
33	10/30/2019 17:00	30.75	0.3	0.01	0.03	0.00	0.00	<3m	<3m	N/A
34	11/1/2019 0:15	4.5	0.11	0.02	0.04	0.00	0.00	<3m	<3m	N/A
35	11/5/2019 11:00	11	0.4	0.04	0.25	0.02	0.01	<3m	<3m	N/A
36	11/7/2019 16:15	7.75	0.3	0.04	0.08	0.01	0.01	<3m	<3m	N/A
37	11/12/2019 11:00	3.5	0.11	0.03	0.05	0.00	0.00	<3m	<3m	N/A
38	11/18/2019 5:00	32.25	0.65	0.02	0.11	0.02	0.01	<3m	<3m	N/A
39	11/20/2019 2:15	19.25	0.29	0.02	0.04	0.01	0.01	<3m	<3m	N/A
40	11/22/2019 13:45	1.75	0.12	0.07	0.08	0.01	0.00	<3m	<3m	N/A
41	11/24/2019 3:00	17.75	1.66	0.09	0.35	0.07	0.03	<3m	<3m	N/A
42	11/27/2019 17:15	19.25	0.37	0.02	0.2	0.02	0.01	<3m	<3m	N/A
43	12/1/2019 22:45	18	1.43	0.08	0.21	0.06	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/3/2019 12:00	3.75	0.1	0.03	0.05	0.01	0.03	<3m	<3m	N/A
45	12/4/2019 10:15	1.25	0.05	0.04	0.04	0.01	0.01	<3m	<3m	N/A
46	12/7/2019 9:45	3.5	0.02	0.01	0.01	0.00	0.00	<3m	<3m	N/A
47	12/9/2019 6:30	19.5	0.65	0.03	0.14	0.03	0.01	<3m	<3m	N/A
48	12/10/2019 14:00	23.5	0.61	0.03	0.24	0.03	0.02	<3m	<3m	N/A
49	12/13/2019 17:45	17.75	1.4	0.08	0.21	0.06	0.03	<3m	<3m	N/A
50	12/17/2019 15:45	4.75	0.44	0.09	0.14	0.02	0.01	<3m	<3m	N/A
51	12/18/2019 11:00	3.25	0.37	0.11	0.18	0.03	0.02	<3m	<3m	N/A
52	12/29/2019 20:45	36.75	1.88	0.05	0.14	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 11: Lexington Farm

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
1	7/6/2019 15:45	12.25	0.57	0.05	0.31	0.02	0.01	<3m	<3m	N/A
2	7/11/2019 23:45	15.5	1.16	0.07	0.41	0.05	0.02	<3m	<3m	N/A
3	7/17/2019 16:30	6	0.15	0.03	0.13	0.01	0.00	<3m	<3m	N/A
4	7/22/2019 18:30	15.75	1.84	0.12	0.41	0.08	0.04	<3m	3m	N/A
5	7/24/2019 4:45	0.25	0.01	0.04	0.01	0.03	0.04	<3m	<3m	N/A
6	7/31/2019 15:00	1.25	0.23	0.18	0.22	0.01	0.00	<3m	<3m	N/A
7	8/1/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
8	8/7/2019 12:45	12.25	2.09	0.17	0.88	0.09	0.04	6m-1yr	3-6m	N/A
9	8/17/2019 22:30	1	0.08	0.08	0.08	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:15	10.75	0.06	0.01	0.05	0.00	0.00	<3m	<3m	N/A
11	8/28/2019 14:45	15.75	1.41	0.09	0.62	0.06	0.03	3-6m	<3m	N/A
12	9/2/2019 15:30	9.25	1.17	0.13	0.99	0.05	0.02	1 yr	<3m	N/A
13	9/4/2019 17:30	0.5	0.24	0.48	0.24	0.01	0.01	<3m	<3m	N/A
14	9/7/2019 1:00	2.5	0.16	0.06	0.1	0.01	0.00	<3m	<3m	N/A
15	9/12/2019 6:30	6	0.17	0.03	0.12	0.01	0.00	<3m	<3m	N/A
16	9/14/2019 12:30	11.5	0.18	0.02	0.1	0.01	0.00	<3m	<3m	N/A
17	9/23/2019 23:30	2	0.05	0.03	0.04	0.00	0.00	<3m	<3m	N/A
18	9/26/2019 16:00	12.5	0.38	0.03	0.21	0.02	0.01	<3m	<3m	N/A
19	10/1/2019 4:45	1.25	0.04	0.03	0.03	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 13:00	5.5	0.33	0.06	0.13	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:00	7.25	0.2	0.03	0.08	0.01	0.01	<3m	<3m	N/A
22	10/7/2019 19:45	11.25	0.21	0.02	0.11	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 16:15	14.5	0.08	0.01	0.03	0.00	0.01	<3m	<3m	N/A
24	10/11/2019 12:00	21.5	0.48	0.02	0.13	0.02	0.01	<3m	<3m	N/A
25	10/16/2019 20:15	9.25	2.49	0.27	1.2	0.10	0.05	2 yr	6m-1yr	N/A
26	10/20/2019 21:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27	10/22/2019 17:45	13.75	0.66	0.05	0.34	0.03	0.01	<3m	<3m	N/A
28	10/26/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
29	10/27/2019 9:15	12	1.71	0.14	0.54	0.07	0.03	3m	<3m	N/A
30	10/28/2019 20:30	8	0.12	0.02	0.01	0.00	0.04	<3m	<3m	N/A
31	10/29/2019 19:30	9.75	0.03	0.00	1.07	0.00	0.00	1.5 yr	<3m	N/A
32	10/30/2019 17:30	30.25	0.25	0.01	0.03	0.00	0.00	<3m	<3m	N/A
33	11/1/2019 0:15	5.25	0.13	0.02	0.09	0.00	0.00	<3m	<3m	N/A
34	11/5/2019 12:00	13.25	0.48	0.04	0.34	0.02	0.01	<3m	<3m	N/A
35	11/7/2019 16:15	6.75	0.37	0.05	0.11	0.02	0.01	<3m	<3m	N/A
36	11/12/2019 11:15	2.25	0.09	0.04	0.04	0.00	0.00	<3m	<3m	N/A
37	11/18/2019 13:30	23.25	0.4	0.02	0.11	0.02	0.01	<3m	<3m	N/A
38	11/20/2019 7:15	12.5	0.21	0.02	0.06	0.01	0.01	<3m	<3m	N/A
39	11/21/2019 8:00	0.25	0.01	0.04	0.01	0.01	0.01	<3m	<3m	N/A
40	11/22/2019 0:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
41	11/22/2019 13:45	1.75	0.12	0.07	0.09	0.01	0.00	<3m	<3m	N/A
42	11/24/2019 3:30	17.5	1.32	0.08	0.32	0.06	0.03	<3m	<3m	N/A
43	11/27/2019 17:15	19.75	0.38	0.02	0.11	0.01	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/2/2019 2:45	11.75	0.87	0.07	0.19	0.04	0.00	<3m	<3m	N/A
45	12/3/2019 12:15	2.25	0.07	0.03	0.04	0.00	0.02	<3m	<3m	N/A
46	12/4/2019 9:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
47	12/7/2019 9:00	0.75	0.05	0.07	0.05	0.00	0.00	<3m	<3m	N/A
48	12/9/2019 6:00	18.75	0.62	0.03	0.17	0.03	0.01	<3m	<3m	N/A
49	12/10/2019 14:15	24	0.48	0.02	0.16	0.02	0.02	<3m	<3m	N/A
50	12/13/2019 18:00	24	1.37	0.06	0.23	0.06	0.03	<3m	<3m	N/A
51	12/18/2019 9:30	2.75	0.46	0.17	0.21	0.02	0.01	<3m	<3m	N/A
52	12/29/2019 20:15	37	2.17	0.06	0.13	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 12: Longwood

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.5	1.13	0.32	0.84	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.25	0.71	0.03	0.19	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 16:30	17	1.07	0.06	0.46	0.04	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	22.25	2	0.09	0.41	0.08	0.04	<3m	3m	N/A
5	7/24/2019 2:15	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/31/2019 14:15	1.75	0.29	0.17	0.24	0.01	0.01	<3m	<3m	N/A
7	8/7/2019 12:30	12.75	2.45	0.19	1.26	0.10	0.05	2.5 yr	6m	N/A
8	8/18/2019 0:15	0.5	0.12	0.24	0.12	0.01	0.00	<3m	<3m	N/A
9	8/18/2019 15:45	0.5	0.05	0.10	0.05	0.01	0.00	<3m	<3m	N/A
10	8/19/2019 15:30	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 15:00	11.75	1.2	0.10	0.61	0.05	0.03	3-6m	<3m	N/A
14	9/2/2019 16:15	2	0.74	0.37	0.67	0.03	0.00	3-6m	<3m	N/A
15	9/4/2019 17:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
16	9/7/2019 0:45	3	0.11	0.04	0.05	0.00	0.00	<3m	<3m	N/A
17	9/12/2019 6:45	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
18	9/14/2019 12:45	12.25	0.31	0.03	0.21	0.01	0.01	<3m	<3m	N/A
19	9/23/2019 22:45	2.5	0.23	0.09	0.22	0.01	0.00	<3m	<3m	N/A
20	9/26/2019 16:00	2.5	0.36	0.14	0.17	0.02	0.01	<3m	<3m	N/A
21	10/1/2019 5:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
22	10/2/2019 13:45	3.25	0.28	0.09	0.16	0.01	0.00	<3m	<3m	N/A
23	10/3/2019 22:30	10.5	0.12	0.01	0.05	0.01	0.01	<3m	<3m	N/A
24	10/7/2019 19:45	11.25	0.23	0.02	0.12	0.01	0.00	<3m	<3m	N/A
25	10/9/2019 16:00	15.25	0.11	0.01	0.05	0.00	0.01	<3m	<3m	N/A
26	10/11/2019 11:15	21.75	0.64	0.03	0.15	0.03	0.01	<3m	<3m	N/A
27	10/16/2019 20:15	9	1.86	0.21	0.74	0.08	0.04	6m-1yr	3m	N/A
28	10/22/2019 18:45	12.75	0.44	0.03	0.12	0.02	0.01	<3m	<3m	N/A
29	10/27/2019 8:45	11	1.58	0.14	0.49	0.07	0.03	<3m	<3m	N/A
30	10/28/2019 10:00	17.25	0.06	0.00	0.02	0.06	0.03	<3m	<3m	N/A
31	10/30/2019 17:15	29.5	0.2	0.01	0.04	0.00	0.00	<3m	<3m	N/A
32	11/1/2019 0:30	4.5	0.07	0.02	0.03	0.00	0.00	<3m	<3m	N/A
33	11/5/2019 11:00	5	0.43	0.09	0.29	0.02	0.01	<3m	<3m	N/A
34	11/7/2019 16:30	6.5	0.29	0.04	0.11	0.01	0.01	<3m	<3m	N/A
35	11/12/2019 11:00	2.25	0.1	0.04	0.06	0.00	0.00	<3m	<3m	N/A
36	11/18/2019 12:30	24.75	0.59	0.02	0.11	0.02	0.01	<3m	<3m	N/A
37	11/20/2019 3:15	15.75	0.2	0.01	0.04	0.01	0.01	<3m	<3m	N/A
38	11/22/2019 0:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
39	11/22/2019 13:45	1.75	0.08	0.05	0.06	0.00	0.00	<3m	<3m	N/A
40	11/24/2019 3:15	17.25	1.34	0.08	0.34	0.06	0.03	<3m	<3m	N/A
41	11/27/2019 17:15	18.75	0.29	0.02	0.11	0.01	0.01	<3m	<3m	N/A
42	12/1/2019 22:45	17	0.88	0.05	0.17	0.04	0.00	<3m	<3m	N/A
43	12/3/2019 12:45	0.25	0.01	0.04	0.01	0.01	0.02	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/4/2019 16:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
45	12/6/2019 19:15	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
46	12/9/2019 7:15	18.25	0.55	0.03	0.17	0.02	0.01	<3m	<3m	N/A
47	12/10/2019 14:00	25.25	0.41	0.02	0.08	0.02	0.02	<3m	<3m	N/A
48	12/13/2019 9:30	33.75	1.51	0.04	0.25	0.06	0.03	<3m	<3m	N/A
49	12/17/2019 16:45	3.75	0.14	0.04	0.11	0.01	0.00	<3m	<3m	N/A
50	12/18/2019 9:30	5.5	0.12	0.02	0.04	0.01	0.01	<3m	<3m	N/A
51	12/22/2019 11:00	6	0.17	0.03	0.04	0.01	0.00	<3m	<3m	N/A
52	12/29/2019 21:00	36	2.06	0.06	0.16	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 13: RG-WF-1

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
1	7/6/2019 15:30	3.75	1.02	0.27	0.73	0.04	0.02	6m	<3m	N/A
2	7/12/2019 0:00	20.25	1.27	0.06	0.52	0.05	0.03	<3m	<3m	N/A
3	7/17/2019 16:45	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
4	7/22/2019 12:45	21.75	1.63	0.07	0.37	0.07	0.03	<3m	<3m	N/A
5	7/31/2019 15:15	1.5	0.1	0.07	0.09	0.00	0.00	<3m	<3m	N/A
6	8/4/2019 16:45	0.5	0.05	0.10	0.05	0.00	0.00	<3m	<3m	N/A
7	8/7/2019 13:00	12.25	2.07	0.17	0.91	0.09	0.04	1 yr	3-6m	N/A
8	8/17/2019 22:30	0.75	0.14	0.19	0.14	0.01	0.00	<3m	<3m	N/A
9	8/21/2019 15:15	0.75	0.02	0.03	0.02	0.00	0.00	<3m	<3m	N/A
10	8/28/2019 15:15	9.25	1.26	0.14	0.76	0.05	0.03	6m-1yr	<3m	N/A
11	9/2/2019 15:30	2.25	0.74	0.33	0.5	0.03	0.00	<3m	<3m	N/A
12	9/4/2019 17:30	0.25	0.02	0.08	0.02	0.00	0.00	<3m	<3m	N/A
13	9/7/2019 0:45	2	0.07	0.04	0.04	0.00	0.00	<3m	<3m	N/A
14	9/14/2019 12:30	11.25	0.22	0.02	0.11	0.01	0.00	<3m	<3m	N/A
15	9/24/2019 1:00	1	0.03	0.03	0.03	0.00	0.00	<3m	<3m	N/A
16	9/26/2019 16:00	2.75	0.33	0.12	0.21	0.01	0.01	<3m	<3m	N/A
17	10/1/2019 5:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
18	10/2/2019 10:15	6.5	0.32	0.05	0.19	0.01	0.00	<3m	<3m	N/A
19	10/3/2019 22:00	5.75	0.13	0.02	0.06	0.01	0.01	<3m	<3m	N/A
20	10/7/2019 20:15	3.25	0.18	0.06	0.12	0.01	0.00	<3m	<3m	N/A
21	10/9/2019 16:00	17.75	0.14	0.01	0.06	0.01	0.01	<3m	<3m	N/A
22	10/11/2019 10:45	23.5	0.73	0.03	0.22	0.03	0.02	<3m	<3m	N/A
23	10/16/2019 20:30	8.5	1.91	0.22	0.84	0.08	0.04	6m-1yr	3m	N/A
24	10/22/2019 18:30	13	0.54	0.04	0.24	0.02	0.01	<3m	<3m	N/A
25	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
26	10/27/2019 9:00	11.75	1.48	0.13	0.48	0.06	0.03	<3m	<3m	N/A
27	10/28/2019 23:45	3	0.02	0.01	0.01	0.00	0.03	<3m	<3m	N/A
28	10/30/2019 17:15	29.25	0.17	0.01	0.05	0.00	0.00	<3m	<3m	N/A
29	11/1/2019 0:30	4.25	0.04	0.01	0.02	0.00	0.00	<3m	<3m	N/A
30	11/5/2019 13:00	3	0.37	0.12	0.28	0.02	0.01	<3m	<3m	N/A
31	11/7/2019 16:15	7	0.26	0.04	0.08	0.01	0.01	<3m	<3m	N/A
32	11/12/2019 11:30	2.5	0.07	0.03	0.04	0.00	0.00	<3m	<3m	N/A
33	11/18/2019 5:00	12.75	0.36	0.03	0.09	0.02	0.01	<3m	<3m	N/A
34	11/19/2019 5:45	6.75	0.26	0.04	0.13	0.02	0.01	<3m	<3m	N/A
35	11/20/2019 2:30	18.5	0.29	0.02	0.06	0.01	0.01	<3m	<3m	N/A
36	11/22/2019 14:00	1	0.04	0.04	0.04	0.00	0.00	<3m	<3m	N/A
37	11/24/2019 3:15	17.5	1.84	0.11	0.53	0.08	0.04	3m	3m	N/A
38	11/27/2019 17:15	18.5	0.29	0.02	0.18	0.01	0.01	<3m	<3m	N/A
39	12/2/2019 5:30	10.75	0.52	0.05	0.18	0.02	0.00	<3m	<3m	N/A
40	12/3/2019 9:00	8	0.06	0.01	0.02	0.01	0.01	<3m	<3m	N/A
41	12/4/2019 10:15	31	0.63	0.02	0.17	0.02	0.01	<3m	<3m	N/A
42	12/6/2019 9:15	0.25	0.01	0.04	0.01	0.02	0.01	<3m	<3m	N/A
43	12/7/2019 12:00	2	0.06	0.03	0.04	0.00	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
44	12/8/2019 11:00	38	0.57	0.02	0.17	0.02	0.01	<3m	<3m	N/A
45	12/10/2019 14:30	24.5	0.45	0.02	0.09	0.02	0.02	<3m	<3m	N/A
46	12/12/2019 9:15	4.75	0.03	0.01	0.02	0.01	0.01	<3m	<3m	N/A
47	12/13/2019 10:30	32.75	1.42	0.04	0.3	0.06	0.03	<3m	<3m	N/A
48	12/18/2019 12:45	5.25	0.15	0.03	0.07	0.01	0.00	<3m	<3m	N/A
49	12/21/2019 12:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
50	12/22/2019 10:15	3.75	0.17	0.05	0.06	0.01	0.00	<3m	<3m	N/A
51	12/29/2019 20:30	37	1.49	0.04	0.14	0.05	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 14: Roslindale

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:30	3.25	1.28	0.39	1.08	0.05	0.03	1.5 yr	<3m	N/A
2	7/11/2019 23:30	25.5	1.14	0.04	0.32	0.05	0.02	<3m	<3m	N/A
3	7/17/2019 15:00	18.5	0.81	0.04	0.33	0.03	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	23	2.38	0.10	0.5	0.10	0.05	<3m	6m	N/A
5	7/24/2019 4:30	0.25	0.01	0.04	0.01	0.05	0.05	<3m	<3m	N/A
6	7/29/2019 15:15	0.25	0.21	0.84	0.21	0.01	0.00	<3m	<3m	N/A
7	7/31/2019 14:00	2.25	0.3	0.13	0.22	0.01	0.01	<3m	<3m	N/A
8	8/7/2019 11:30	16	2.93	0.18	1.46	0.12	0.06	4 yr	1 yr	N/A
9	8/18/2019 0:00	1.5	0.12	0.08	0.11	0.01	0.00	<3m	<3m	N/A
10	8/19/2019 16:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.11	0.11	0.11	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 14:45	12.25	1.37	0.11	0.58	0.06	0.03	3m	<3m	N/A
14	9/2/2019 16:30	4.5	0.4	0.09	0.37	0.02	0.00	<3m	<3m	N/A
15	9/6/2019 23:15	5	0.24	0.05	0.08	0.01	0.01	<3m	<3m	N/A
16	9/12/2019 6:45	3.75	0.05	0.01	0.03	0.00	0.00	<3m	<3m	N/A
17	9/14/2019 13:00	9.75	0.15	0.02	0.11	0.01	0.00	<3m	<3m	N/A
18	9/24/2019 0:00	1	0.05	0.05	0.05	0.00	0.00	<3m	<3m	N/A
19	9/24/2019 17:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
20	9/26/2019 16:15	9.75	0.39	0.04	0.19	0.02	0.01	<3m	<3m	N/A
21	10/1/2019 5:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
22	10/2/2019 13:45	5.5	0.33	0.06	0.18	0.01	0.00	<3m	<3m	N/A
23	10/3/2019 20:15	6.5	0.1	0.02	0.04	0.00	0.01	<3m	<3m	N/A
24	10/7/2019 20:15	11	0.22	0.02	0.15	0.01	0.00	<3m	<3m	N/A
25	10/9/2019 11:45	22.25	0.2	0.01	0.05	0.01	0.01	<3m	<3m	N/A
26	10/11/2019 8:30	25.5	1.05	0.04	0.19	0.04	0.02	<3m	<3m	N/A
27	10/16/2019 20:15	8.75	2.42	0.28	1.03	0.10	0.05	1.5 yr	6m	N/A
28	10/20/2019 22:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
29	10/22/2019 18:30	13	0.47	0.04	0.13	0.02	0.01	<3m	<3m	N/A
30	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
31	10/27/2019 6:00	18.5	1.69	0.09	0.54	0.07	0.04	3m	<3m	N/A
32	10/28/2019 17:45	8.75	0.05	0.01	0.02	0.01	0.04	<3m	<3m	N/A
33	10/30/2019 17:00	30.25	0.28	0.01	0.06	0.01	0.00	<3m	<3m	N/A
34	11/1/2019 0:30	4.25	0.09	0.02	0.03	0.00	0.00	<3m	<3m	N/A
35	11/5/2019 13:00	4.5	0.43	0.10	0.3	0.02	0.01	<3m	<3m	N/A
36	11/7/2019 16:15	8.75	0.32	0.04	0.09	0.01	0.01	<3m	<3m	N/A
37	11/12/2019 11:00	3.75	0.1	0.03	0.05	0.00	0.00	<3m	<3m	N/A
38	11/18/2019 4:45	32.5	0.65	0.02	0.11	0.03	0.01	<3m	<3m	N/A
39	11/20/2019 2:45	18	0.26	0.01	0.04	0.01	0.01	<3m	<3m	N/A
40	11/22/2019 0:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
41	11/22/2019 13:45	1.75	0.1	0.06	0.07	0.00	0.00	<3m	<3m	N/A
42	11/24/2019 3:00	17.5	1.73	0.10	0.41	0.07	0.04	<3m	<3m	N/A
43	11/27/2019 17:15	19	0.39	0.02	0.22	0.02	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/1/2019 23:30	16.75	1.65	0.10	0.24	0.07	0.00	<3m	<3m	N/A
45	12/4/2019 10:00	11	0.02	0.00	0.01	0.00	0.01	<3m	<3m	N/A
46	12/5/2019 9:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
47	12/9/2019 6:45	19.25	0.68	0.04	0.17	0.03	0.01	<3m	<3m	N/A
48	12/10/2019 14:00	25.5	0.55	0.02	0.16	0.02	0.02	<3m	<3m	N/A
49	12/13/2019 10:30	29.75	1.54	0.05	0.25	0.06	0.03	<3m	<3m	N/A
50	12/17/2019 16:45	3.5	0.22	0.06	0.14	0.01	0.00	<3m	<3m	N/A
51	12/18/2019 9:15	5.75	0.26	0.05	0.09	0.02	0.01	<3m	<3m	N/A
52	12/22/2019 10:45	5	0.18	0.04	0.06	0.01	0.00	<3m	<3m	N/A
53	12/29/2019 20:30	36.5	2.28	0.06	0.17	0.08	0.04	<3m	3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 15: Roxbury

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.75	1.13	0.30	0.87	0.05	0.02	6m-1yr	<3m	N/A
2	7/11/2019 23:45	21.5	0.98	0.05	0.22	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 15:00	18.5	1.11	0.06	0.44	0.05	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	23	2	0.09	0.46	0.08	0.04	<3m	3m	N/A
5	7/24/2019 4:30	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
6	7/29/2019 15:15	0.25	0.03	0.12	0.03	0.00	0.00	<3m	<3m	N/A
7	7/31/2019 14:00	2.25	0.46	0.20	0.43	0.02	0.01	<3m	<3m	N/A
8	8/7/2019 11:30	16	2.93	0.18	1.02	0.08	0.04	4 yr	1 yr	N/A
9	8/18/2019 0:00	1.5	0.12	0.08	0.1	0.00	0.00	<3m	<3m	N/A
10	8/19/2019 16:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 15:00	1	0.11	0.11	0.1	0.00	0.00	<3m	<3m	N/A
12	8/23/2019 5:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 14:45	12.25	1.37	0.11	0.47	0.05	0.02	<3m	<3m	N/A
14	9/2/2019 16:30	2.75	0.49	0.18	0.44	0.02	0.00	<3m	<3m	N/A
15	9/7/2019 0:30	10.5	0.15	0.01	0.06	0.01	0.00	<3m	<3m	N/A
16	9/12/2019 6:45	2.25	0.05	0.02	0.03	0.00	0.00	<3m	<3m	N/A
17	9/14/2019 13:00	10.75	0.28	0.03	0.2	0.01	0.01	<3m	<3m	N/A
18	9/23/2019 23:00	2.25	0.08	0.04	0.07	0.00	0.00	<3m	<3m	N/A
19	9/26/2019 16:15	2.25	0.31	0.14	0.15	0.01	0.01	<3m	<3m	N/A
20	10/1/2019 5:00	0.5	0.03	0.06	0.03	0.00	0.00	<3m	<3m	N/A
21	10/2/2019 13:45	5.5	0.25	0.05	0.12	0.01	0.00	<3m	<3m	N/A
22	10/3/2019 22:00	6.25	0.11	0.02	0.04	0.00	0.01	<3m	<3m	N/A
23	10/7/2019 20:00	10.75	0.2	0.02	0.12	0.01	0.00	<3m	<3m	N/A
24	10/9/2019 11:30	22.25	0.15	0.01	0.04	0.01	0.01	<3m	<3m	N/A
25	10/11/2019 10:45	22.75	0.74	0.03	0.19	0.03	0.02	<3m	<3m	N/A
26	10/16/2019 20:15	8.75	2.02	0.23	0.85	0.08	0.04	6m-1yr	3m	N/A
27	10/22/2019 18:45	12.75	0.42	0.03	0.13	0.02	0.01	<3m	<3m	N/A
28	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
29	10/27/2019 8:45	12	1.6	0.13	0.5	0.07	0.03	<3m	<3m	N/A
30	10/28/2019 10:45	14.75	0.03	0.00	0.01	0.06	0.03	<3m	<3m	N/A
31	10/30/2019 9:00	38.5	0.22	0.01	0.05	0.00	0.00	<3m	<3m	N/A
32	11/1/2019 0:15	4.75	0.09	0.02	0.03	0.00	0.00	<3m	<3m	N/A
33	11/5/2019 13:00	3	0.4	0.13	0.28	0.28	0.01	<3m	<3m	N/A
34	11/7/2019 16:15	7.5	0.28	0.04	0.08	0.08	0.01	<3m	<3m	N/A
35	11/12/2019 11:15	3.75	0.09	0.02	0.04	0.04	0.00	<3m	<3m	N/A
36	11/18/2019 5:30	26.75	0.54	0.02	0.1	0.10	0.01	<3m	<3m	N/A
37	11/20/2019 2:00	17.25	0.24	0.01	0.04	0.04	0.01	<3m	<3m	N/A
38	11/22/2019 7:45	7.5	0.08	0.01	0.05	0.05	0.00	<3m	<3m	N/A
39	11/24/2019 3:00	17.75	1.54	0.09	0.36	0.36	0.03	<3m	<3m	N/A
40	11/27/2019 17:15	21	0.37	0.02	0.18	0.18	0.01	<3m	<3m	N/A
41	12/1/2019 22:45	17.5	1.22	0.07	0.14	0.05	0.00	<3m	<3m	N/A
42	12/4/2019 13:45	7.25	0.22	0.03	0.11	0.01	0.00	<3m	<3m	N/A
43	12/5/2019 9:45	2.25	0.1	0.04	0.06	0.01	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/9/2019 6:45	19.5	0.61	0.03	0.16	0.03	0.01	<3m	<3m	N/A
45	12/10/2019 14:15	23.75	0.38	0.02	0.08	0.02	0.02	<3m	<3m	N/A
46	12/13/2019 9:45	25.75	1.44	0.06	0.25	0.06	0.03	<3m	<3m	N/A
47	12/17/2019 17:30	2.25	0.2	0.09	0.14	0.01	0.00	<3m	<3m	N/A
48	12/18/2019 10:00	5	0.17	0.03	0.05	0.02	0.01	<3m	<3m	N/A
49	12/22/2019 11:00	7.25	0.16	0.02	0.04	0.01	0.00	<3m	<3m	N/A
50	12/23/2019 9:45	0.75	0.03	0.04	0.03	0.01	0.00	<3m	<3m	N/A
51	12/29/2019 20:30	36.75	2	0.05	0.15	0.07	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 16: Somerville

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 15:45	3.75	1.4	0.37	0.45	0.06	0.03	<3m	<3m	N/A
2	7/11/2019 23:45	24.25	0.69	0.03	0.16	0.03	0.01	<3m	<3m	N/A
3	7/17/2019 13:45	8.75	0.62	0.07	0.41	0.03	0.01	<3m	<3m	N/A
4	7/22/2019 18:30	16.75	1.8	0.11	0.12	0.08	0.04	<3m	3m	N/A
5	7/31/2019 14:45	1.5	0.87	0.58	0.64	0.04	0.02	3-6m	<3m	N/A
6	8/7/2019 12:45	12.5	2.36	0.19	0.37	0.10	0.05	<3m	6m	N/A
7	8/8/2019 19:45	0.25	0.01	0.04	0.01	0.09	0.05	<3m	3-6m	N/A
8	8/21/2019 15:15	1	0.08	0.08	0.04	0.00	0.00	<3m	<3m	N/A
9	8/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
10	8/28/2019 15:15	10	1.32	0.13	0.34	0.06	0.03	<3m	<3m	N/A
11	9/2/2019 15:45	14.25	1.24	0.09	0.42	0.05	0.03	<3m	<3m	N/A
12	9/4/2019 17:45	0.75	0.32	0.43	0.31	0.01	0.01	<3m	<3m	N/A
13	9/7/2019 3:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
14	9/12/2019 7:00	3.5	0.06	0.02	0.03	0.00	0.00	<3m	<3m	N/A
15	9/14/2019 12:45	17.75	0.25	0.01	0.05	0.01	0.01	<3m	<3m	N/A
16	9/23/2019 23:00	2.25	0.29	0.13	0.21	0.01	0.01	<3m	<3m	N/A
17	9/26/2019 16:15	10	0.36	0.04	0.06	0.02	0.01	<3m	<3m	N/A
18	10/1/2019 5:00	0.75	0.04	0.05	0.02	0.00	0.00	<3m	<3m	N/A
19	10/2/2019 12:45	3.75	0.31	0.08	0.04	0.01	0.00	<3m	<3m	N/A
20	10/3/2019 22:15	5.5	0.16	0.03	0.02	0.01	0.01	<3m	<3m	N/A
21	10/7/2019 19:45	11	0.19	0.02	0.04	0.01	0.00	<3m	<3m	N/A
22	10/9/2019 16:00	14.25	0.09	0.01	0.02	0.00	0.01	<3m	<3m	N/A
23	10/11/2019 12:30	20	0.45	0.02	0.04	0.02	0.01	<3m	<3m	N/A
24	10/16/2019 20:30	8.75	1.65	0.19	0.28	0.07	0.03	<3m	<3m	N/A
25	10/22/2019 18:45	13	0.51	0.04	0.07	0.02	0.01	<3m	<3m	N/A
26	10/25/2019 23:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27	10/27/2019 8:45	20.5	1.46	0.07	0.54	0.07	0.03	3m	<3m	N/A
28	10/28/2019 19:45	7.75	0.07	0.01	0.01	0.00	0.04	<3m	<3m	N/A
29	10/29/2019 19:30	41	0.14	0.00	0.03	0.00	0.00	<3m	<3m	N/A
30	11/1/2019 0:30	4.25	0.06	0.01	0.02	0.00	0.00	<3m	<3m	N/A
31	11/5/2019 11:15	12.75	0.41	0.03	0.11	0.02	0.01	<3m	<3m	N/A
32	11/7/2019 17:00	7	0.29	0.04	0.03	0.01	0.01	<3m	<3m	N/A
33	11/12/2019 11:00	2.5	0.08	0.03	0.01	0.00	0.00	<3m	<3m	N/A
34	11/17/2019 17:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 12:30	23	0.48	0.02	0.04	0.02	0.01	<3m	<3m	N/A
36	11/20/2019 11:30	8	0.2	0.03	0.02	0.01	0.01	<3m	<3m	N/A
37	11/22/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
38	11/22/2019 13:45	1.75	0.09	0.05	0.05	0.00	0.00	<3m	<3m	N/A
39	11/24/2019 3:15	18.5	1.24	0.07	0.35	0.06	0.03	<3m	<3m	N/A
40	11/27/2019 17:15	17.75	0.28	0.02	0.11	0.01	0.01	<3m	<3m	N/A
41	12/2/2019 2:45	12.75	0.88	0.07	0.04	0.04	0.00	<3m	<3m	N/A
42	12/4/2019 11:45	9.25	0.22	0.02	0.03	0.01	0.00	<3m	<3m	N/A
43	12/8/2019 11:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [(1)]		
								1-hr	24-hr	48-hr
44	12/9/2019 8:00	17.5	0.46	0.03	0.05	0.02	0.01	<3m	<3m	N/A
45	12/10/2019 14:15	24	0.37	0.02	0.04	0.02	0.01	<3m	<3m	N/A
46	12/13/2019 18:15	22.25	1.42	0.06	0.06	0.06	0.03	<3m	<3m	N/A
47	12/18/2019 2:30	13.5	0.2	0.01	0.03	0.01	0.00	<3m	<3m	N/A
48	12/21/2019 13:15	2.25	0.02	0.01	0.01	0.00	0.00	<3m	<3m	N/A
49	12/22/2019 10:45	3	0.12	0.04	0.05	0.01	0.00	<3m	<3m	N/A
50	12/29/2019 20:30	37	1.49	0.04	0.17	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 17: Spot Pond

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 15:45	3.75	0.61	0.16	0.36	0.03	0.01	<3m	<3m	N/A
2	7/12/2019 0:00	15	1.86	0.12	0.69	0.08	0.04	6m	3m	N/A
3	7/17/2019 16:45	1.25	0.13	0.10	0.12	0.01	0.00	<3m	<3m	N/A
4	7/22/2019 18:45	15.75	1.79	0.11	0.37	0.07	0.04	<3m	3m	N/A
5	7/31/2019 15:00	1.25	0.1	0.08	0.09	0.00	0.00	<3m	<3m	N/A
6	8/1/2019 6:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
7	8/7/2019 12:45	12.75	2.47	0.19	1.26	0.10	0.05	2.5	6m-1yr	N/A
8	8/17/2019 22:30	1	0.21	0.21	0.21	0.01	0.00	<3m	<3m	N/A
9	8/21/2019 15:15	5.5	0.05	0.01	0.04	0.00	0.00	<3m	<3m	N/A
10	8/28/2019 15:00	10.75	1.31	0.12	0.62	0.05	0.03	3-6m	<3m	N/A
11	9/2/2019 15:00	12	0.91	0.08	0.76	0.04	0.02	6m-1yr	<3m	N/A
12	9/4/2019 17:30	0.5	0.1	0.20	0.1	0.00	0.00	<3m	<3m	N/A
13	9/7/2019 1:15	2.5	0.06	0.02	0.03	0.00	0.00	<3m	<3m	N/A
14	9/12/2019 7:00	3.75	0.08	0.02	0.04	0.00	0.00	<3m	<3m	N/A
15	9/14/2019 12:45	11.25	0.16	0.01	0.1	0.01	0.00	<3m	<3m	N/A
16	9/23/2019 23:30	2.25	0.06	0.03	0.03	0.00	0.00	<3m	<3m	N/A
17	9/26/2019 16:15	2.25	0.36	0.16	0.21	0.02	0.01	<3m	<3m	N/A
18	10/1/2019 4:45	1	0.06	0.06	0.06	0.00	0.00	<3m	<3m	N/A
19	10/2/2019 12:30	4	0.38	0.10	0.15	0.02	0.00	<3m	<3m	N/A
20	10/3/2019 22:00	5.5	0.22	0.04	0.09	0.01	0.01	<3m	<3m	N/A
21	10/7/2019 19:30	11.5	0.22	0.02	0.13	0.01	0.00	<3m	<3m	N/A
22	10/9/2019 16:15	1.75	0.05	0.03	0.03	0.00	0.01	<3m	<3m	N/A
23	10/11/2019 12:00	21.25	0.68	0.03	0.12	0.03	0.01	<3m	<3m	N/A
24	10/16/2019 20:30	9	2.07	0.23	0.92	0.09	0.04	1y	3-6m	N/A
25	10/22/2019 18:15	16	0.59	0.04	0.13	0.02	0.01	<3m	<3m	N/A
26	10/26/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27	10/27/2019 9:30	11.25	1.62	0.14	0.48	0.07	0.03	<3m	<3m	N/A
28	10/28/2019 18:00	13.75	0.08	0.01	0.03	0.01	0.04	<3m	<3m	N/A
29	10/29/2019 19:45	51.5	0.25	0.00	0.04	0.00	0.00	<3m	<3m	N/A
30	11/1/2019 0:30	4.75	0.12	0.03	0.07	0.00	0.00	<3m	<3m	N/A
31	11/5/2019 13:15	2.5	0.32	0.13	0.25	0.01	0.01	<3m	<3m	N/A
32	11/7/2019 16:30	10	0.3	0.03	0.09	0.01	0.01	<3m	<3m	N/A
33	11/12/2019 11:15	2.25	0.07	0.03	0.04	0.00	0.00	<3m	<3m	N/A
34	11/18/2019 12:45	20.25	0.4	0.02	0.1	0.02	0.01	<3m	<3m	N/A
35	11/20/2019 10:30	10.25	0.19	0.02	0.05	0.01	0.01	<3m	<3m	N/A
36	11/22/2019 6:00	9.25	0.06	0.01	0.04	0.00	0.00	<3m	<3m	N/A
37	11/24/2019 3:30	17	1.27	0.07	0.31	0.05	0.03	<3m	<3m	N/A
38	11/27/2019 17:30	18.5	0.29	0.02	0.07	0.01	0.01	<3m	<3m	N/A
39	12/2/2019 4:00	12.75	0.9	0.07	0.21	0.04	0.00	<3m	<3m	N/A
40	12/4/2019 10:00	10.5	0.07	0.01	0.02	0.00	0.00	<3m	<3m	N/A
41	12/5/2019 10:15	1.75	0.28	0.16	0.24	0.01	0.01	<3m	<3m	N/A
42	12/7/2019 11:00	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
43	12/9/2019 6:15	20	0.51	0.03	0.16	0.02	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/10/2019 14:30	22.75	0.33	0.01	0.08	0.01	0.02	<3m	<3m	N/A
45	12/13/2019 18:45	21.25	1.43	0.07	0.26	0.06	0.03	<3m	<3m	N/A
46	12/18/2019 10:30	4	0.3	0.08	0.12	0.01	0.01	<3m	<3m	N/A
47	12/29/2019 21:15	36.25	1.86	0.05	0.12	0.06	0.03	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 18: Union Park

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	4	1.26	0.32	0.97	0.05	0.03	1 yr	<3m	N/A
2	7/11/2019 23:45	21.75	0.79	0.04	0.23	0.03	0.02	<3m	<3m	N/A
3	7/17/2019 16:30	17	1.02	0.06	0.45	0.04	0.02	<3m	<3m	N/A
4	7/22/2019 12:15	23	2.03	0.09	0.44	0.08	0.04	<3m	3m	N/A
5	7/31/2019 14:15	2	0.52	0.26	0.49	0.02	0.01	<3m	<3m	N/A
6	8/7/2019 13:30	11.75	1.77	0.15	0.83	0.07	0.04	6m-1yr	3m	N/A
7	8/18/2019 0:15	0.5	0.15	0.30	0.15	0.01	0.00	<3m	<3m	N/A
8	8/18/2019 15:00	1.25	0.03	0.02	0.02	0.01	0.00	<3m	<3m	N/A
9	8/19/2019 15:45	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
10	8/21/2019 15:15	1	0.1	0.10	0.1	0.00	0.00	<3m	<3m	N/A
11	8/23/2019 6:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
12	8/28/2019 15:00	12	0.98	0.08	0.4	0.04	0.02	<3m	<3m	N/A
13	9/2/2019 16:30	8.25	0.69	0.08	0.61	0.03	0.01	3-6m	<3m	N/A
14	9/4/2019 17:45	0.25	0.04	0.16	0.04	0.00	0.01	<3m	<3m	N/A
15	9/7/2019 0:30	3.25	0.1	0.03	0.05	0.00	0.00	<3m	<3m	N/A
16	9/12/2019 6:45	2.25	0.05	0.02	0.03	0.00	0.00	<3m	<3m	N/A
17	9/14/2019 12:45	11.25	0.31	0.03	0.22	0.01	0.01	<3m	<3m	N/A
18	10/1/2019 4:45	1	0.06	0.06	0.01	0.00	0.00	<3m	<3m	N/A
19	10/2/2019 12:30	4	0.38	0.10	0.19	0.01	0.00	<3m	<3m	N/A
20	10/3/2019 22:00	5.5	0.22	0.04	0.06	0.01	0.01	<3m	<3m	N/A
21	10/7/2019 19:30	11.5	0.22	0.02	0.12	0.01	0.00	<3m	<3m	N/A
22	10/9/2019 16:15	1.75	0.05	0.03	0.06	0.00	0.01	<3m	<3m	N/A
23	10/11/2019 12:00	21.25	0.68	0.03	0.22	0.03	0.02	<3m	<3m	N/A
24	10/16/2019 20:30	9	2.07	0.23	0.84	0.08	0.04	6m-1yr	3m	N/A
25	10/22/2019 18:15	16	0.59	0.04	0.24	0.02	0.01	<3m	<3m	N/A
26	10/26/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27	10/27/2019 9:30	11.25	1.62	0.14	0.48	0.06	0.03	<3m	<3m	N/A
28	10/28/2019 18:00	13.75	0.08	0.01	0.01	0.01	0.04	<3m	<3m	N/A
29	10/29/2019 19:45	51.5	0.25	0.00	0.03	0.00	0.00	<3m	<3m	N/A
30	11/1/2019 0:30	4.25	0.04	0.01	0.02	0.00	0.00	<3m	<3m	N/A
31	11/5/2019 13:00	3	0.37	0.12	0.28	0.02	0.01	<3m	<3m	N/A
32	11/7/2019 16:15	7	0.26	0.04	0.08	0.01	0.01	<3m	<3m	N/A
33	11/12/2019 11:30	2.5	0.07	0.03	0.04	0.00	0.00	<3m	<3m	N/A
34	11/18/2019 5:00	12.75	0.36	0.03	0.09	0.02	0.01	<3m	<3m	N/A
35	11/19/2019 5:45	6.75	0.26	0.04	0.13	0.02	0.01	<3m	<3m	N/A
36	11/20/2019 2:30	18.5	0.29	0.02	0.06	0.01	0.01	<3m	<3m	N/A
37	11/22/2019 14:00	1	0.04	0.04	0.04	0.00	0.00	<3m	<3m	N/A
38	11/24/2019 3:15	17.5	1.84	0.11	0.53	0.08	0.04	3m	3m	N/A
39	11/27/2019 17:15	18.5	0.29	0.02	0.18	0.01	0.01	<3m	<3m	N/A
40	12/1/2019 22:45	19.25	0.87	0.05	0.12	0.04	0.00	<3m	<3m	N/A
41	12/4/2019 17:30	18	0.36	0.02	0.08	0.02	0.01	<3m	<3m	N/A
42	12/6/2019 20:15	0.5	0.02	0.04	0.02	0.00	0.01	<3m	<3m	N/A
43	12/9/2019 7:15	18.5	0.51	0.03	0.16	0.02	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
44	12/10/2019 14:15	35.25	0.39	0.01	0.11	0.02	0.02	<3m	<3m	N/A
45	12/13/2019 9:45	25.75	1.5	0.06	0.27	0.06	0.03	<3m	<3m	N/A
46	12/14/2019 23:30	0.25	0.01	0.04	0.01	0.06	0.03	<3m	<3m	N/A
47	12/17/2019 17:30	2.25	0.2	0.09	0.14	0.01	0.00	<3m	<3m	N/A
48	12/18/2019 10:00	5	0.17	0.03	0.05	0.02	0.01	<3m	<3m	N/A
49	12/22/2019 11:00	7.25	0.16	0.02	0.04	0.01	0.00	<3m	<3m	N/A
50	12/23/2019 9:45	0.75	0.03	0.04	0.03	0.01	0.00	<3m	<3m	N/A
51	12/29/2019 20:30	36.75	2	0.05	0.17	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 19: USGS Fresh Pond

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
1	7/6/2019 16:15	3.75	1.09	0.29	0.82	0.05	0.02	6m-1yr	<3m	N/A
2	7/12/2019 0:45	20.25	1.05	0.05	0.41	0.04	0.02	<3m	<3m	N/A
3	7/17/2019 14:45	9	0.75	0.08	0.67	0.03	0.02	3-6m	<3m	N/A
4	7/22/2019 13:45	21.75	1.51	0.07	0.25	0.06	0.03	<3m	<3m	N/A
5	7/31/2019 15:00	1.5	0.64	0.43	0.62	0.03	0.01	3-6m	<3m	N/A
6	8/7/2019 12:45	13	2.98	0.23	1.41	0.12	0.06	3.5	1.5 yr	N/A
7	8/8/2019 22:00	0.25	0.01	0.04	0.01	0.12	0.06	<3m	1 yr	N/A
8	8/18/2019 16:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
9	8/21/2019 15:00	1.5	0.1	0.07	0.04	0.00	0.00	<3m	<3m	N/A
10	8/23/2019 6:00	0.75	0.02	0.03	0.01	0.00	0.00	<3m	<3m	N/A
11	8/28/2019 15:00	10.25	1.37	0.13	0.6	0.06	0.03	3m	<3m	N/A
12	9/2/2019 16:00	6.5	1.41	0.22	1.25	0.06	0.00	2.5 yr	<3m	N/A
13	9/4/2019 17:45	0.5	0.27	0.54	0.27	0.01	0.03	<3m	<3m	N/A
14	9/7/2019 1:15	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
15	9/12/2019 7:00	3.75	0.07	0.02	0.04	0.00	0.00	<3m	<3m	N/A
16	9/14/2019 12:45	18	0.27	0.02	0.13	0.01	0.01	<3m	<3m	N/A
17	9/23/2019 23:00	10.25	0.17	0.02	0.13	0.01	0.00	<3m	<3m	N/A
18	9/26/2019 16:15	2.25	0.32	0.14	0.17	0.01	0.01	<3m	<3m	N/A
19	10/1/2019 4:45	1	0.06	0.06	0.01	0.00	0.00	<3m	<3m	N/A
20	10/2/2019 12:30	4	0.38	0.10	0.11	0.01	0.00	<3m	<3m	N/A
21	10/3/2019 22:00	5.5	0.22	0.04	0.04	0.00	0.01	<3m	<3m	N/A
22	10/7/2019 19:30	11.5	0.22	0.02	0.11	0.01	0.00	<3m	<3m	N/A
23	10/9/2019 16:15	1.75	0.05	0.03	0.03	0.00	0.01	<3m	<3m	N/A
24	10/11/2019 12:00	21.25	0.68	0.03	0.13	0.02	0.01	<3m	<3m	N/A
25	10/16/2019 20:30	9	2.07	0.23	0.66	0.06	0.03	3-6m	<3m	N/A
26	10/22/2019 18:15	16	0.59	0.04	0.15	0.02	0.01	<3m	<3m	N/A
27	10/26/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
28	10/27/2019 9:30	11.25	1.62	0.14	0.37	0.05	0.03	<3m	<3m	N/A
29	10/28/2019 18:00	13.75	0.08	0.01	0.03	0.01	0.03	<3m	<3m	N/A
30	10/29/2019 19:45	51.5	0.25	0.00	0.02	0.00	0.00	<3m	<3m	N/A
31	11/1/2019 0:30	5.75	0.12	0.02	0.07	0.00	0.00	<3m	<3m	N/A
32	11/5/2019 10:15	6.75	0.41	0.06	0.3	0.02	0.01	<3m	<3m	N/A
33	11/7/2019 17:15	5.75	0.17	0.03	0.07	0.01	0.00	<3m	<3m	N/A
34	11/12/2019 11:00	2.5	0.07	0.03	0.03	0.00	0.00	<3m	<3m	N/A
35	11/18/2019 13:00	5	0.23	0.05	0.06	0.01	0.00	<3m	<3m	N/A
36	11/19/2019 6:00	5	0.23	0.05	0.1	0.02	0.01	<3m	<3m	N/A
37	11/20/2019 7:30	11	0.15	0.01	0.05	0.01	0.01	<3m	<3m	N/A
38	11/22/2019 1:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
39	11/22/2019 14:00	1.5	0.08	0.05	0.06	0.00	0.00	<3m	<3m	N/A
40	11/24/2019 3:15	18	1.34	0.07	0.35	0.06	0.03	<3m	<3m	N/A
41	11/27/2019 17:15	19	0.28	0.01	0.11	0.01	0.01	<3m	<3m	N/A
42	12/2/2019 0:45	15	1.43	0.10	0.22	0.06	0.00	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
43	12/4/2019 9:45	3.25	0.13	0.04	0.07	0.01	0.00	<3m	<3m	N/A
44	12/9/2019 7:45	17.75	0.51	0.03	0.16	0.02	0.01	<3m	<3m	N/A
45	12/10/2019 14:00	23.75	0.39	0.02	0.13	0.02	0.02	<3m	<3m	N/A
46	12/13/2019 18:00	24.75	1.41	0.06	0.19	0.06	0.03	<3m	<3m	N/A
47	12/17/2019 16:30	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
48	12/18/2019 9:15	5.75	0.23	0.04	0.07	0.01	0.01	<3m	<3m	N/A
49	12/22/2019 10:15	5.5	0.19	0.03	0.05	0.01	0.00	<3m	<3m	N/A
50	12/29/2019 20:45	36.25	2.09	0.06	0.17	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Rain Gauge 20: Waltham Farm

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval (1)		
								1-hr	24-hr	48-hr
1	7/1/2019 5:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
2	7/6/2019 15:45	10	1.36	0.14	1.01	0.06	0.03	1 yr	<3m	N/A
3	7/11/2019 23:30	21.25	1.01	0.05	0.27	0.04	0.02	<3m	<3m	N/A
4	7/17/2019 13:30	18.5	0.87	0.05	0.81	0.04	0.02	6m-1yr	<3m	N/A
5	7/22/2019 12:30	22	1.87	0.09	0.34	0.08	0.04	<3m	3m	N/A
6	7/31/2019 14:45	5.5	0.46	0.08	0.43	0.02	0.01	<3m	<3m	N/A
7	8/7/2019 11:00	14	2.9	0.21	1.22	0.12	0.06	2 yr	1 yr	N/A
8	8/9/2019 18:30	0.25	0.06	0.24	0.06	0.00	0.05	<3m	<3m	N/A
9	8/17/2019 23:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
10	8/18/2019 16:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	8/21/2019 14:30	2	0.13	0.07	0.11	0.01	0.00	<3m	<3m	N/A
12	8/23/2019 6:00	0.25	0.02	0.08	0.02	0.00	0.00	<3m	<3m	N/A
13	8/28/2019 15:00	9.5	2.01	0.21	0.87	0.08	0.04	6m-1yr	3m	N/A
14	9/2/2019 15:45	14	1.51	0.11	1.34	0.06	0.03	3 yr	<3m	N/A
15	9/4/2019 17:30	12	0.42	0.04	0.41	0.02	0.02	<3m	<3m	N/A
16	9/7/2019 0:30	3	0.11	0.04	0.06	0.00	0.00	<3m	<3m	N/A
17	9/12/2019 6:45	4	0.09	0.02	0.05	0.00	0.00	<3m	<3m	N/A
18	9/14/2019 12:45	11.5	0.25	0.02	0.13	0.01	0.01	<3m	<3m	N/A
19	9/23/2019 22:45	3	0.16	0.05	0.11	0.01	0.00	<3m	<3m	N/A
20	9/24/2019 18:15	0.25	0.01	0.04	0.01	0.01	0.00	<3m	<3m	N/A
21	9/26/2019 16:00	7.5	0.38	0.05	0.2	0.02	0.01	<3m	<3m	N/A
22	10/1/2019 4:45	7	0.03	0.00	0.02	0.00	0.00	<3m	<3m	N/A
23	10/2/2019 13:45	6	0.33	0.06	0.18	0.01	0.00	<3m	<3m	N/A
24	10/3/2019 20:45	10	0.13	0.01	0.05	0.01	0.01	<3m	<3m	N/A
25	10/7/2019 19:30	11.5	0.22	0.02	0.11	0.01	0.00	<3m	<3m	N/A
26	10/9/2019 16:30	16.25	0.11	0.01	0.02	0.00	0.01	<3m	<3m	N/A
27	10/11/2019 11:45	20.75	0.67	0.03	0.16	0.03	0.01	<3m	<3m	N/A
28	10/16/2019 19:45	9.25	2.53	0.27	1.29	0.11	0.05	3 yr	6m-1yr	N/A
29	10/21/2019 0:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
30	10/22/2019 18:30	12.75	0.6	0.05	0.3	0.03	0.01	<3m	<3m	N/A
31	10/24/2019 7:00	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
32	10/26/2019 0:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
33	10/27/2019 8:45	12.5	1.6	0.13	0.48	0.07	0.03	<3m	<3m	N/A
34	10/28/2019 14:15	12.5	0.09	0.01	0.03	0.03	0.04	<3m	<3m	N/A
35	10/29/2019 20:00	8.5	0.02	0.00	0.01	0.00	0.00	<3m	<3m	N/A
36	10/30/2019 17:30	30	0.22	0.01	0.03	0.06	0.00	<3m	<3m	N/A
37	11/1/2019 0:45	4.25	0.15	0.04	0.12	0.00	0.00	<3m	<3m	N/A
38	11/5/2019 11:00	4.75	0.34	0.07	0.23	0.01	0.01	<3m	<3m	N/A
39	11/7/2019 16:15	6.75	0.34	0.05	0.09	0.01	0.01	<3m	<3m	N/A
40	11/12/2019 11:00	6.25	0.09	0.01	0.04	0.00	0.00	<3m	<3m	N/A
41	11/18/2019 13:00	22.75	0.48	0.02	0.12	0.02	0.01	<3m	<3m	N/A
42	11/20/2019 7:15	13.75	0.24	0.02	0.06	0.01	0.01	<3m	<3m	N/A
43	11/22/2019 0:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity (in/hr)	Peak 1-hr Intensity (in/hr)	Peak 24-hr Intensity (in/hr)	Peak 48-hr Intensity (in/hr)	Storm Recurrence Interval [1]		
								1-hr	24-hr	48-hr
44	11/22/2019 13:45	2	0.09	0.05	0.07	0.00	0.00	<3m	<3m	N/A
45	11/24/2019 3:15	18	1.31	0.07	0.28	0.05	0.03	<3m	<3m	N/A
46	11/27/2019 17:15	19.5	0.3	0.02	0.09	0.01	0.01	<3m	<3m	N/A
47	12/2/2019 5:00	12	1.04	0.09	0.21	0.04	0.00	<3m	<3m	N/A
48	12/3/2019 11:30	4.75	0.07	0.01	0.03	0.01	0.02	<3m	<3m	N/A
49	12/4/2019 10:45	7.5	0.18	0.02	0.04	0.01	0.01	<3m	<3m	N/A
50	12/5/2019 9:45	4.75	0.65	0.14	0.24	0.03	0.02	<3m	<3m	N/A
51	12/7/2019 9:30	1	0.05	0.05	0.05	0.00	0.01	<3m	<3m	N/A
52	12/9/2019 6:30	54.75	1.22	0.02	0.29	0.03	0.02	<3m	<3m	N/A
53	12/13/2019 18:15	25	1.27	0.05	0.19	0.05	0.03	<3m	<3m	N/A
54	12/17/2019 18:45	1.75	0.04	0.02	0.03	0.00	0.00	<3m	<3m	N/A
55	12/18/2019 9:45	3	0.57	0.19	0.27	0.03	0.01	<3m	<3m	N/A
56	12/28/2019 7:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
57	12/29/2019 20:45	35.75	2.2	0.06	0.14	0.07	0.04	<3m	<3m	N/A

(1) Recurrence intervals given in ranges of less than 3 months (<3m), 3-months, (3m), 3-6 months (3-6m), 6 months (6m), 6 months-1year (6m-1yr) or the nearest half-year.

Appendix D: Rainfall Hyetographs

All hyetographs are plotted using 15-minute peak intensities.

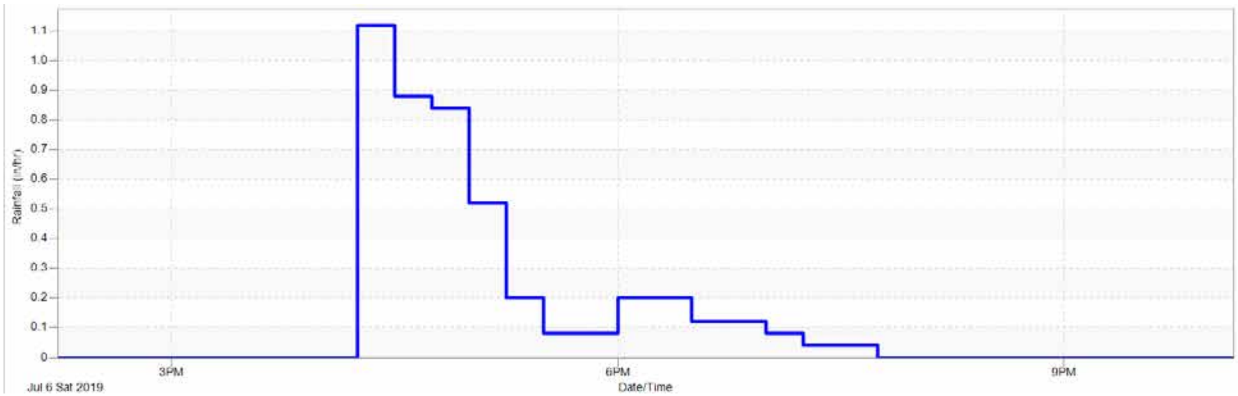


Figure 1. Ward Street July 6, 2019

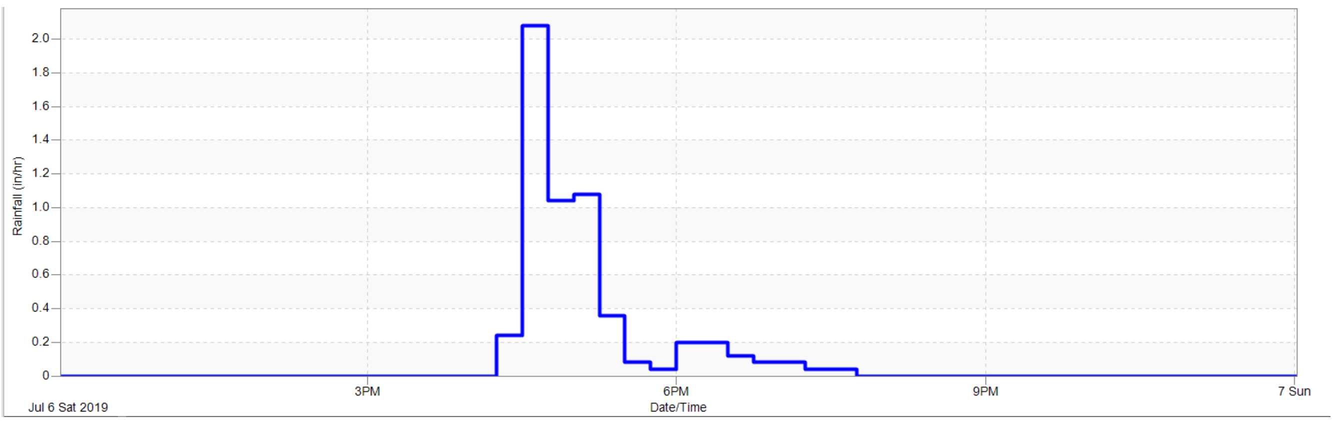


Figure 2. Columbus Park July 6, 2019

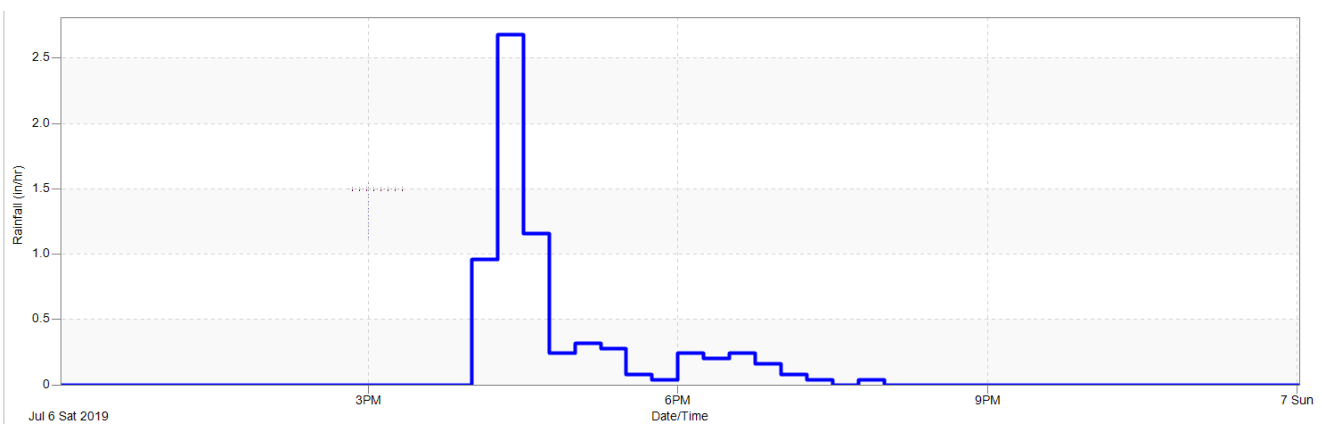


Figure 3. Chelsea Creek July 6, 2019

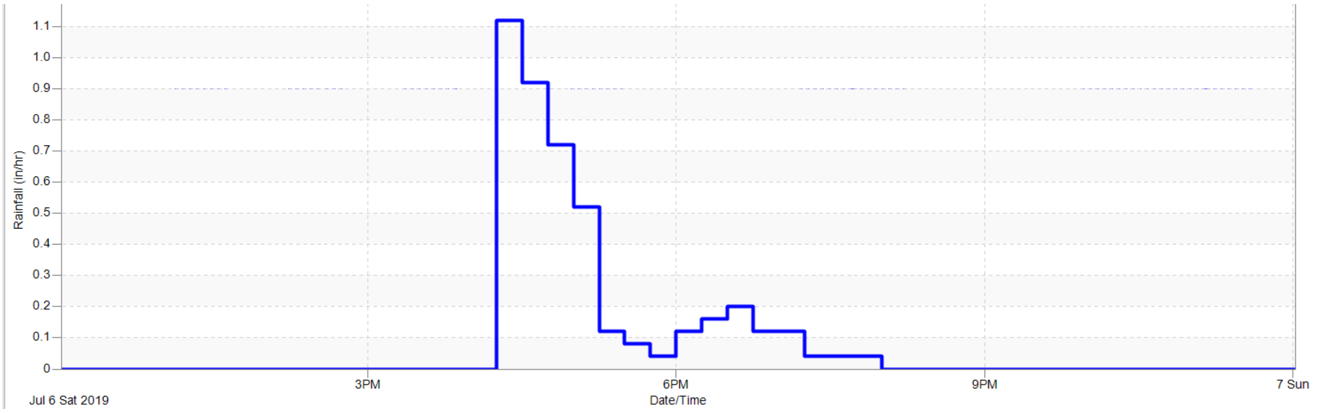


Figure 4. USGS Fresh Pond July 6, 2019

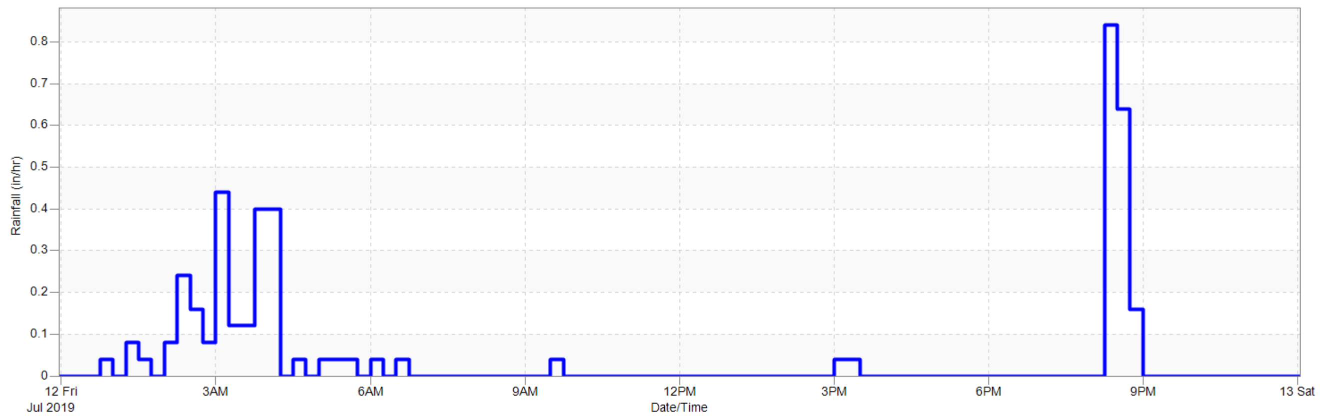


Figure 5. USGS Fresh Pond July 12, 2019

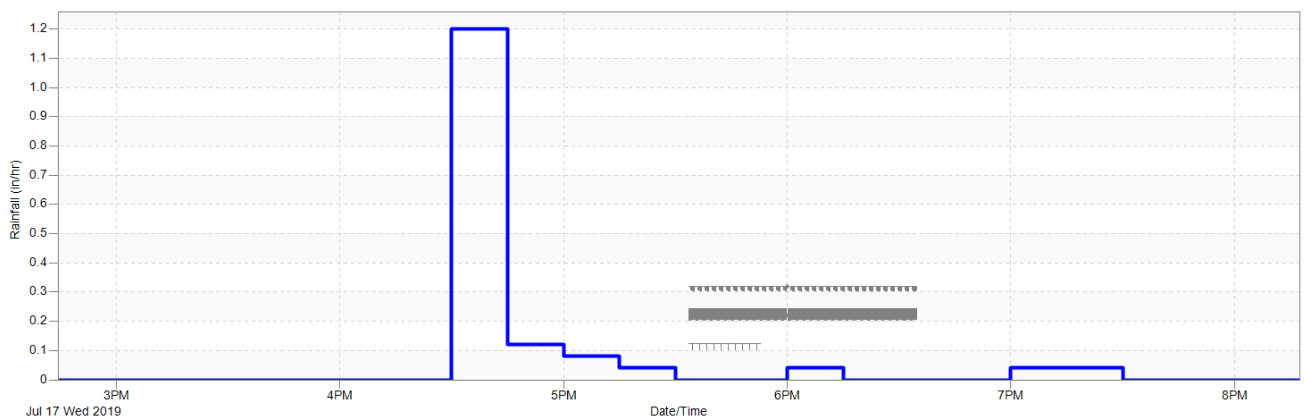


Figure 6. Ward Street July 17, 2019

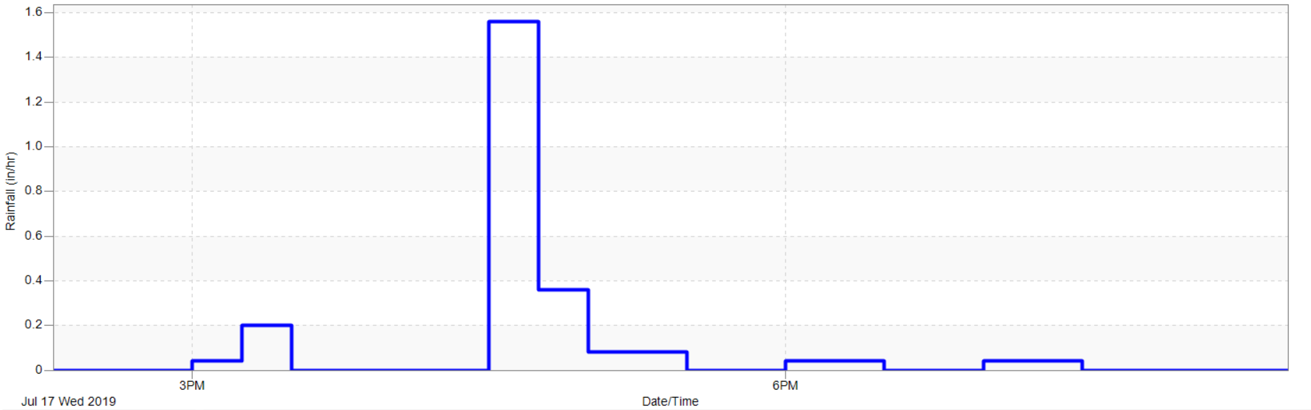


Figure 7. Columbus Park July 17, 2019

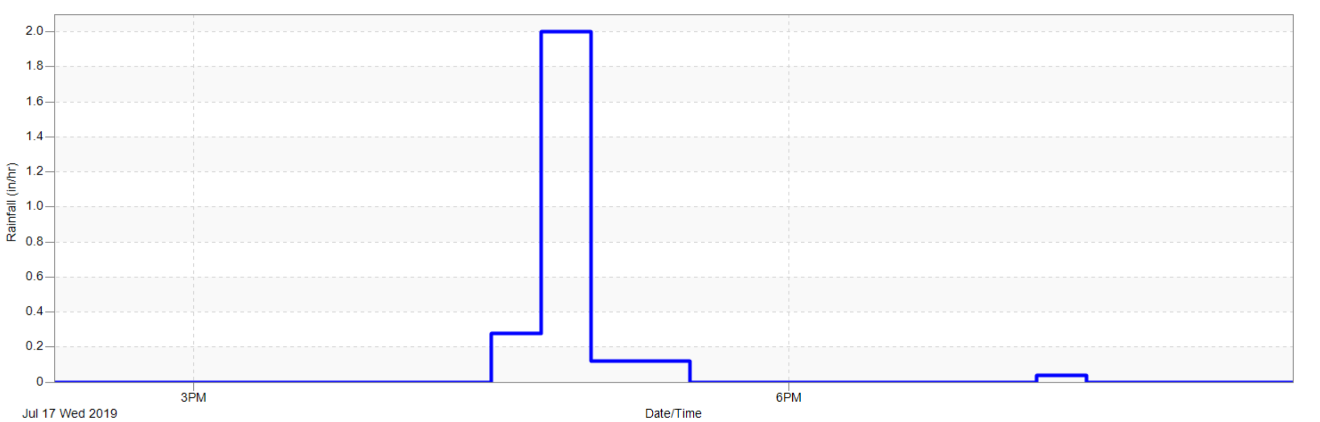


Figure 8. Chelsea Creek July 17, 2019

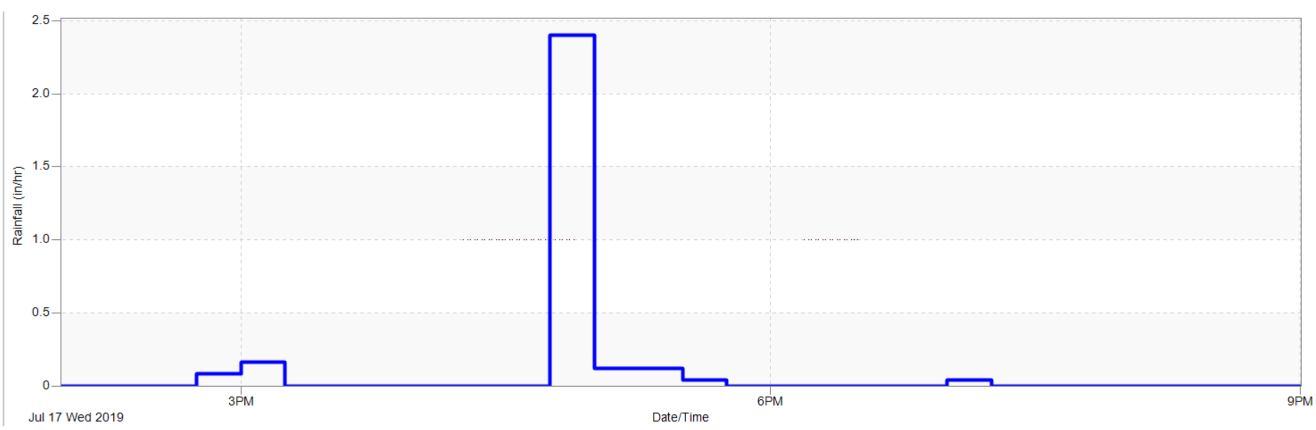


Figure 9. USGS Fresh Pond July 17, 2019

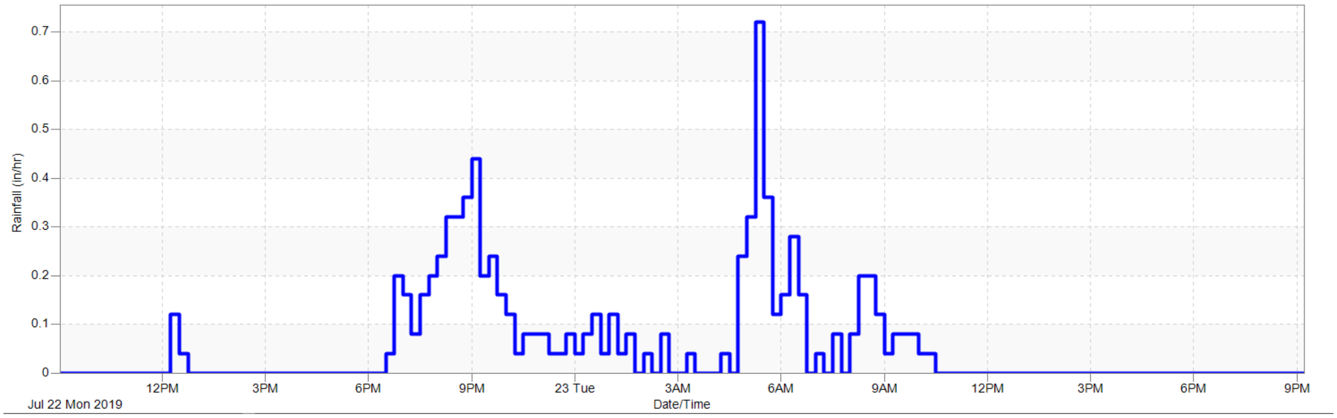


Figure 10. Ward Street July 22, 2019

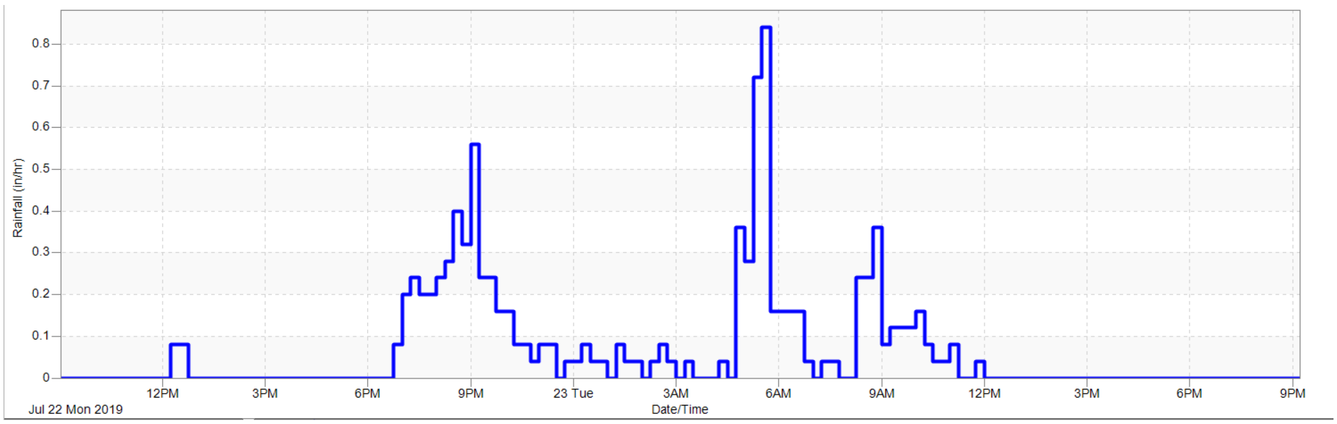


Figure 11. Columbus Park July 22, 2019

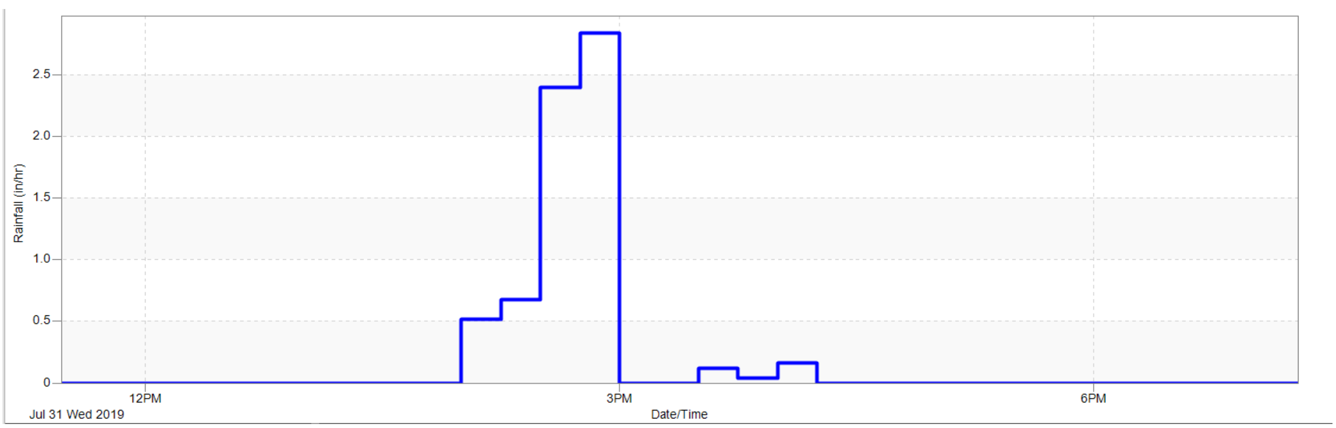


Figure 12. Columbus Park July 31, 2019

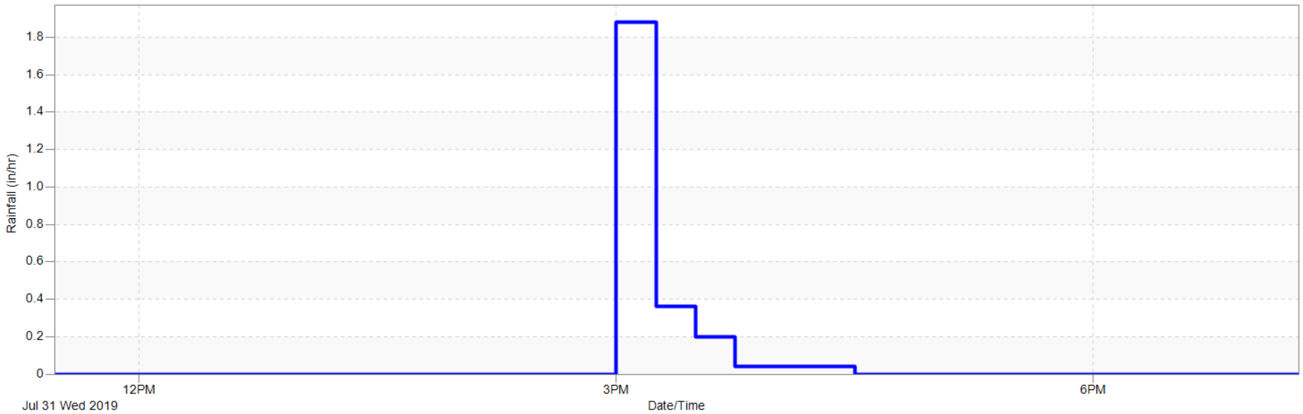


Figure 13. USGS Fresh Pond July 31, 2019

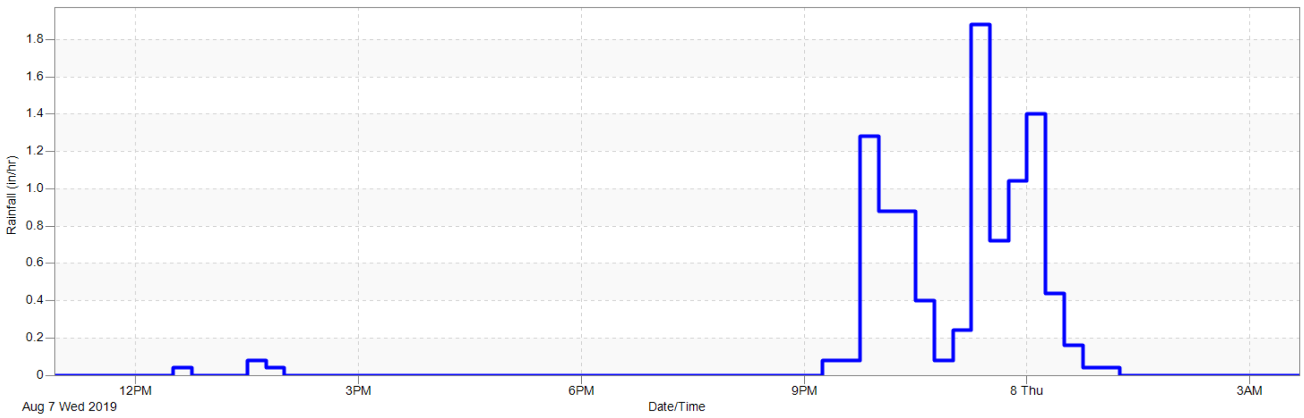


Figure 14. Ward Street August 7, 2019

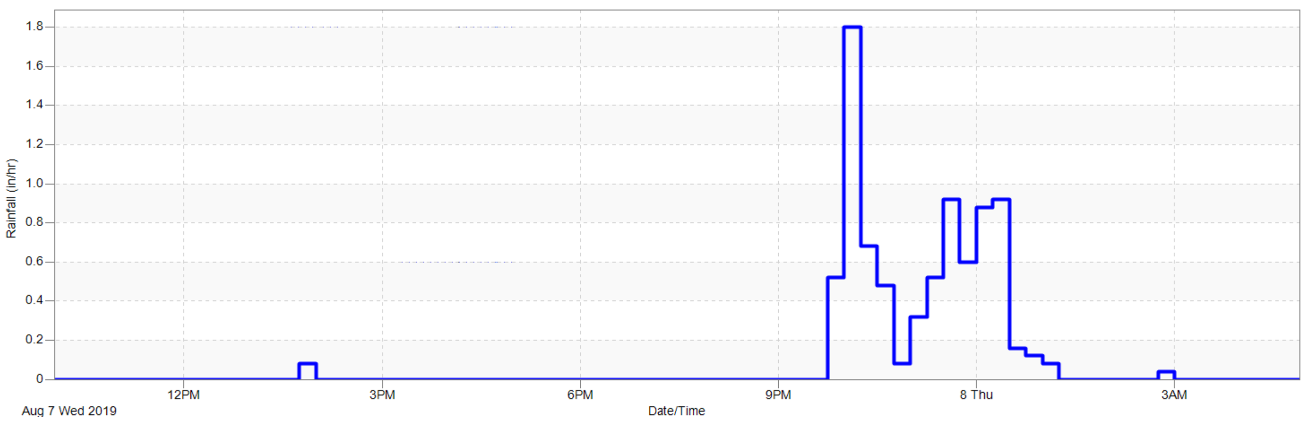


Figure 15. Columbus Park August 7, 2019

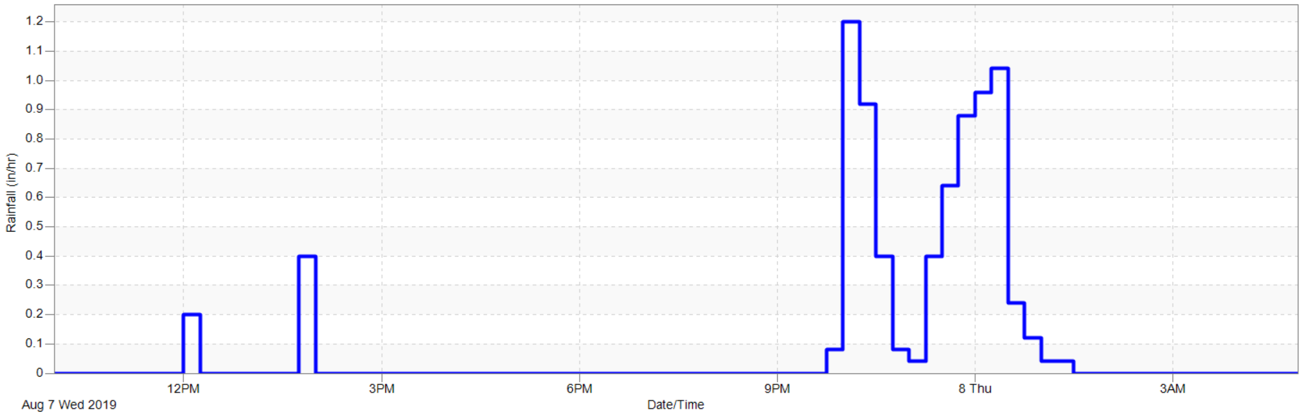


Figure 16. Chelsea Creek August 7, 2019

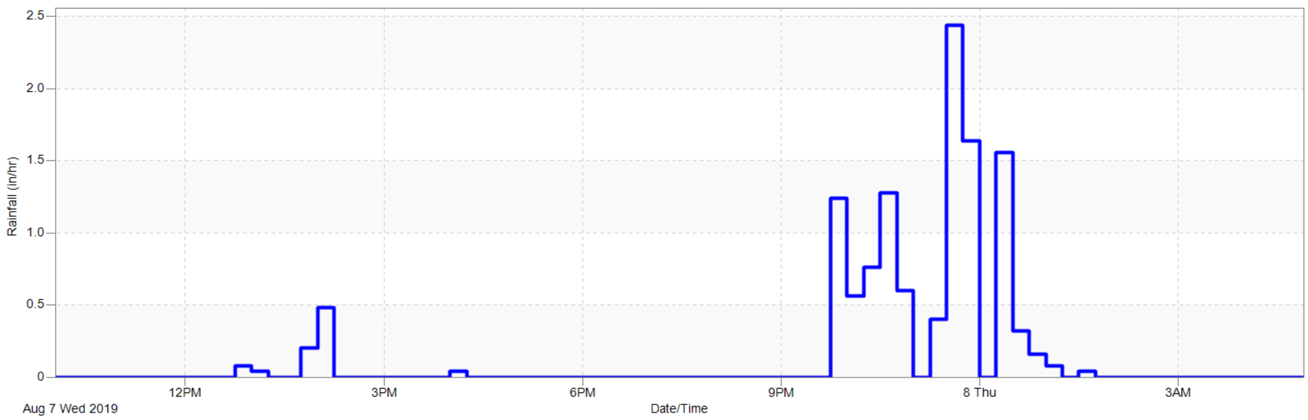


Figure 17. USGS Fresh Pond August 7, 2019

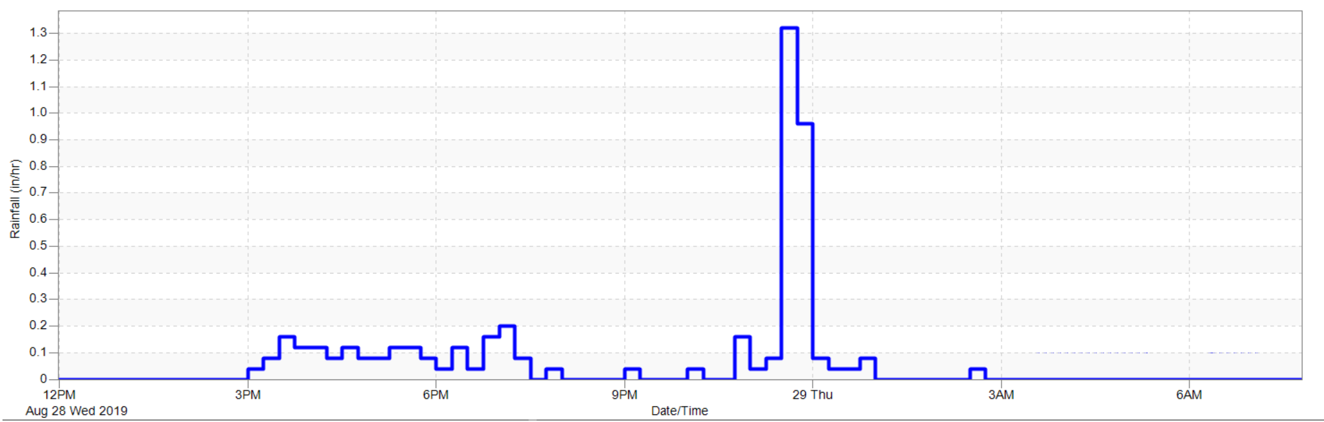


Figure 18. Ward Street August 28, 2019

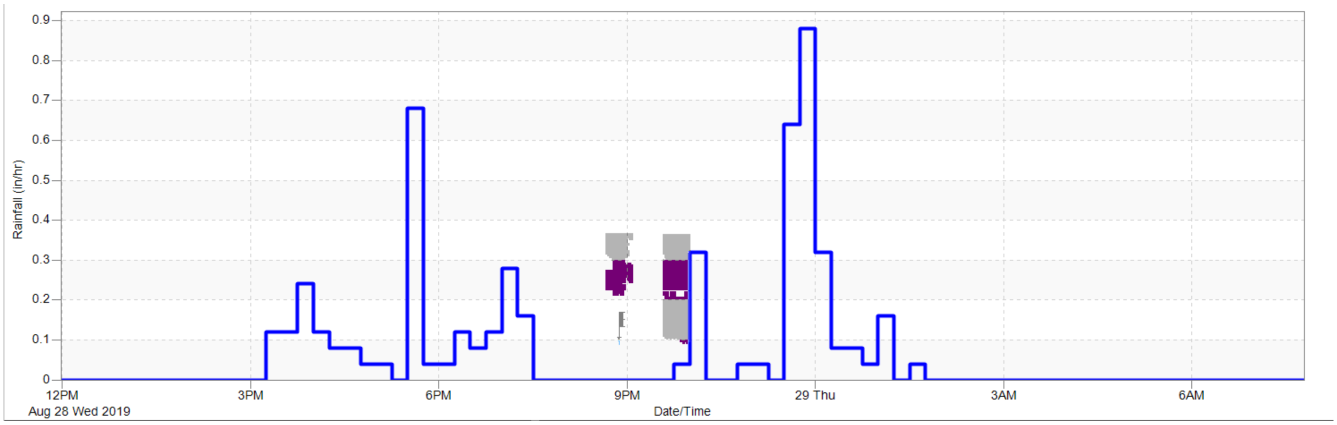


Figure 19. Columbus Park August 28, 2019

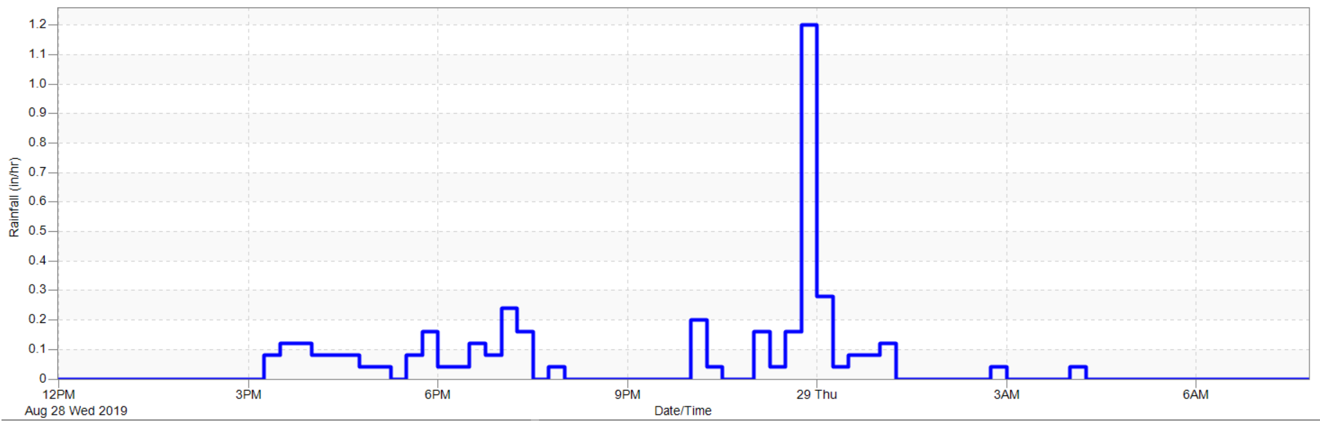


Figure 20. Chelsea Creek August 28, 2019

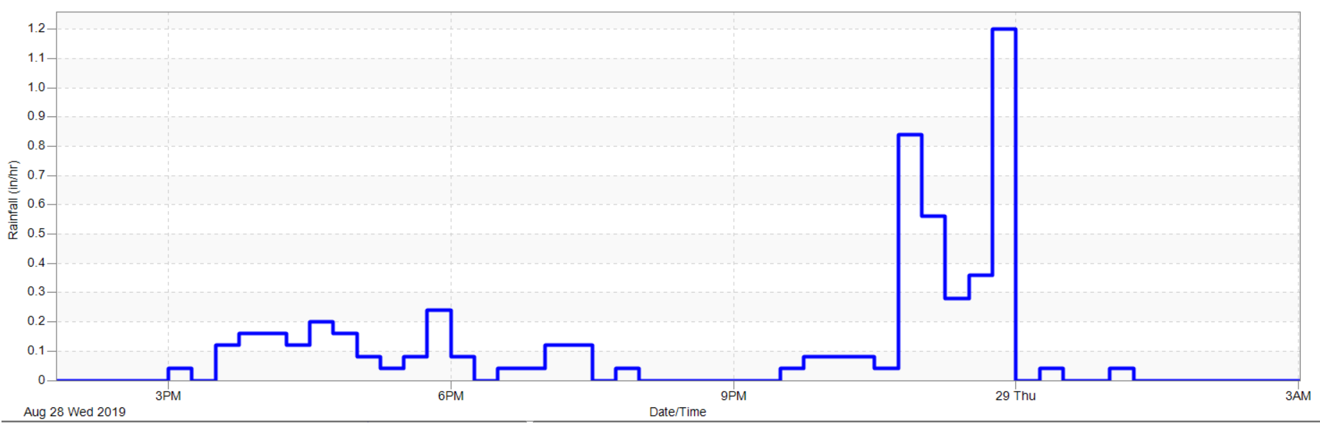


Figure 21. USGS Fresh Pond August 28, 2019

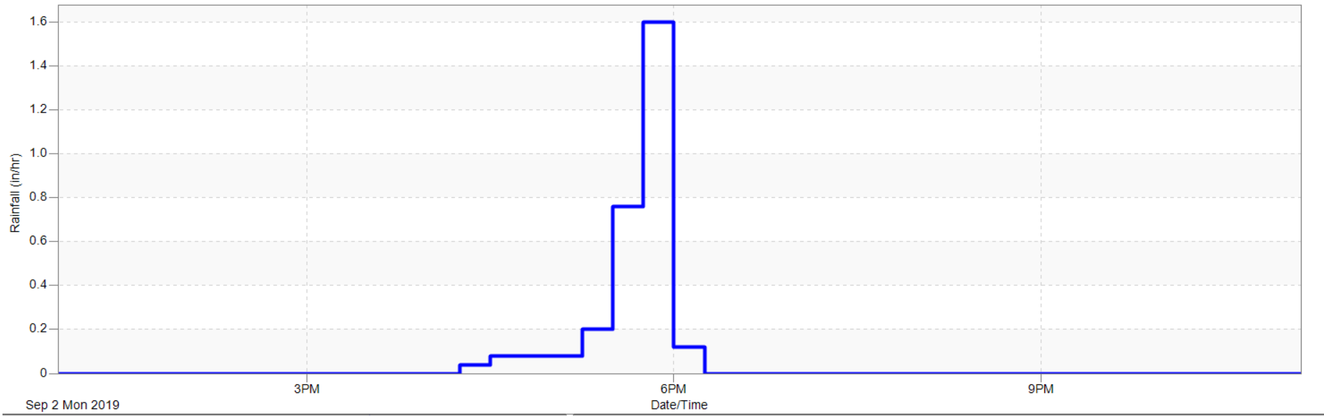


Figure 22. Ward Street September 2, 2019

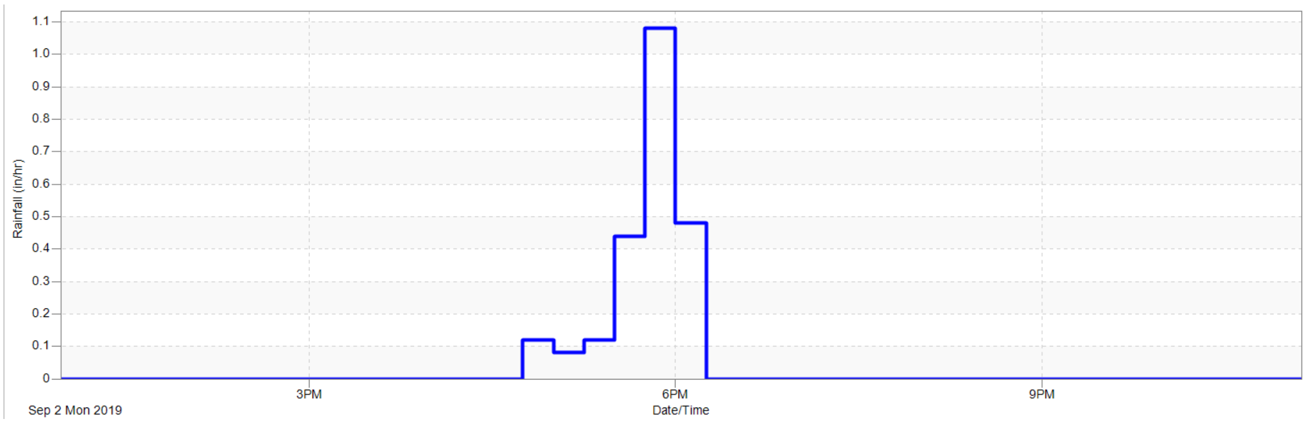


Figure 23. Columbus Park September 2, 2019

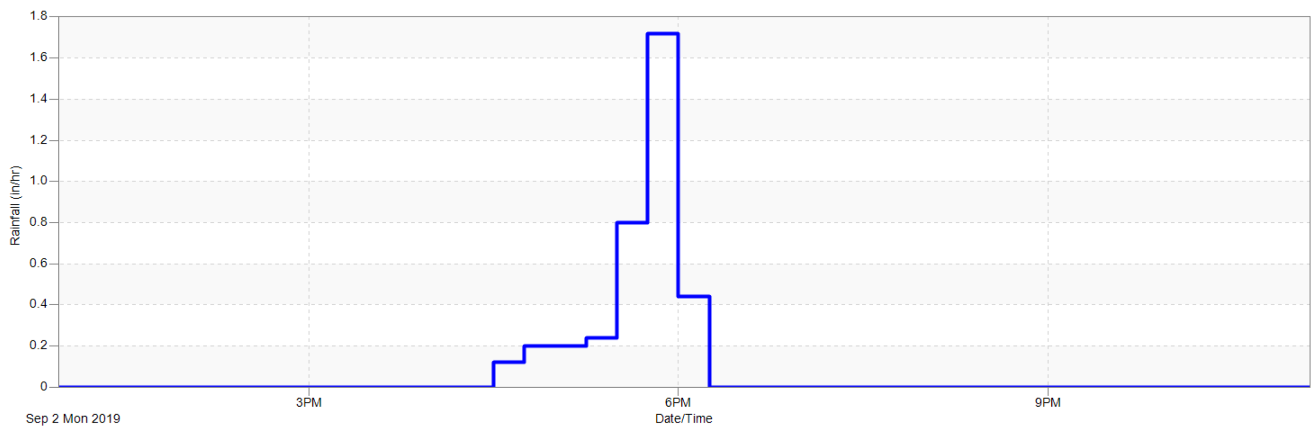


Figure 24. Chelsea Creek September 2, 2019

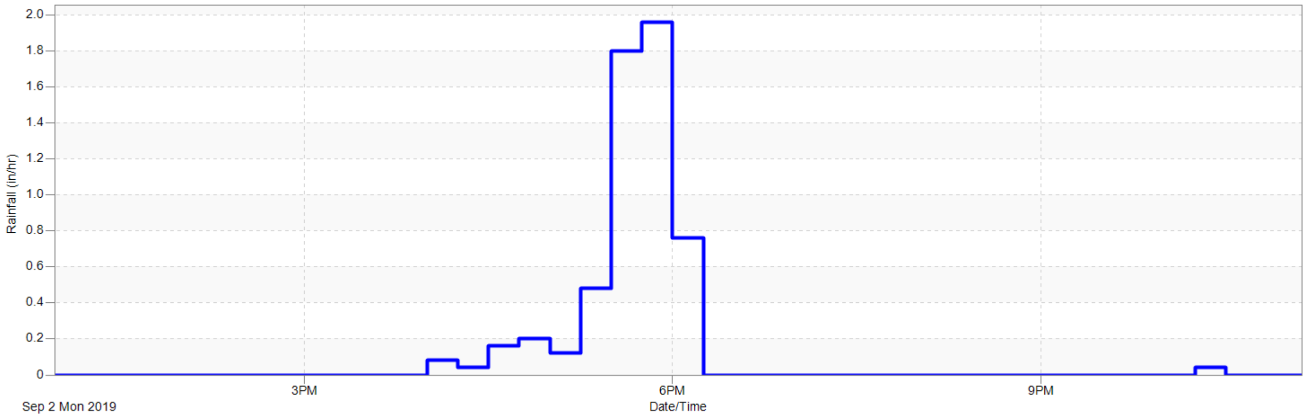


Figure 25. USGS Fresh Pond September 2, 2019

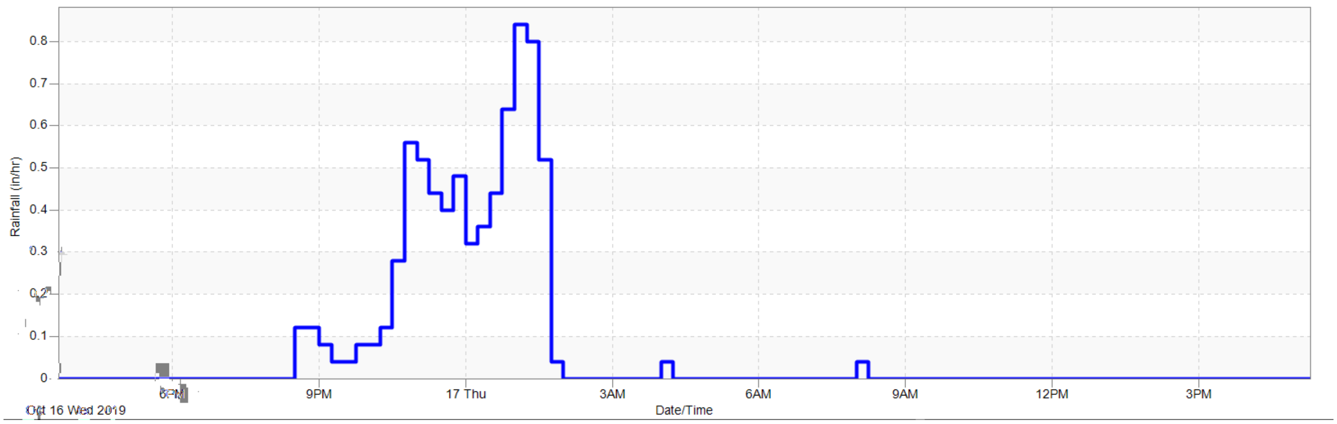


Figure 26. Ward Street October 16, 2019

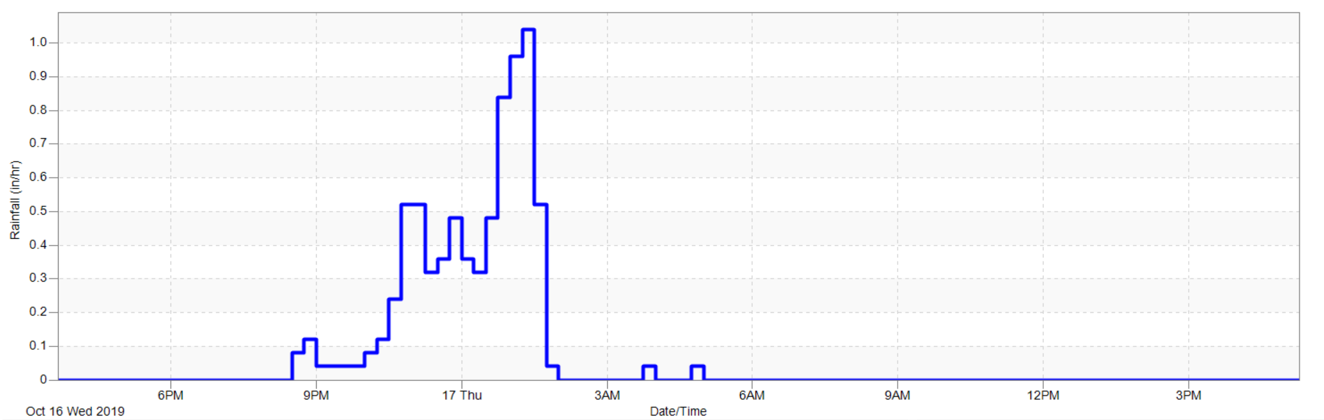


Figure 27. Columbus Park October 16, 2019

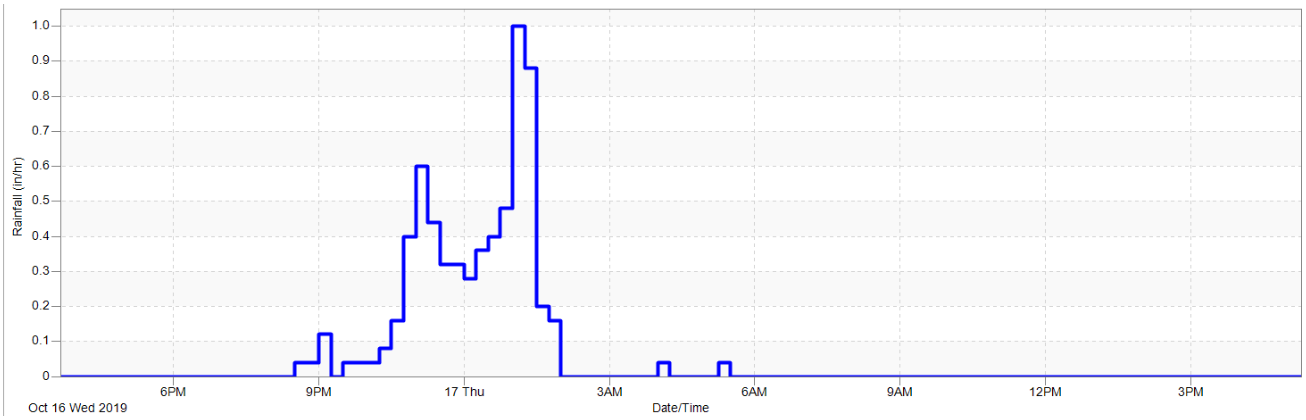


Figure 28. Chelsea Creek October 16, 2019

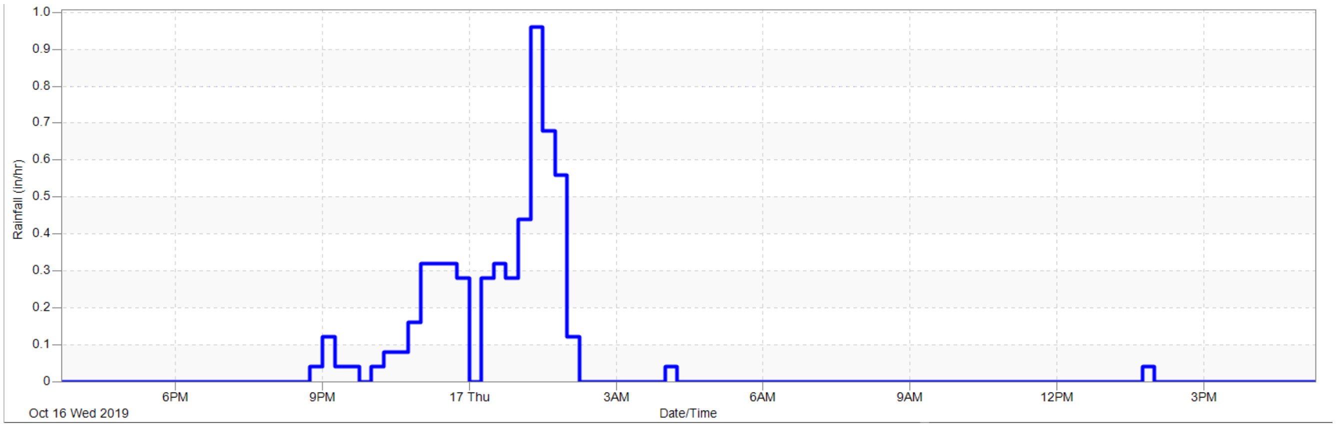


Figure 29. USGS Fresh Pond October 16, 2019

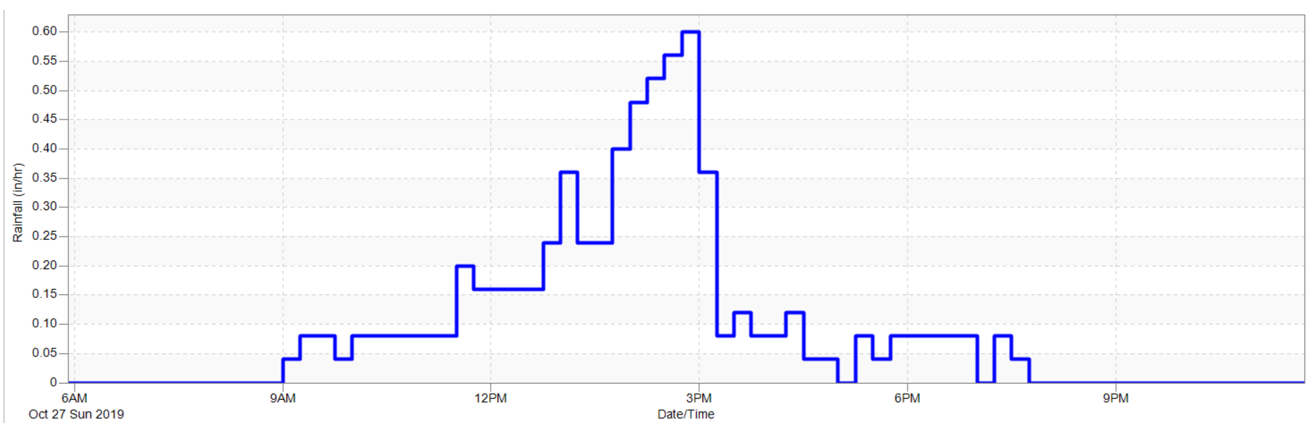


Figure 30. Ward Street October 27, 2019

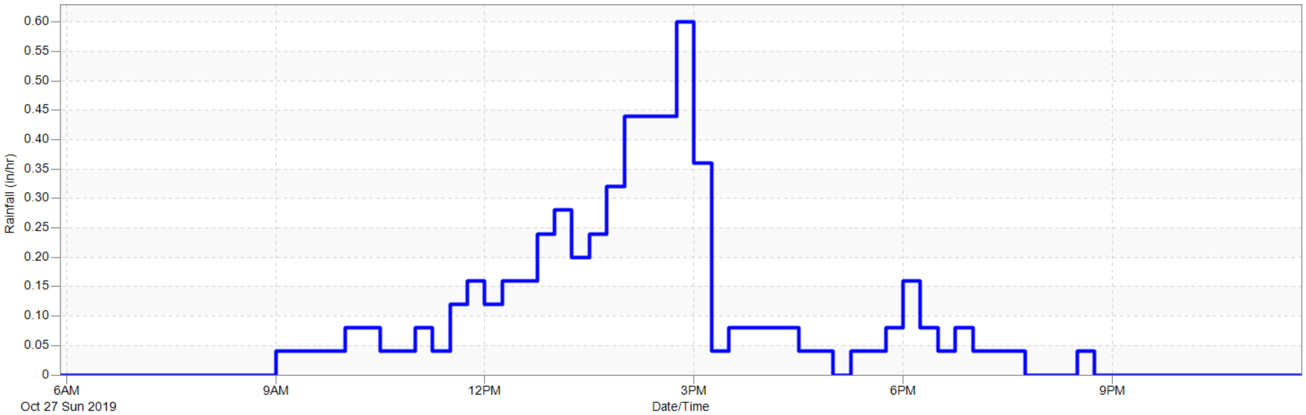


Figure 31. Columbus Park October 27, 2019

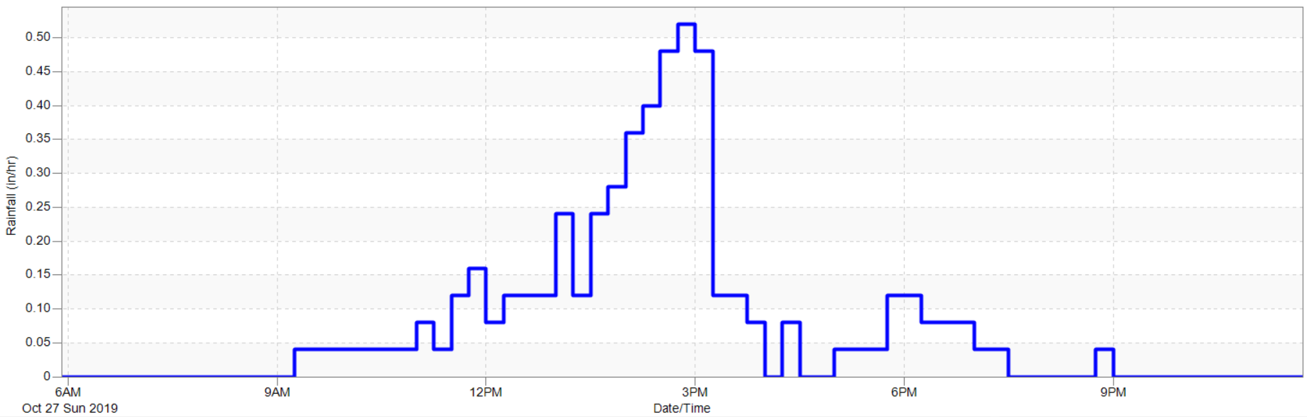


Figure 32. Chelsea Creek October 27, 2019

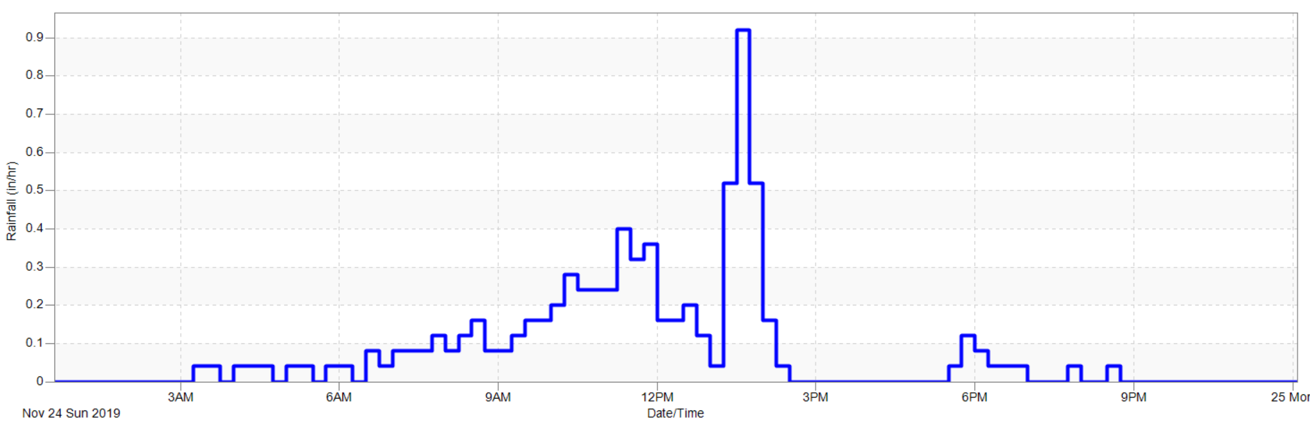


Figure 33. Columbus Park November 24, 2019

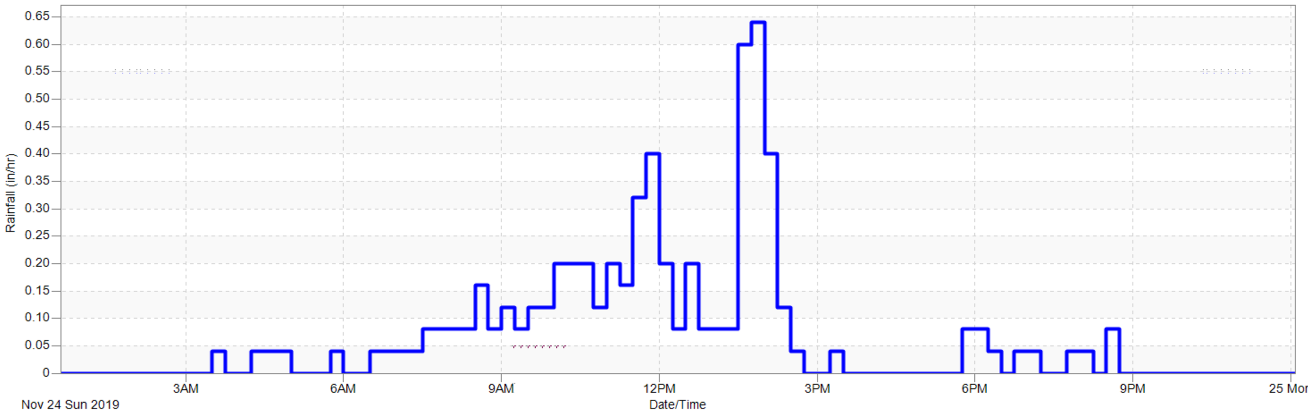


Figure 34. Chelsea Creek November 24, 2019

Appendix E: Meter Data Scattergraphs

Contents

The scattergraphs cover the period of April 15, 2018 to December 31, 2019. In locations where the meter was removed on March 1, 2019 the scattergraphs cover the period of April 15, 2018 to February 28, 2019.

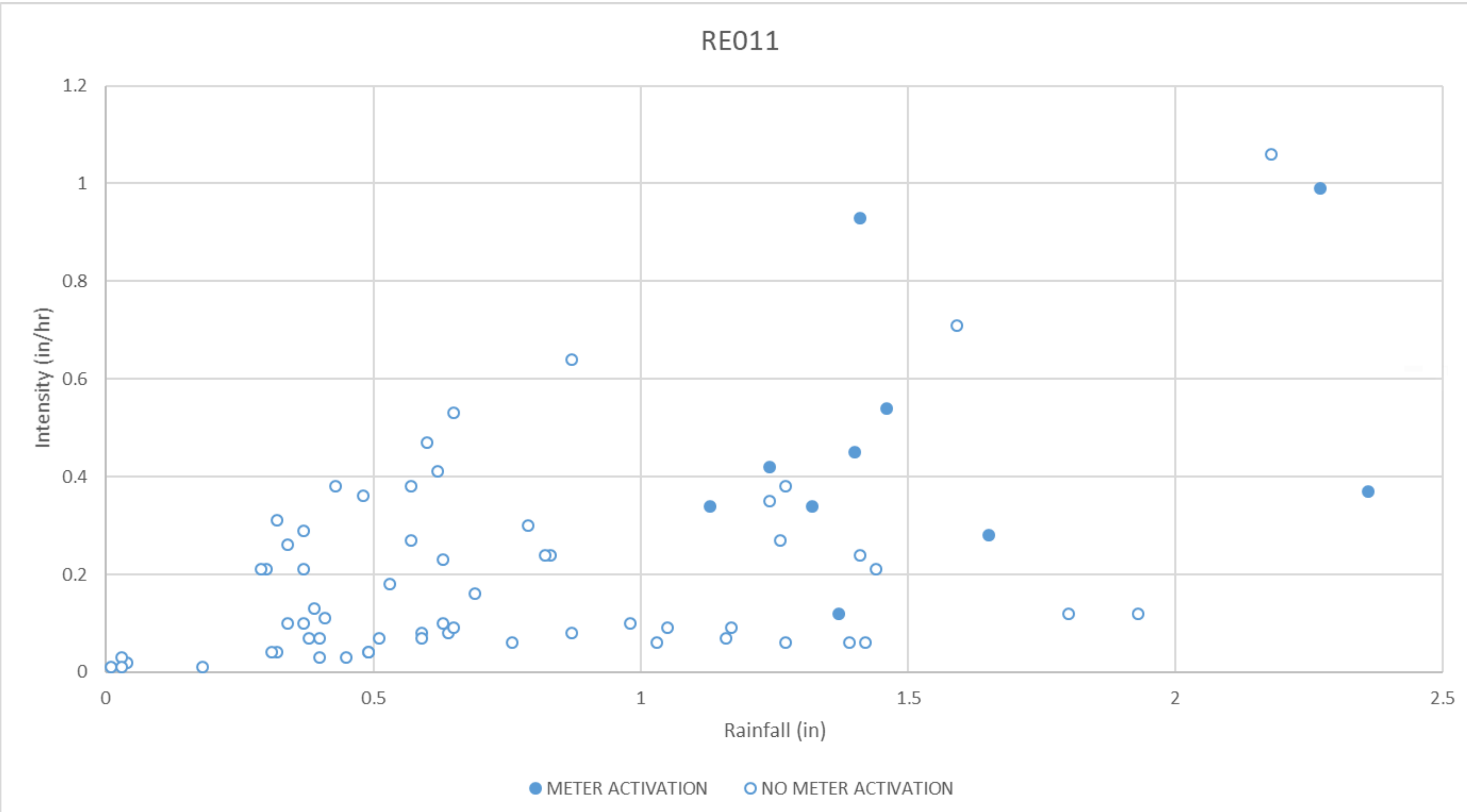
Outfall	Regulator
Alewife Brook	
CAM001	RE-011
CAM002	RE-021
MWR003	RE-031
CAM401A	RE-401
CAM401B	RE-401B
SOM001A	RE-01A
Upper Mystic River	
SOM007A/MWR205A	
Mystic/Chelsea Confluence	
MWR205 (Somerville Marginal Facility)	
BOS013	RE013-1
BOS014	RE014-2
BOS017	RE017-3
CHE003	RE-031
CHE004	RE-041
CHE008	RE-081
Upper Inner Harbor	
BOS009	RE009-2
BOS010	RE010-2
BOS012	RE012-2
BOS019	RE019-2
BOS057	RE057-6
BOS060	RE060-7
	RE060-20
MWR203 (Prison Point)	
Lower Inner Harbor	
BOS003	RE003-2
	RE003-7
	RE003-12
BOS004	RE004-6
BOS005	RE005-1

Fort Point Channel	
BOS062	RE062-4
BOS064	RE064-4
	RE064-5
BOS065	RE065-2
BOS068	RE068-1A
BOS070/DBC	RE070/8-3
	RE070/8-6
	RE070/8-7
	RE070/8-8
	RE070/8-13
	RE070/8-15
	RE070/9-4
	RE070/10-5
	RE070/7-2
MWR215 (Union Park)	
BOS070/RCC	RE070/5-3
BOS073	RE073-4
Reserved Channel	
BOS076	RE076/2-3
	RE076/4-3
BOS078	RE078-1 RE078-2
BOS079	RE079-3
BOS080	RE080-2B
Upper Charles	
CAM005	RE-051
CAM007	RE-071
Lower Charles	
CAM017	CAM017
MWR010	RE036-9
	RE037
MWR201	Cottage Farm
MWR023	RE046-19
	RE046-30
	RE046-50
	RE046-54
	RE046-55
	RE046-62A
	RE046-90
	RE046-100
	RE046-105
	RE046-381
	RE046-192

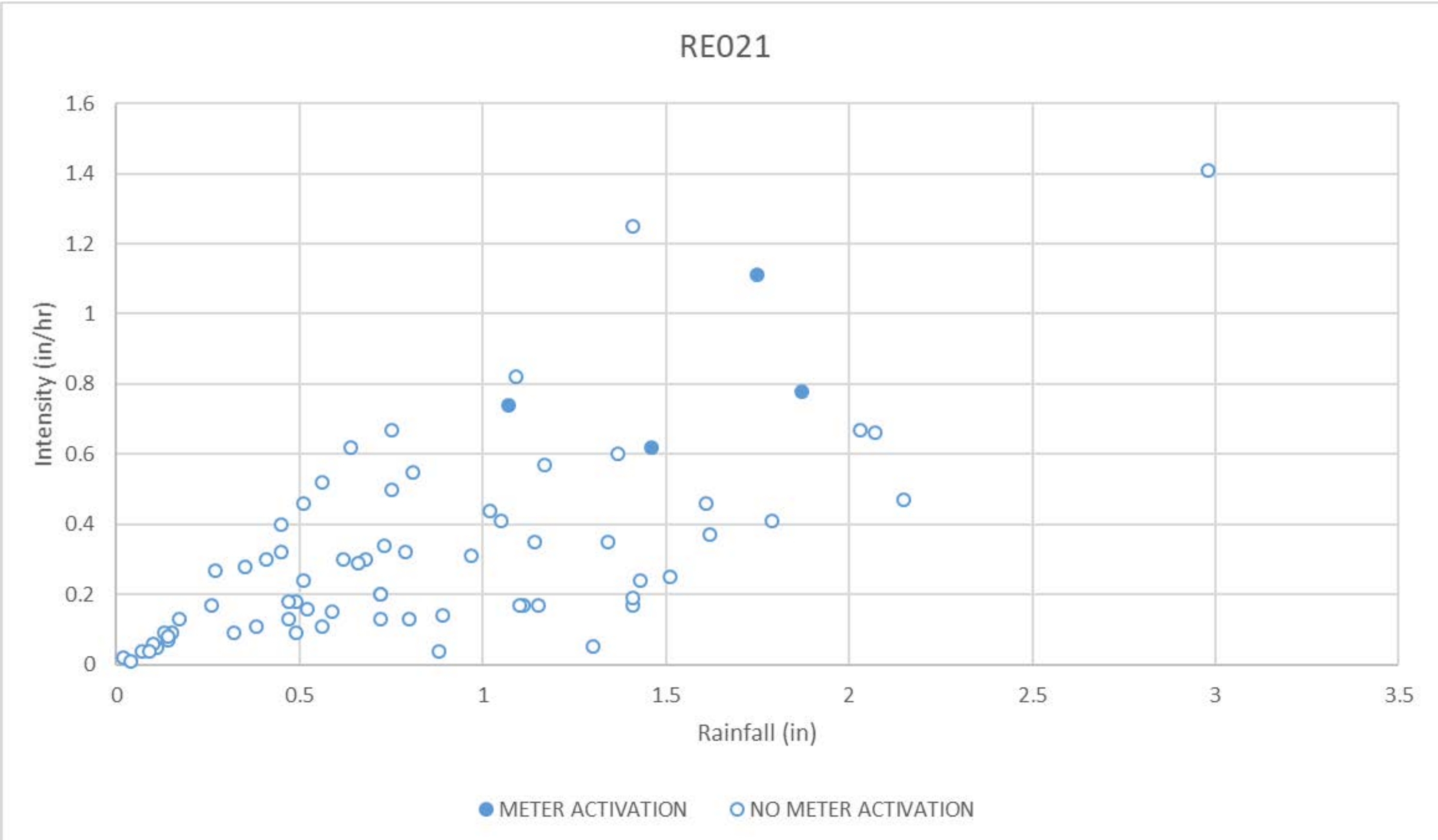
Alewife Brook

CAM001	RE-011
CAM002	RE-021
MWR003	RE-031
CAM401A	RE-401
CAM401B	RE-401B
SOM001A	RE-01A

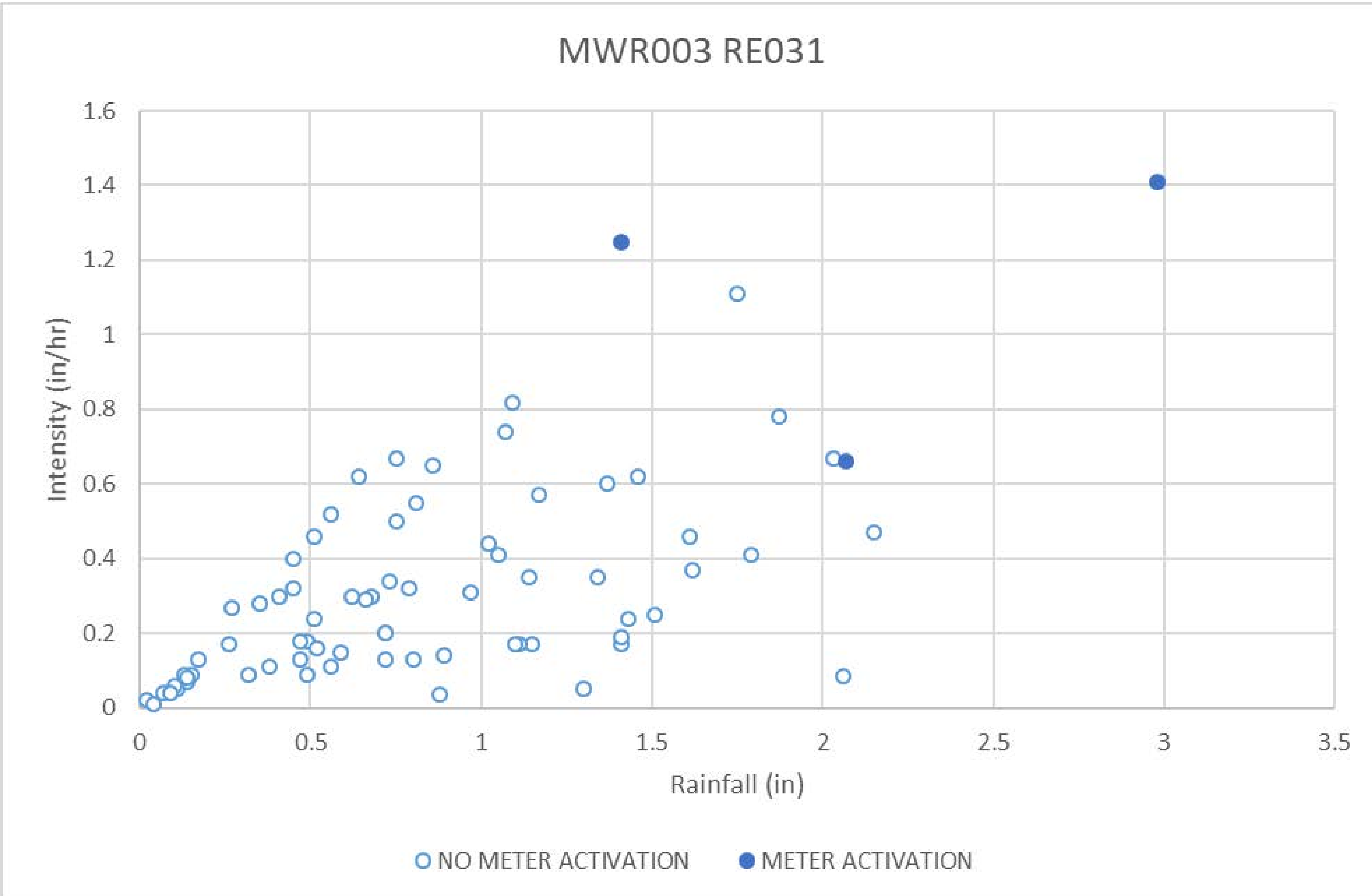
Outfall: CAM001
Regulator: RE011
Related Rain Gauge: 16



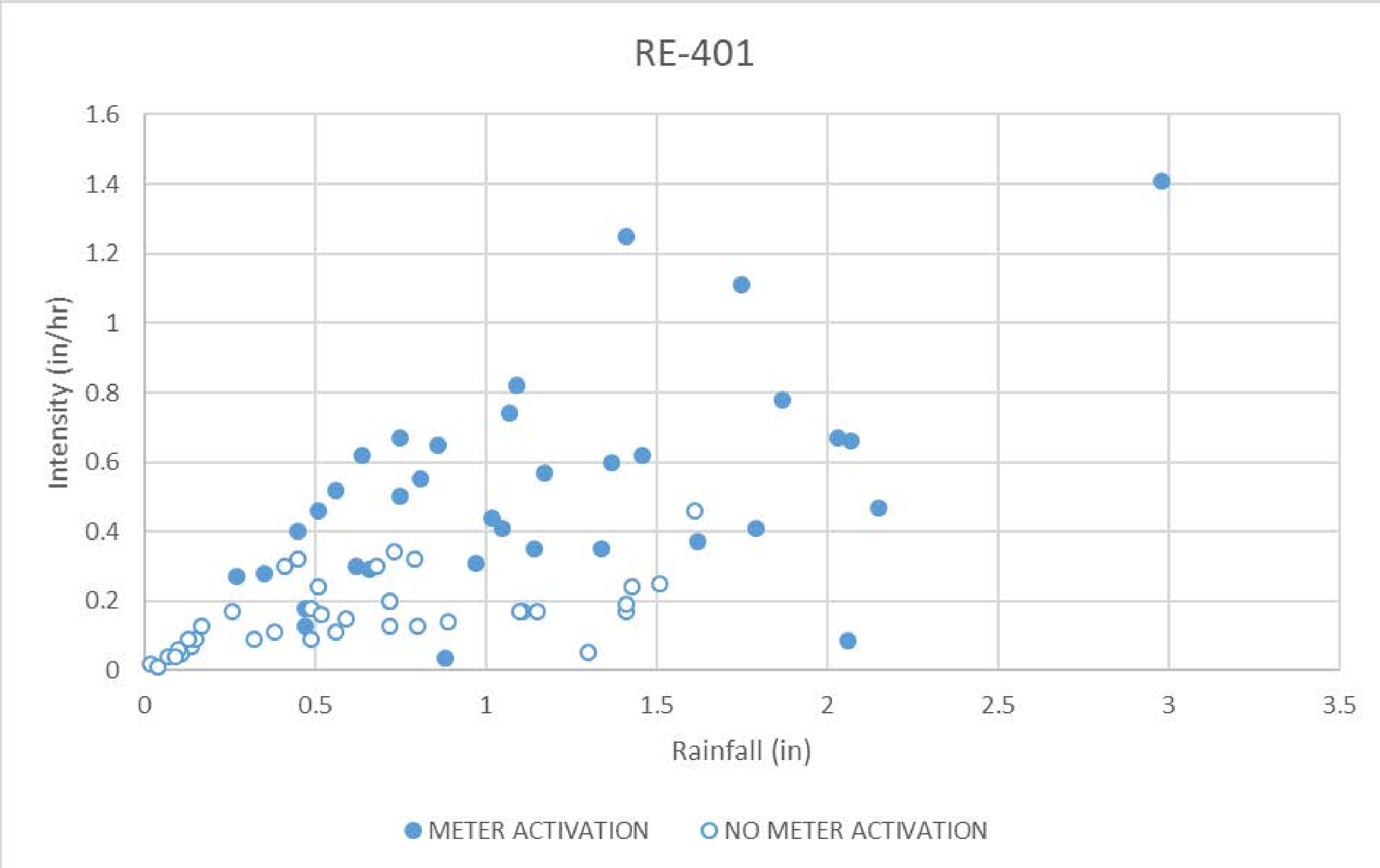
Outfall:CAM002
Regulator: RE021
Related Rain Gauge: 19



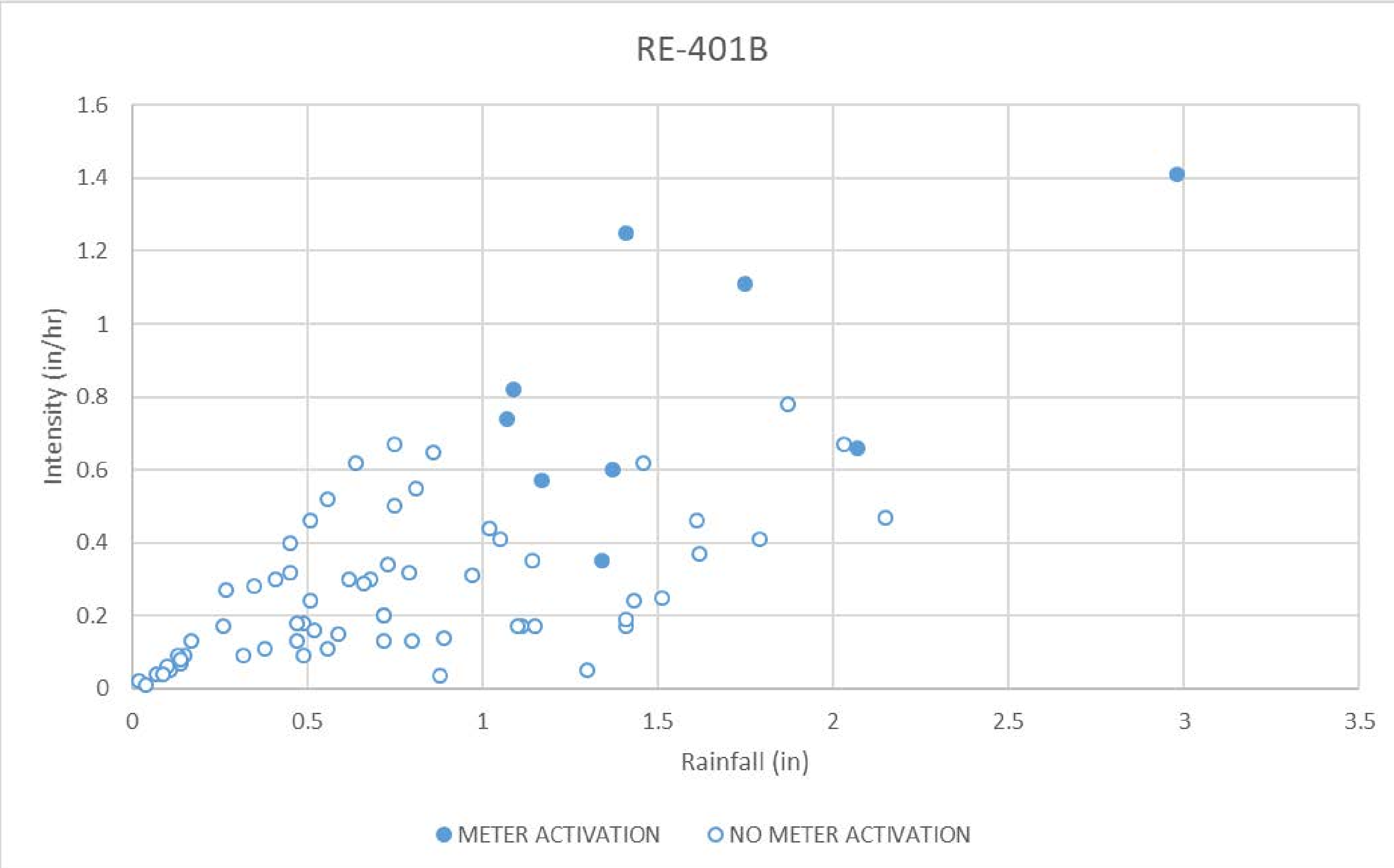
Outfall:MWR003
Regulator: RE031
Related Rain Gauge: 19



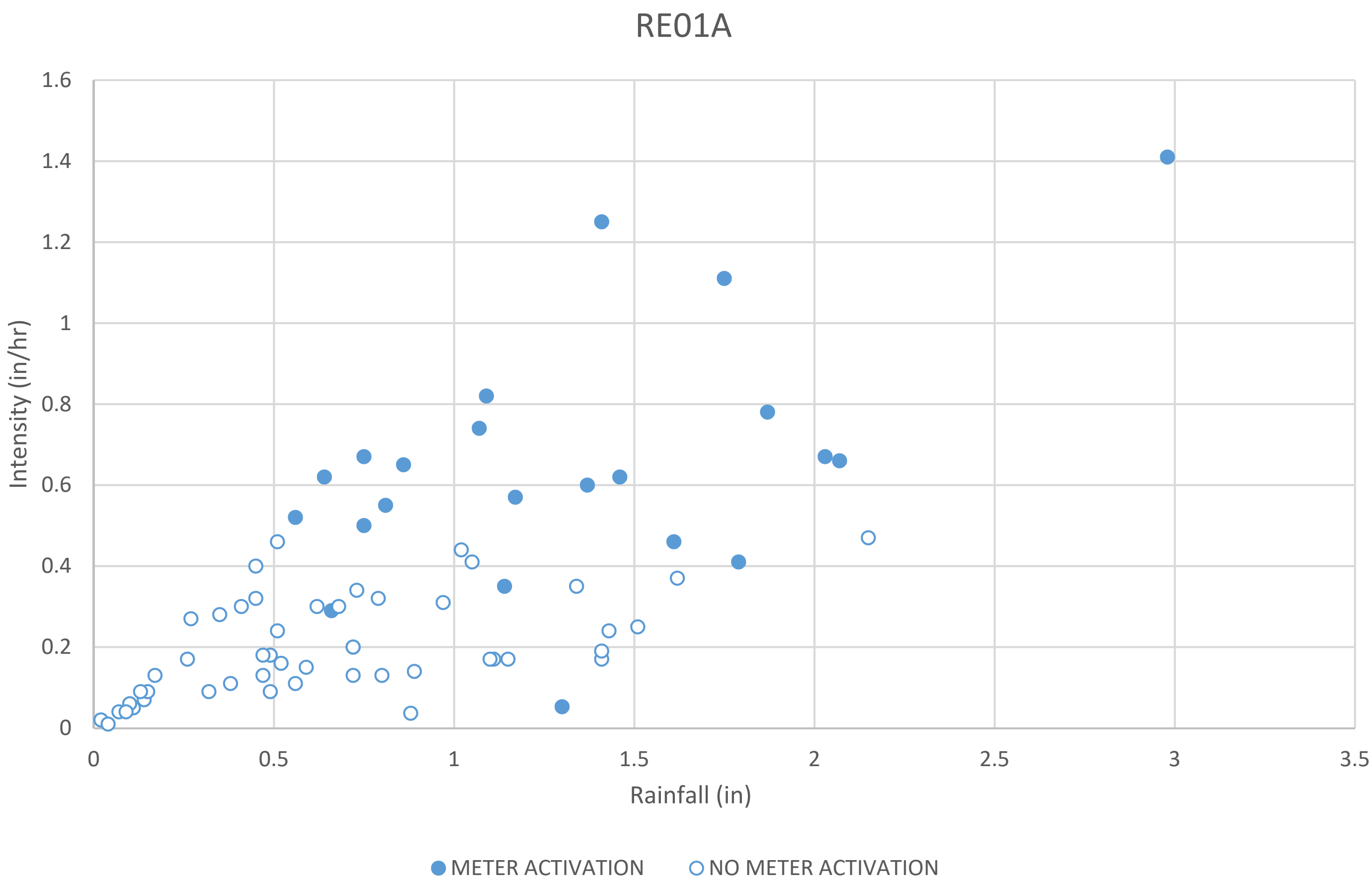
Outfall:CAM401a
Regulator: RE401
Related Rain Gauge: 19



Outfall:CAM401B
Regulator: RE401B
Related Rain Gauge: 19



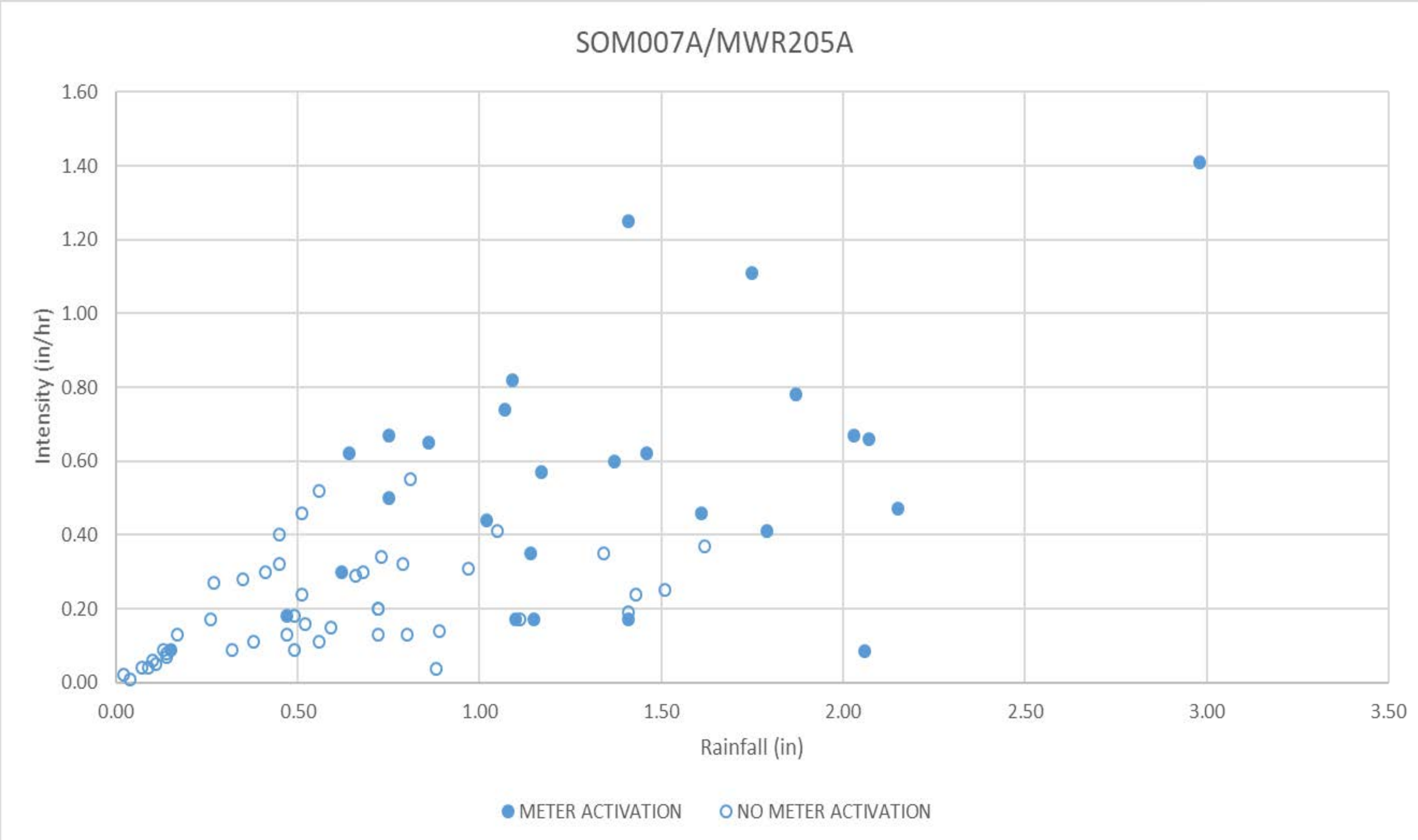
Outfall:SOM001A
Regulator: RE01A
Related Rain Gauge: 19



Upper Mystic River

SOM007/MWR205A

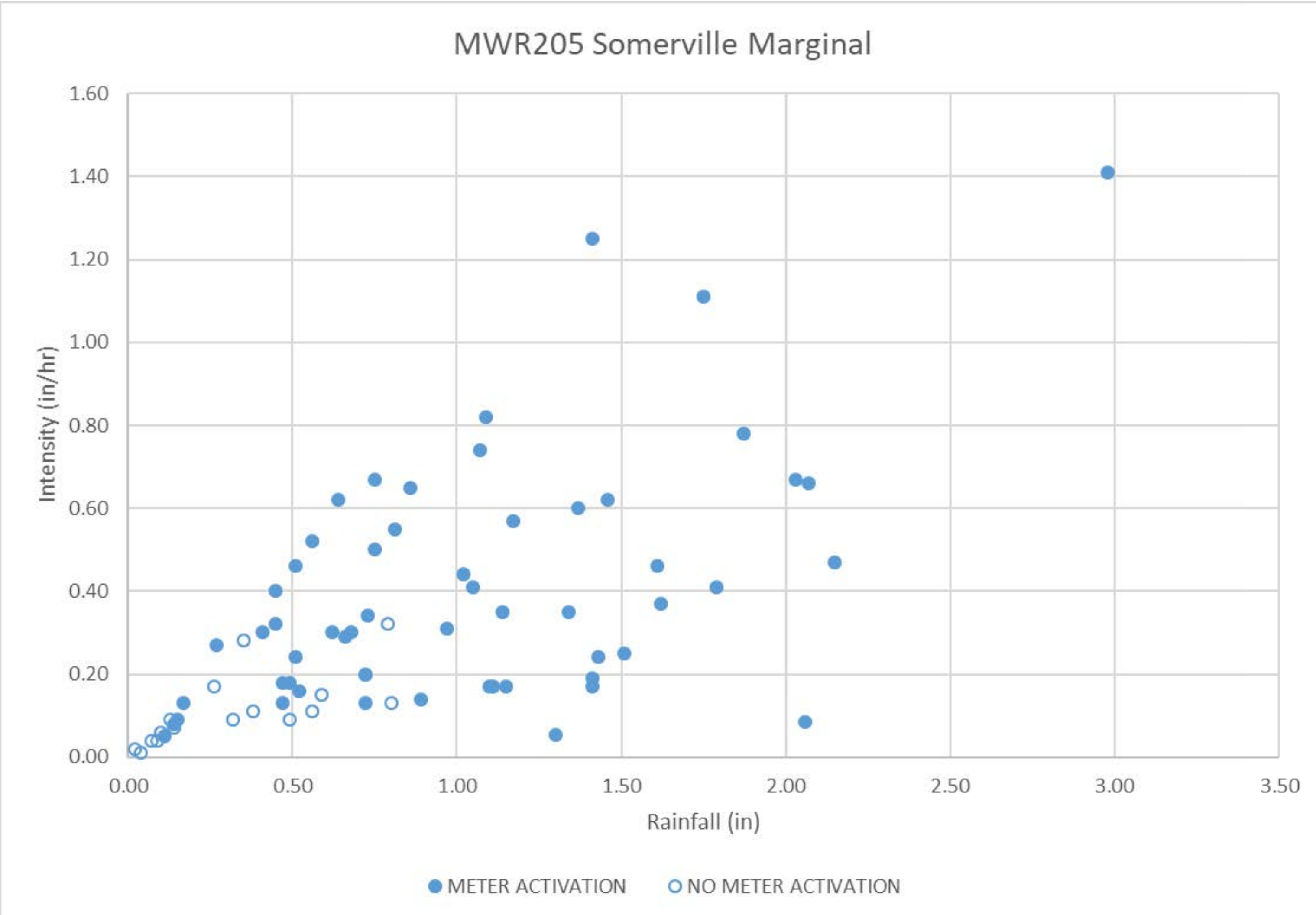
Outfall:SOM007A/MWR205A
Related Rain Gauge: 19



Mystic/Chelsea Confluence

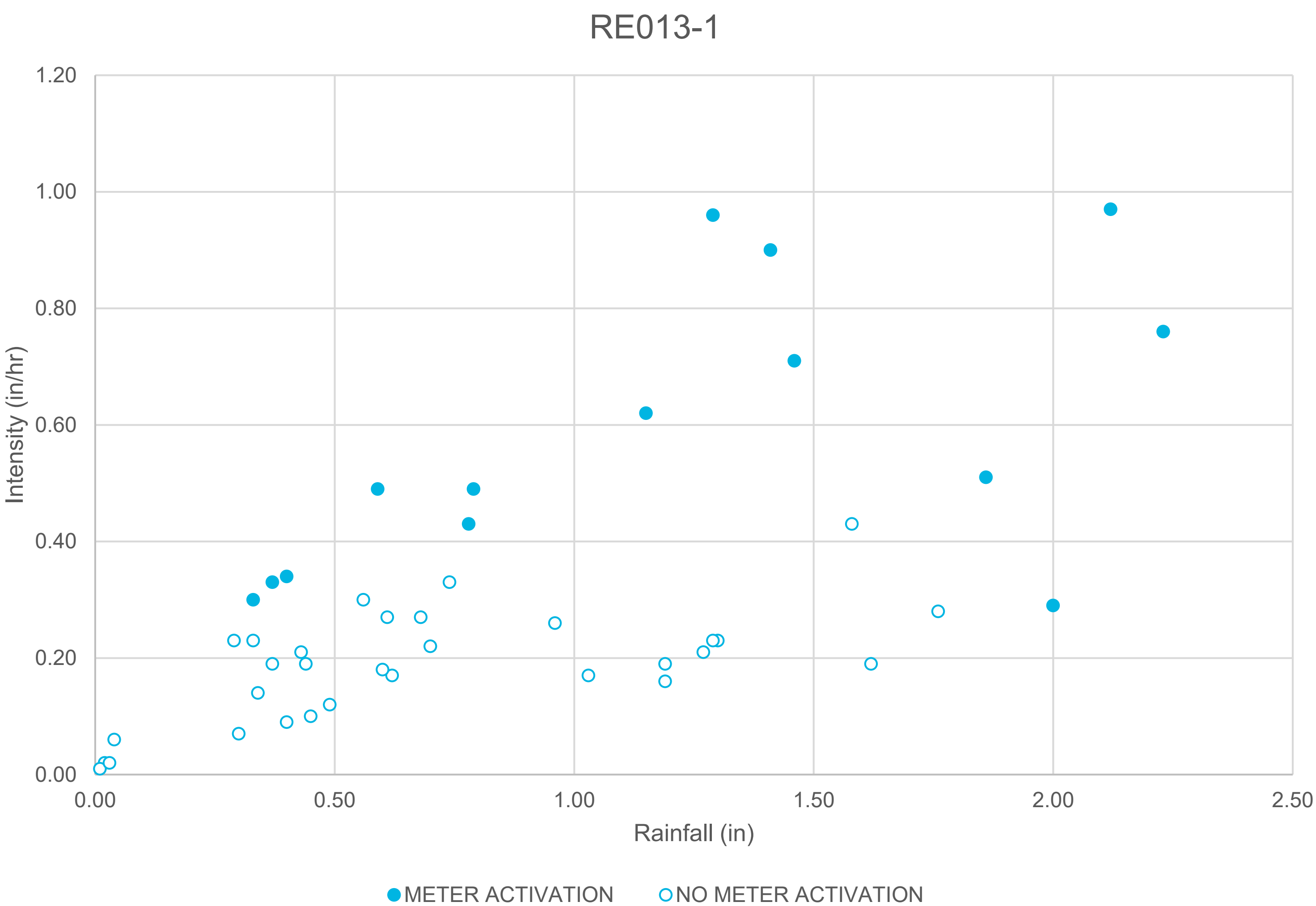
MWR205 (Somerville Marginal Facility)	
BOS013	RE013-1
BOS014	RE014-2
BOS017	RE017-3
CHE003	RE-031
CHE004	RE-041
CHE008	RE-081

Outfall:MWR205 (Somerville Marginal)
Related Rain Gauge: 19



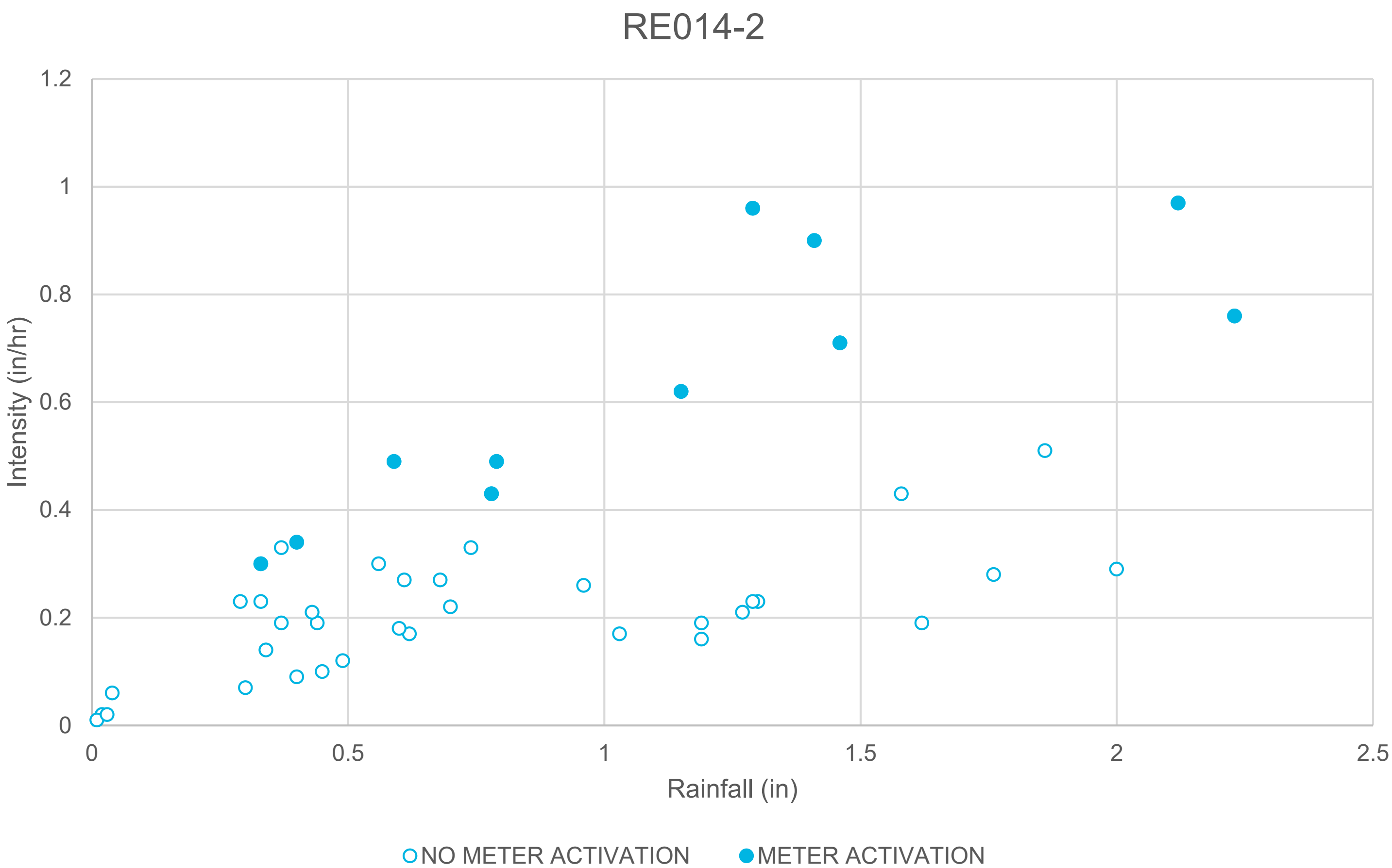
Meter activation represents an activation in which flow was discharged out of Somerville Marginal.

Outfall: BOS013
Regulator: RE013-1
Related Rain Gauge: 8



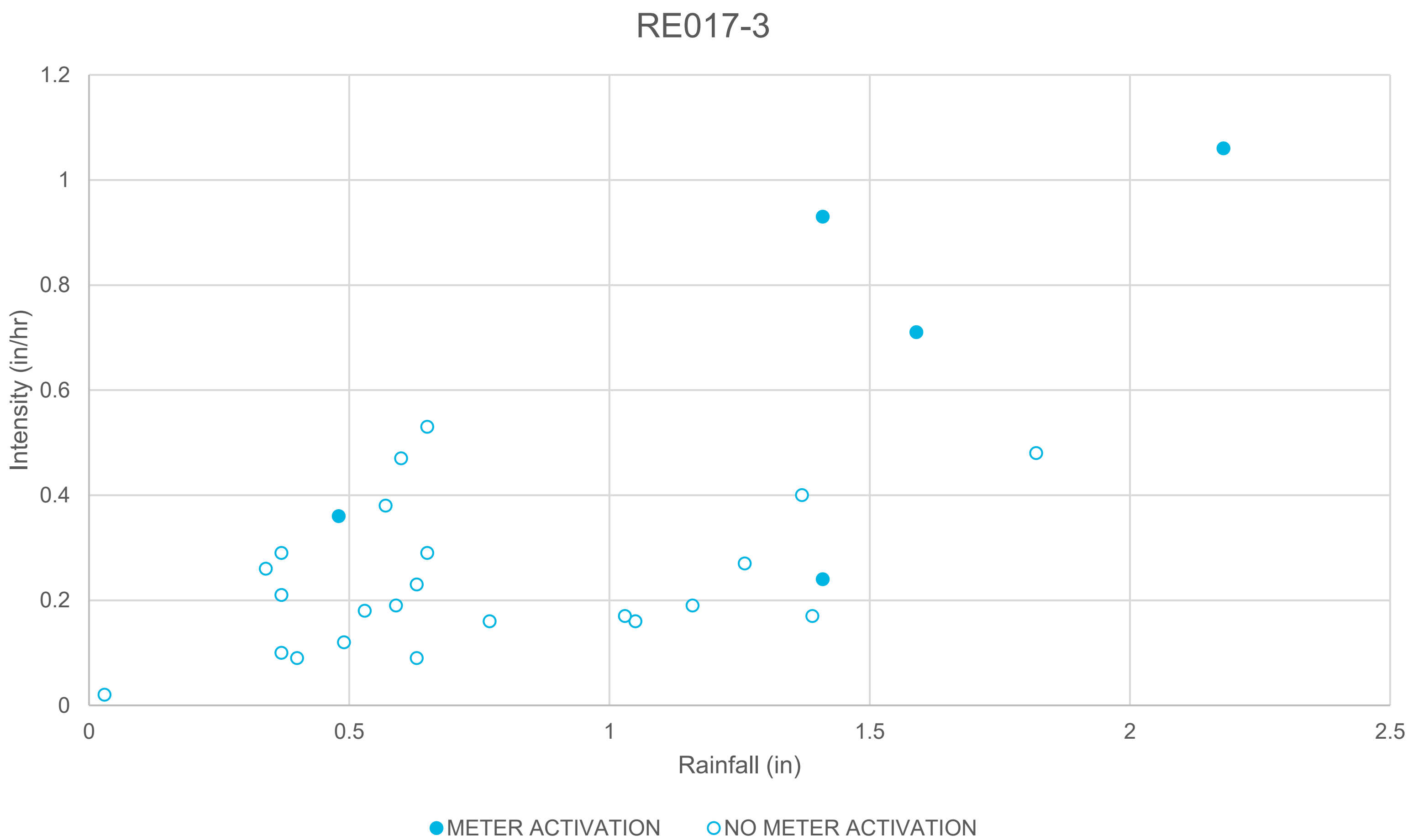
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS014
Regulator: RE014-2
Related Rain Gauge: 8



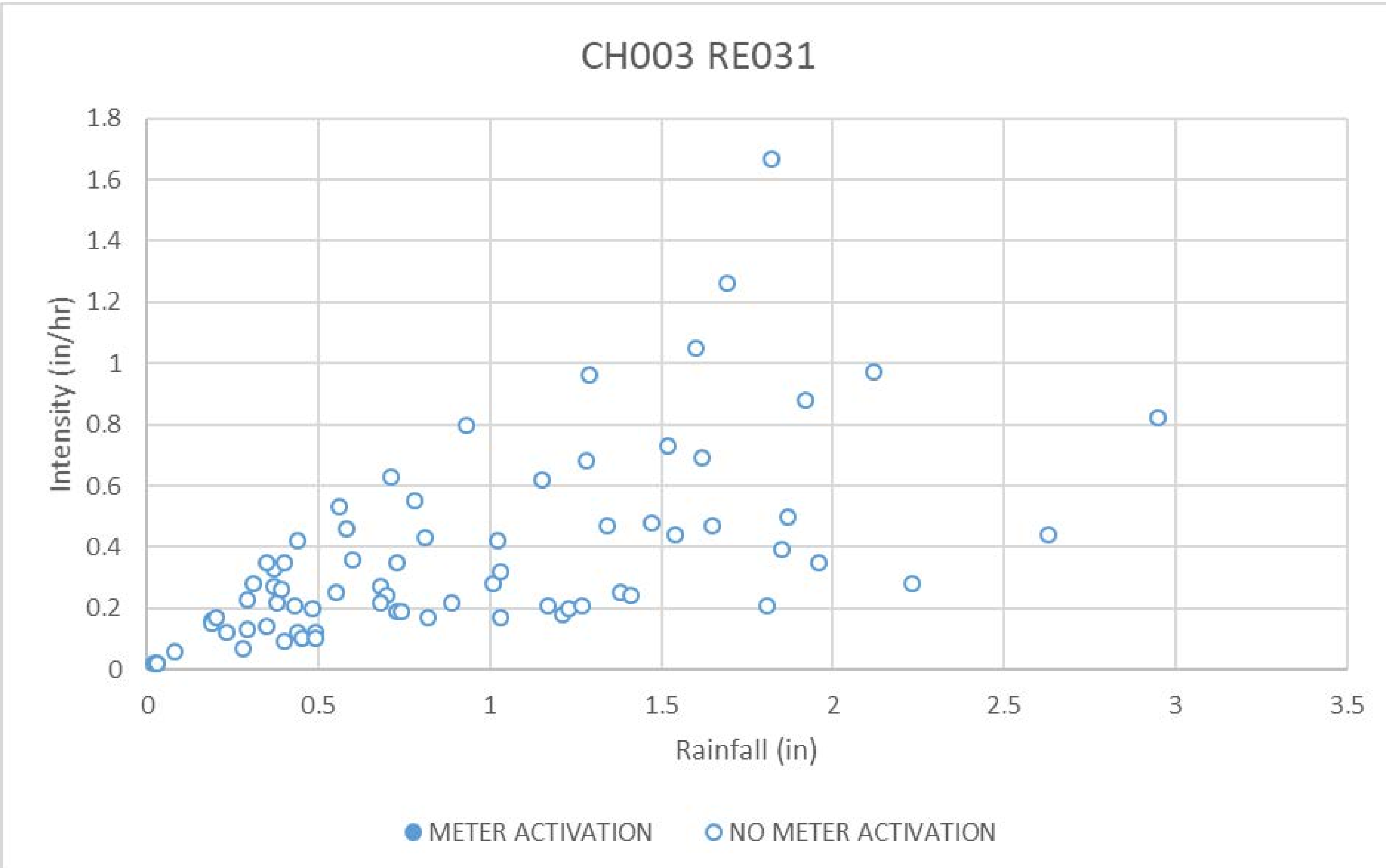
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS017
Regulator: RE017-3
Related Rain Gauge: 4

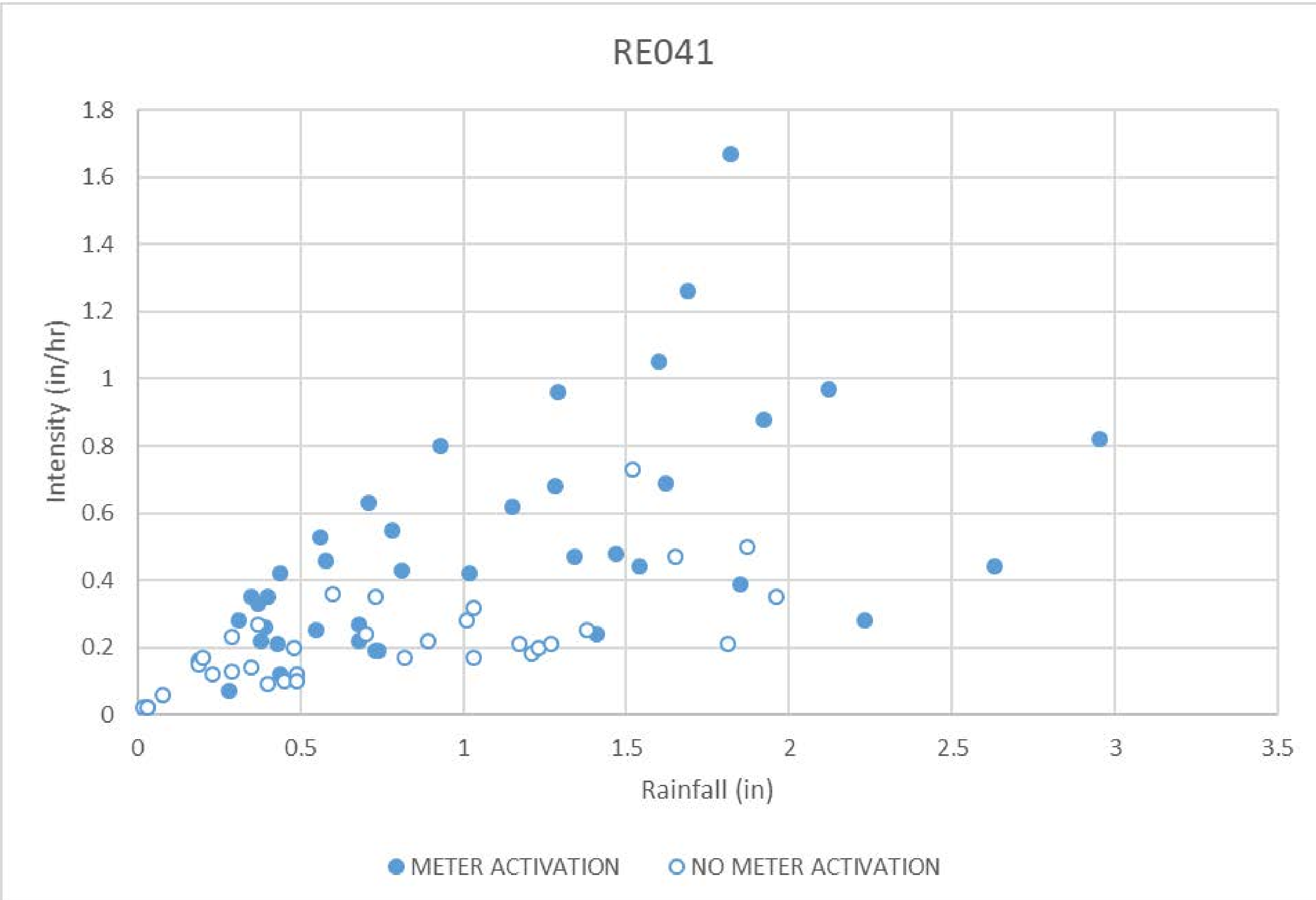


Does not include activations from April 15-July 18. After July 18 an inclinometer was added providing increased confidence in CSO activations
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

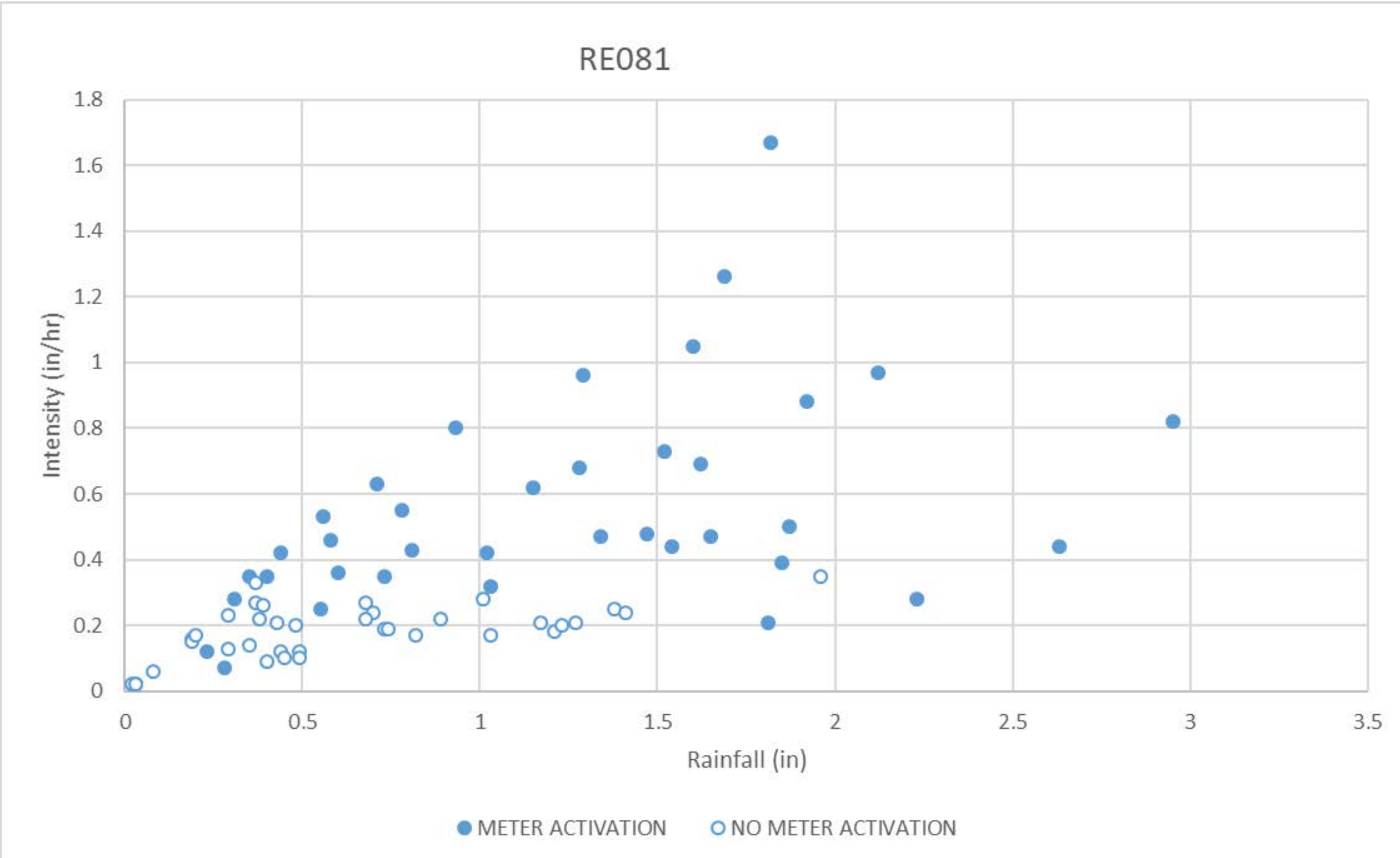
Outfall: CHE003
Regulator: RE031
Related Rain Gauge: 5



Outfall: CHE004
Regulator: RE041
Related Rain Gauge: 5



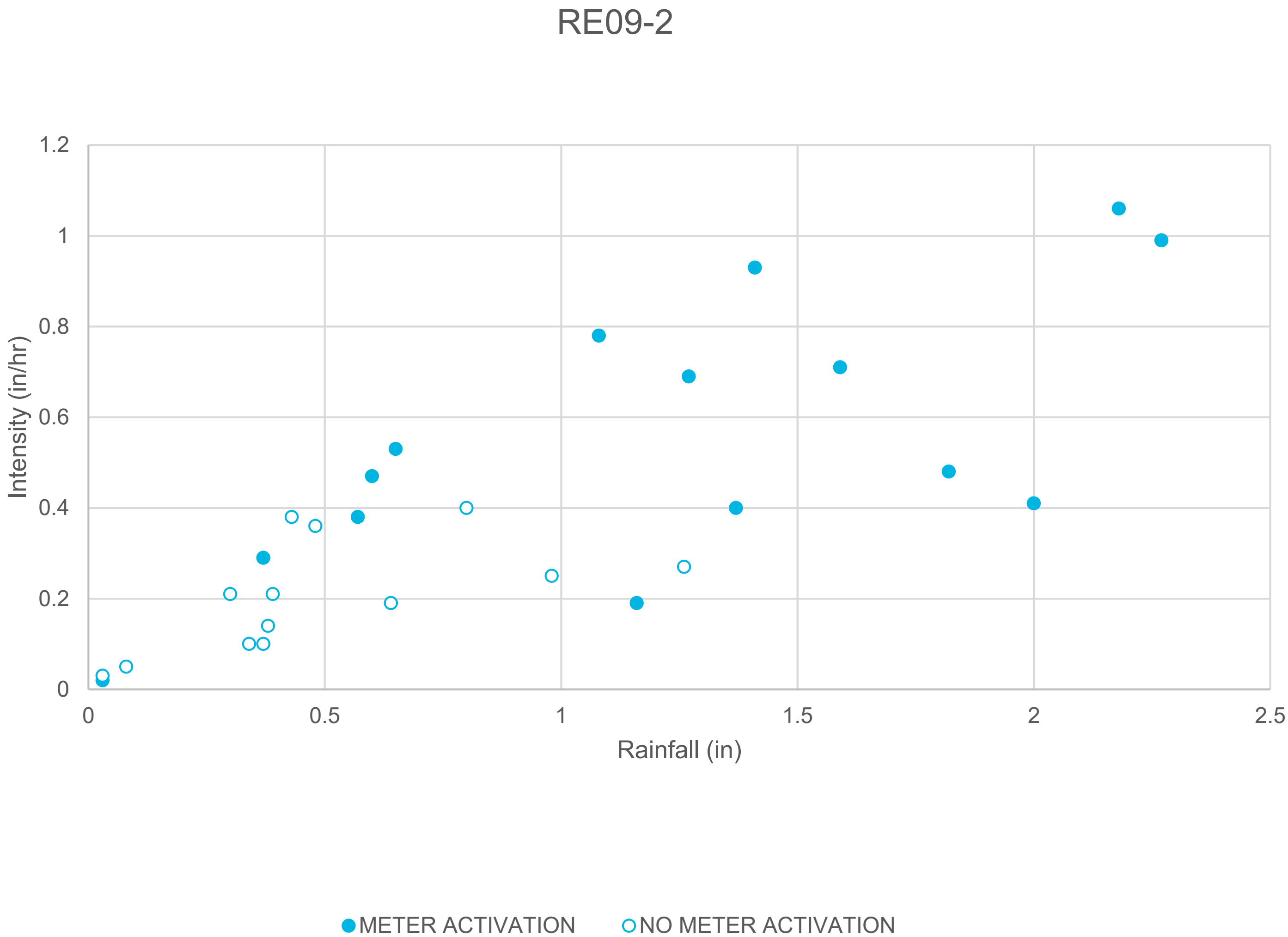
Outfall: CHE008
Regulator: RE081
Related Rain Gauge: 5



Upper Inner Harbor

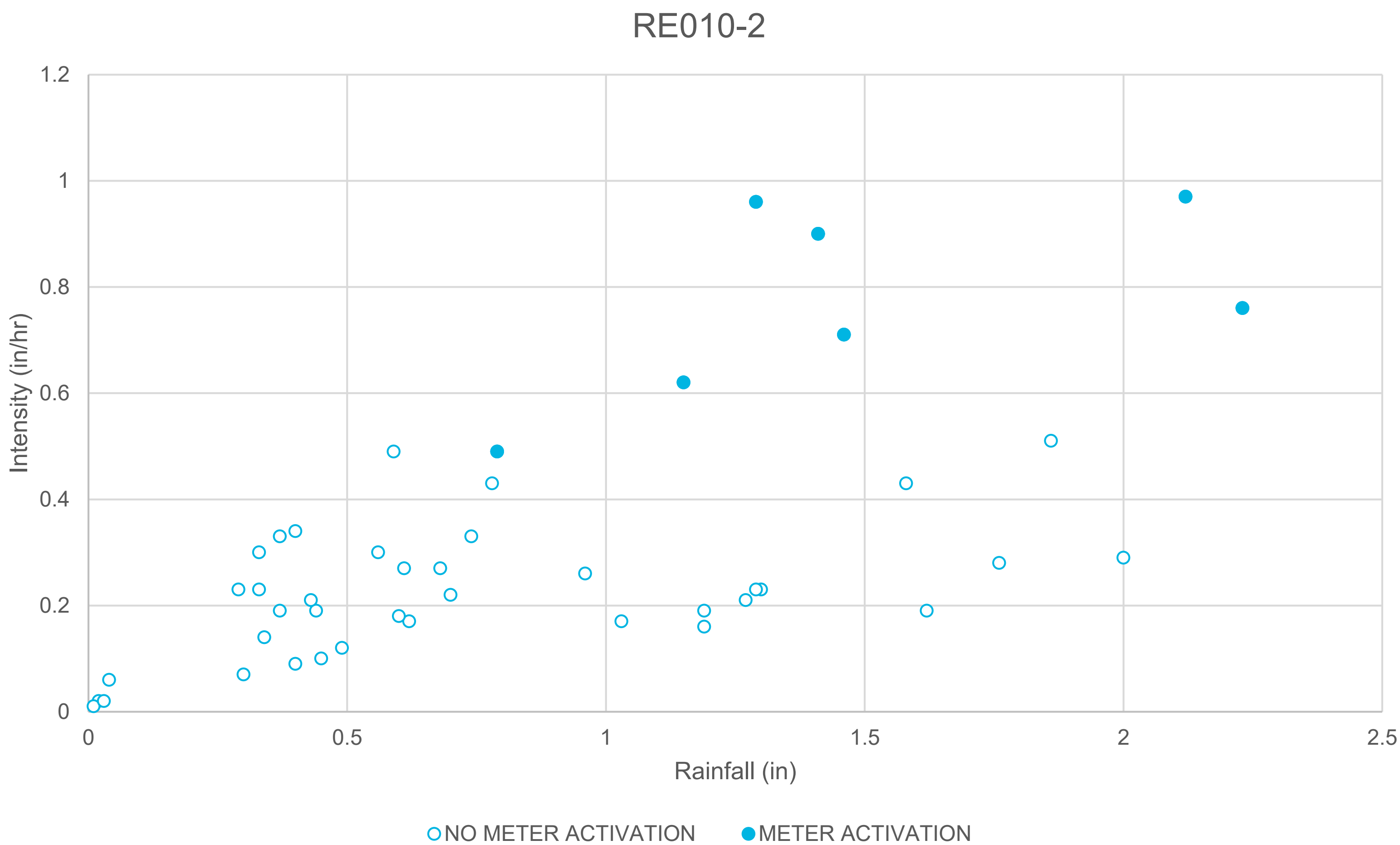
BOS009	RE009-2
BOS010	RE010-2
BOS012	RE012-2
BOS019	RE019-2
BOS057	RE057-6
BOS060	RE060-7
	RE060-20
MWR203 (Prison Point)	

Outfall: BOS09
Regulator: RE09-2
Related Rain Gauge: 4



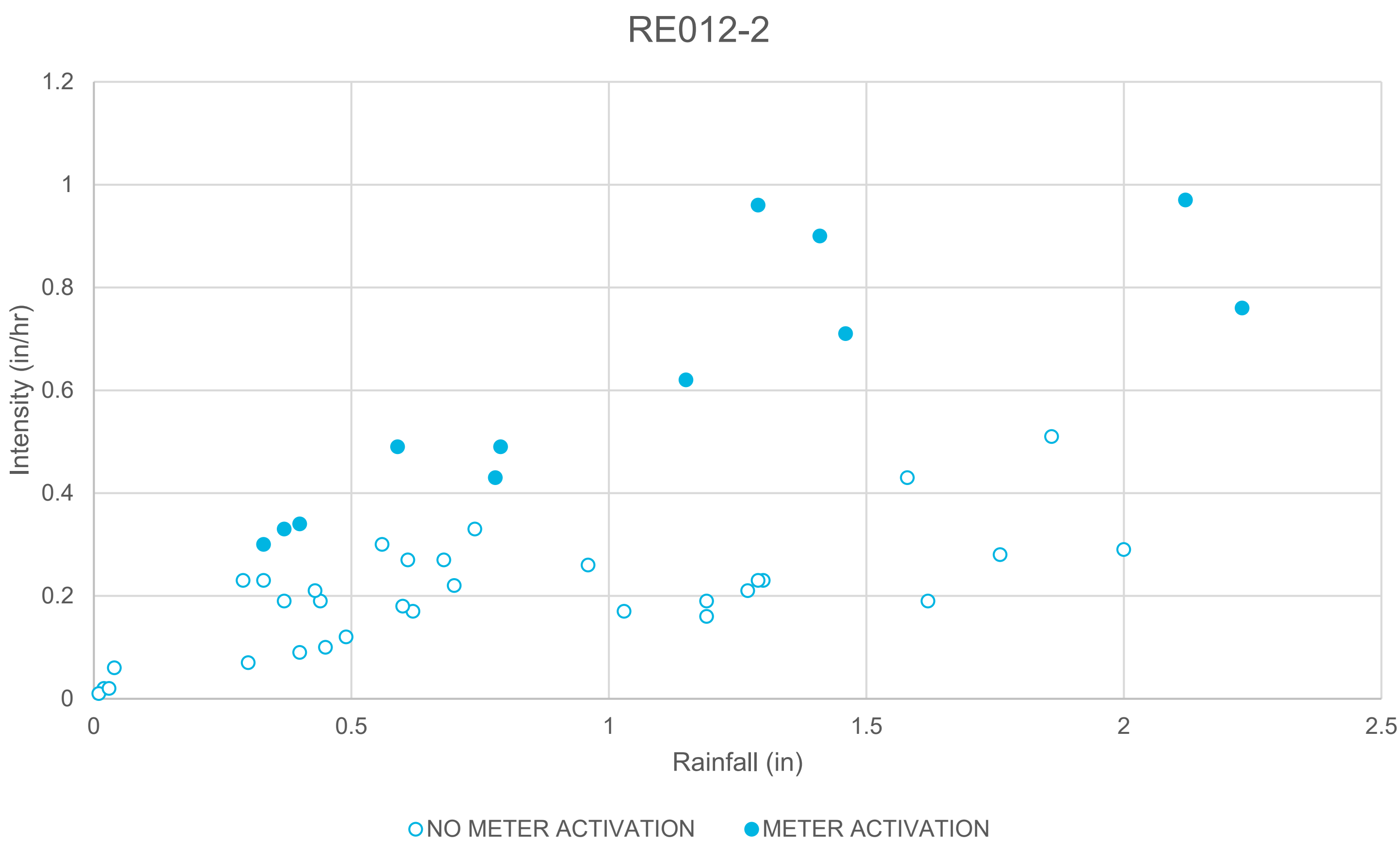
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS010
Regulator: RE010-2
Related Rain Gauge: 8



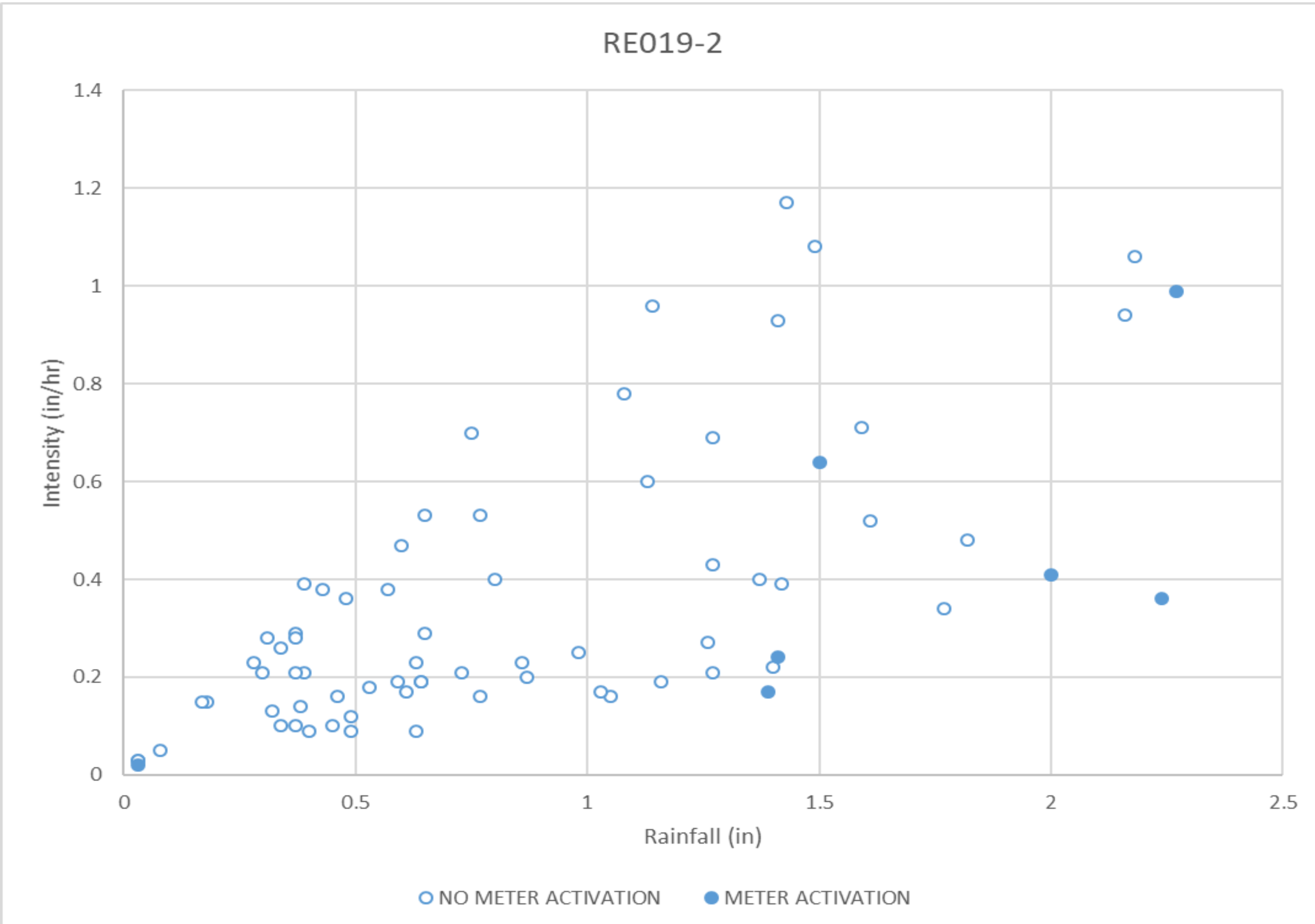
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS012
Regulator: RE012-2
Related Rain Gauge: 8

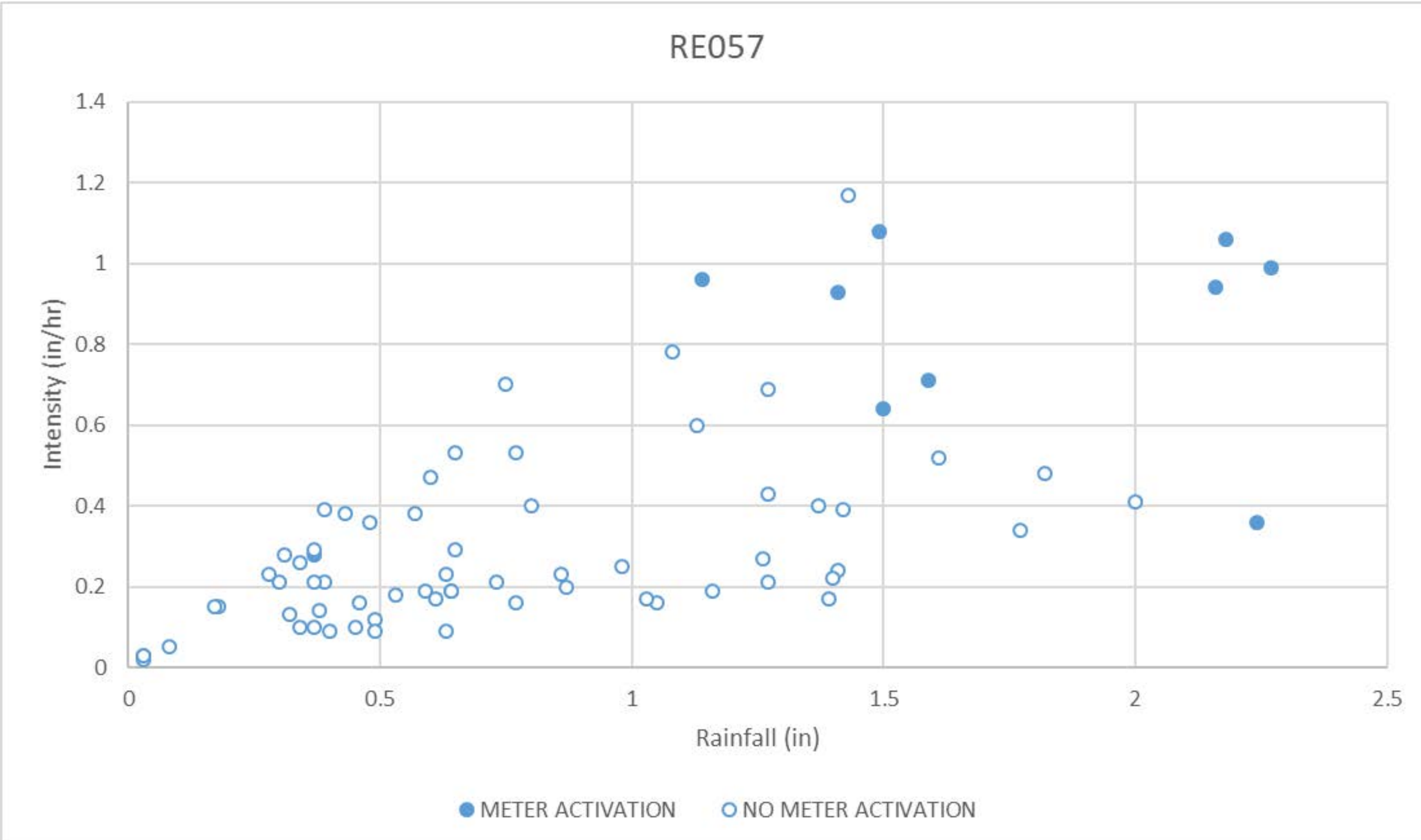


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

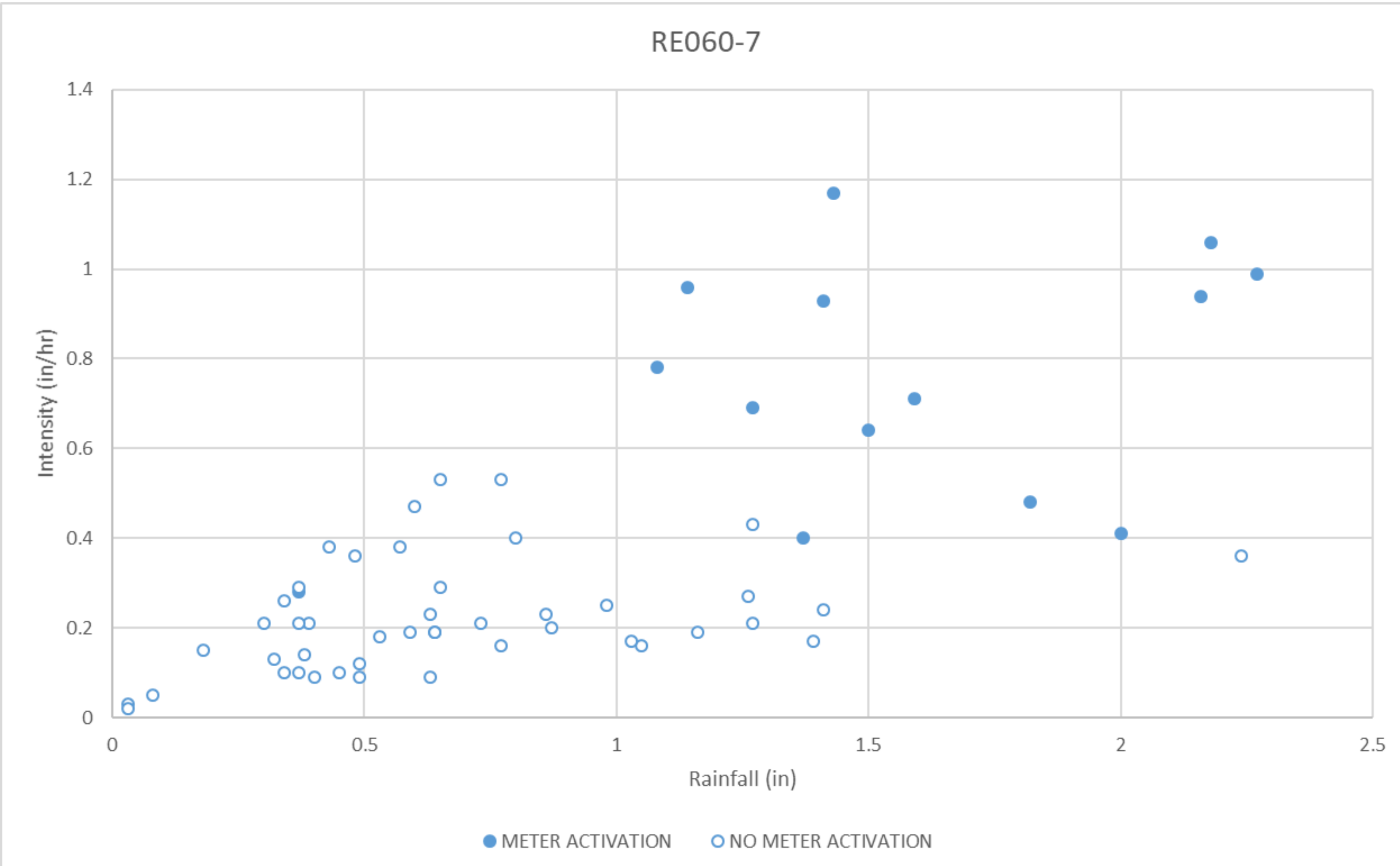
Outfall: BOS019
Regulator: RE019-2
Related Rain Gauge: 4



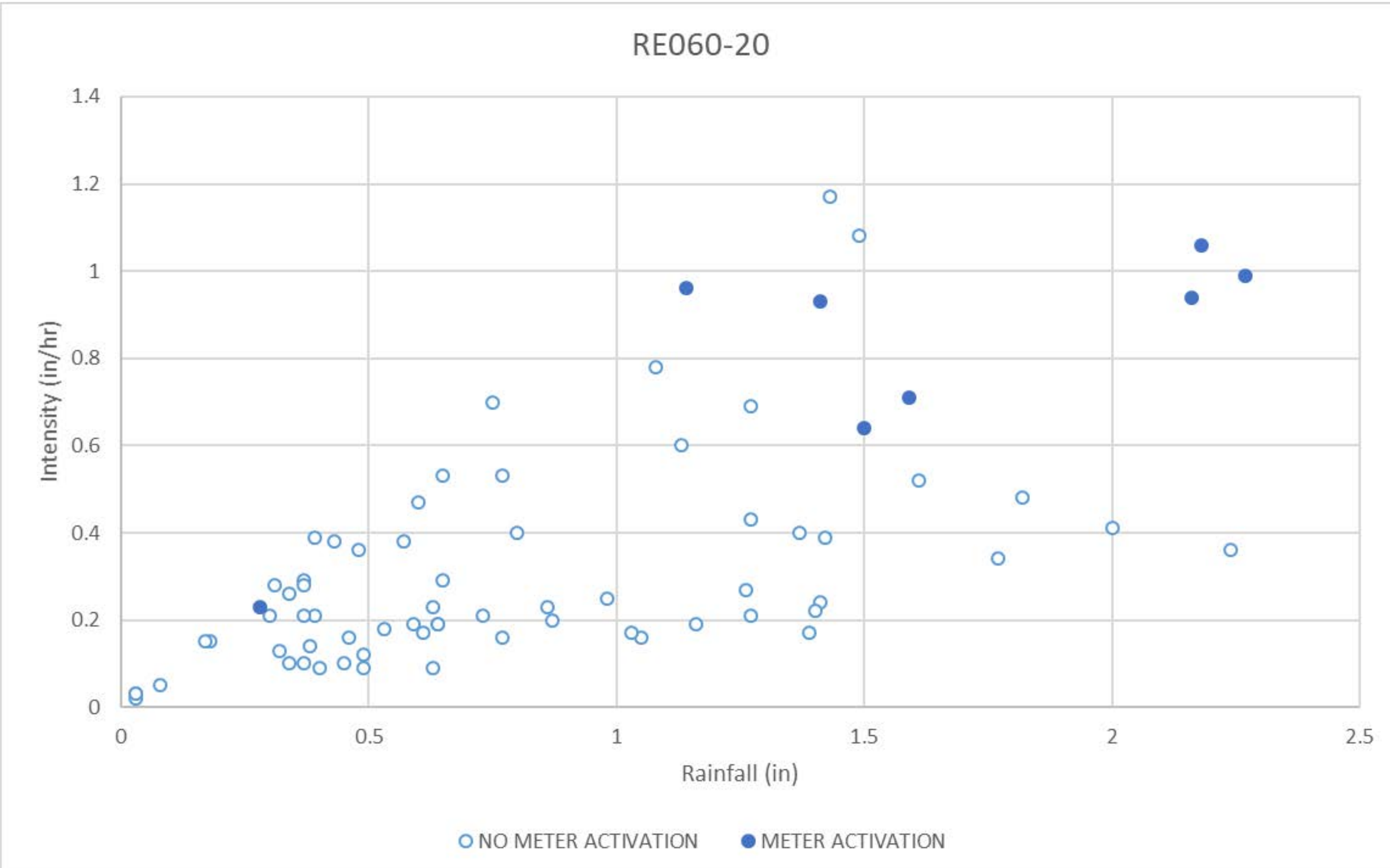
Outfall: BOS057
Regulator: RE057
Related Rain Gauge: 4



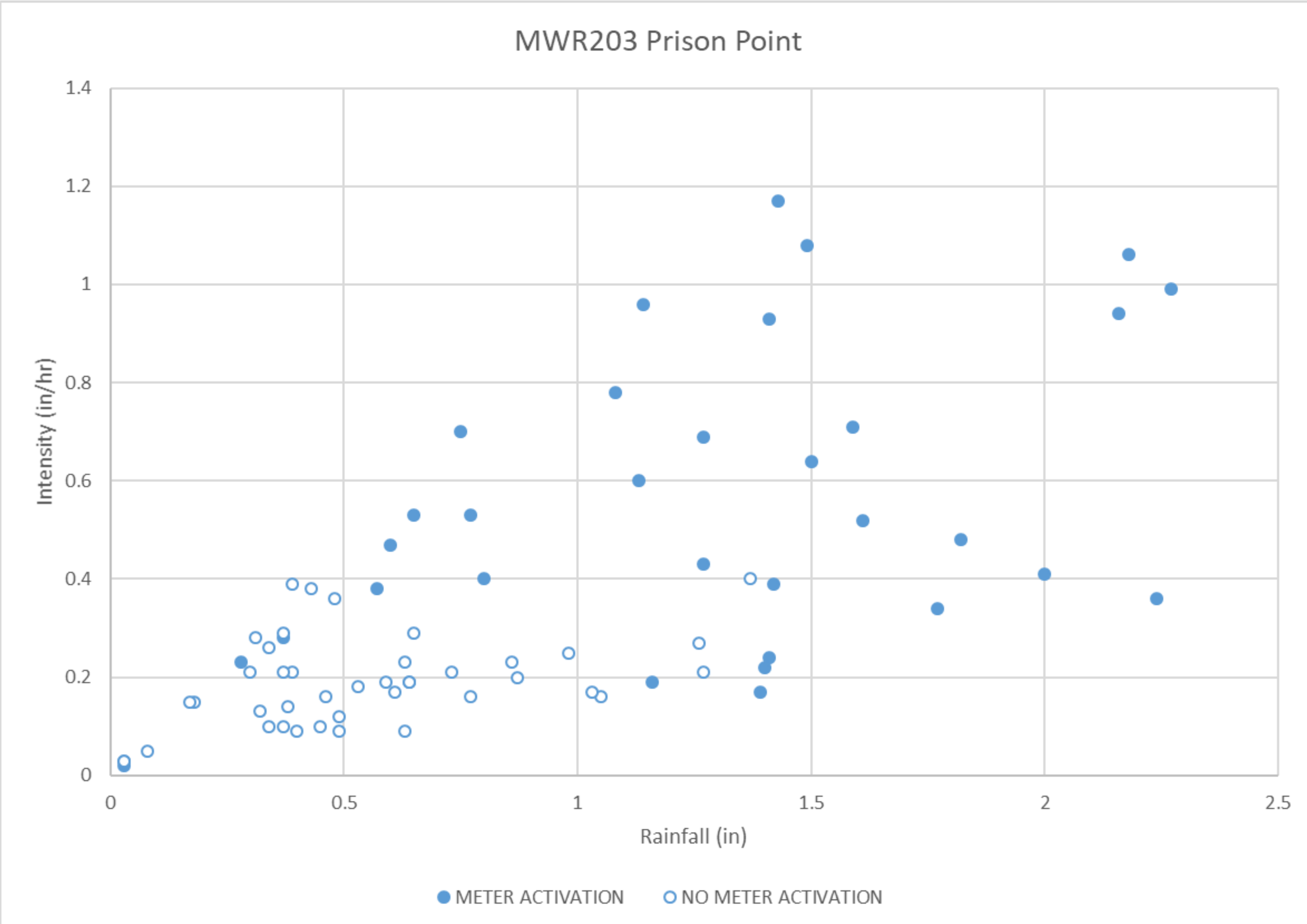
Outfall: BOS060
Regulator: RE060-7
Related Rain Gauge: 4



Outfall: BOS060
Regulator: RE060-20
Related Rain Gauge: 4



Outfall: MWR203
Regulator: Prison Point
Related Rain Gauge: 4

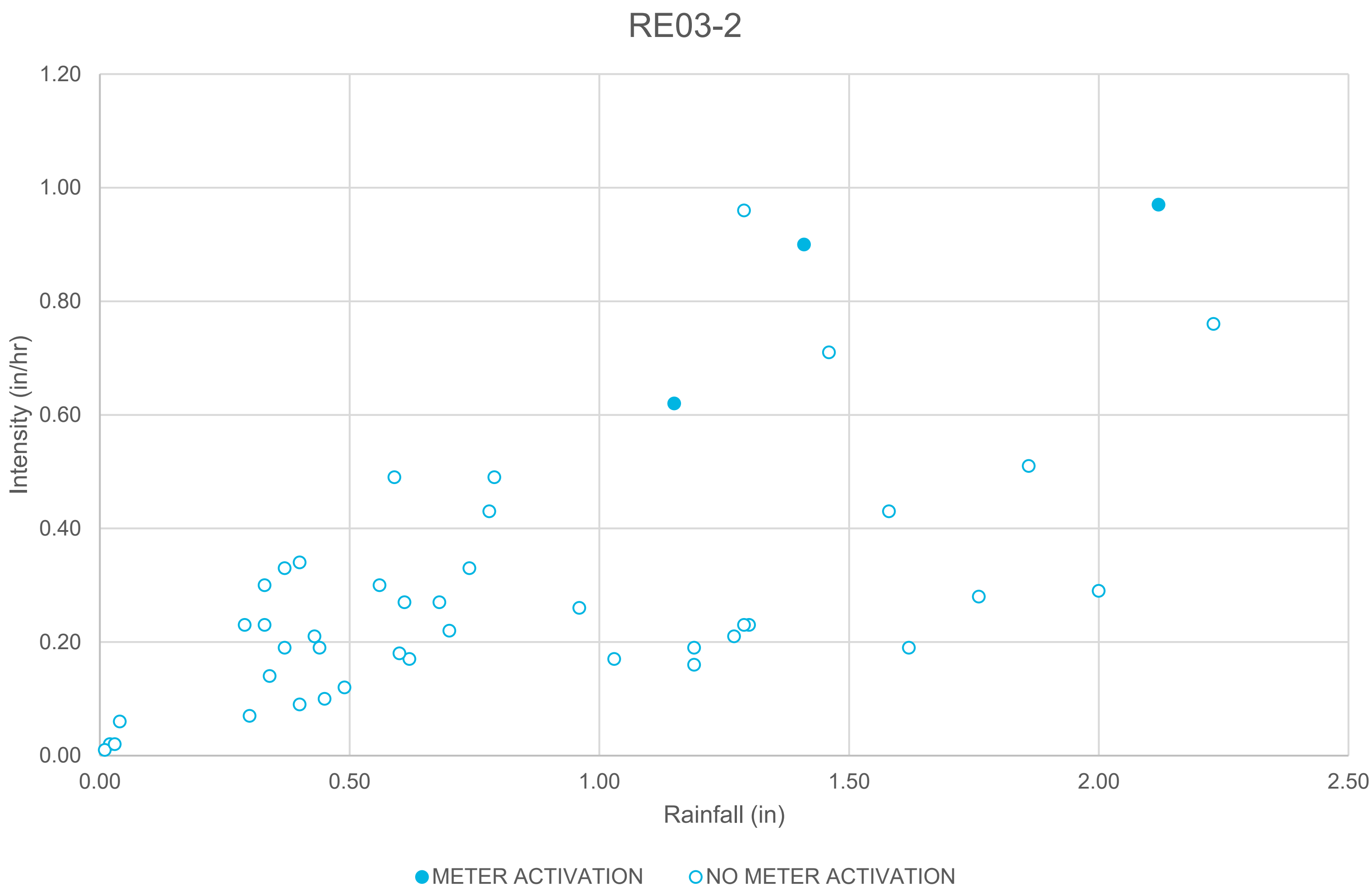


Meter activation represents an activation in which flow was discharged out of Prison Point.

Lower Inner Harbor

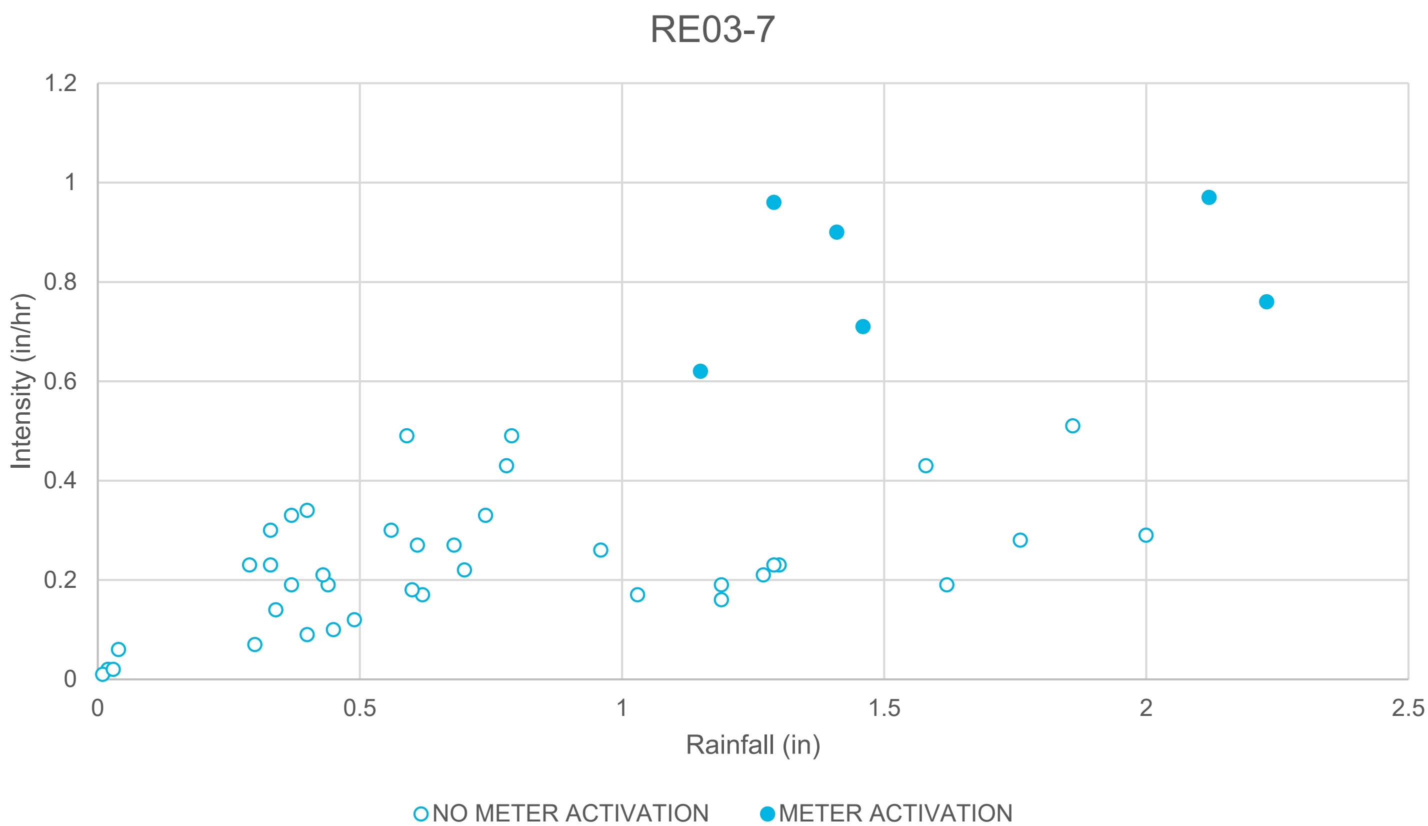
BOS003	RE003-2
	RE003-7
	RE003-12
BOS004	RE004-6
BOS005	RE005-1

Outfall: BOS003
Regulator: RE03-2
Related Rain Gauge: 8



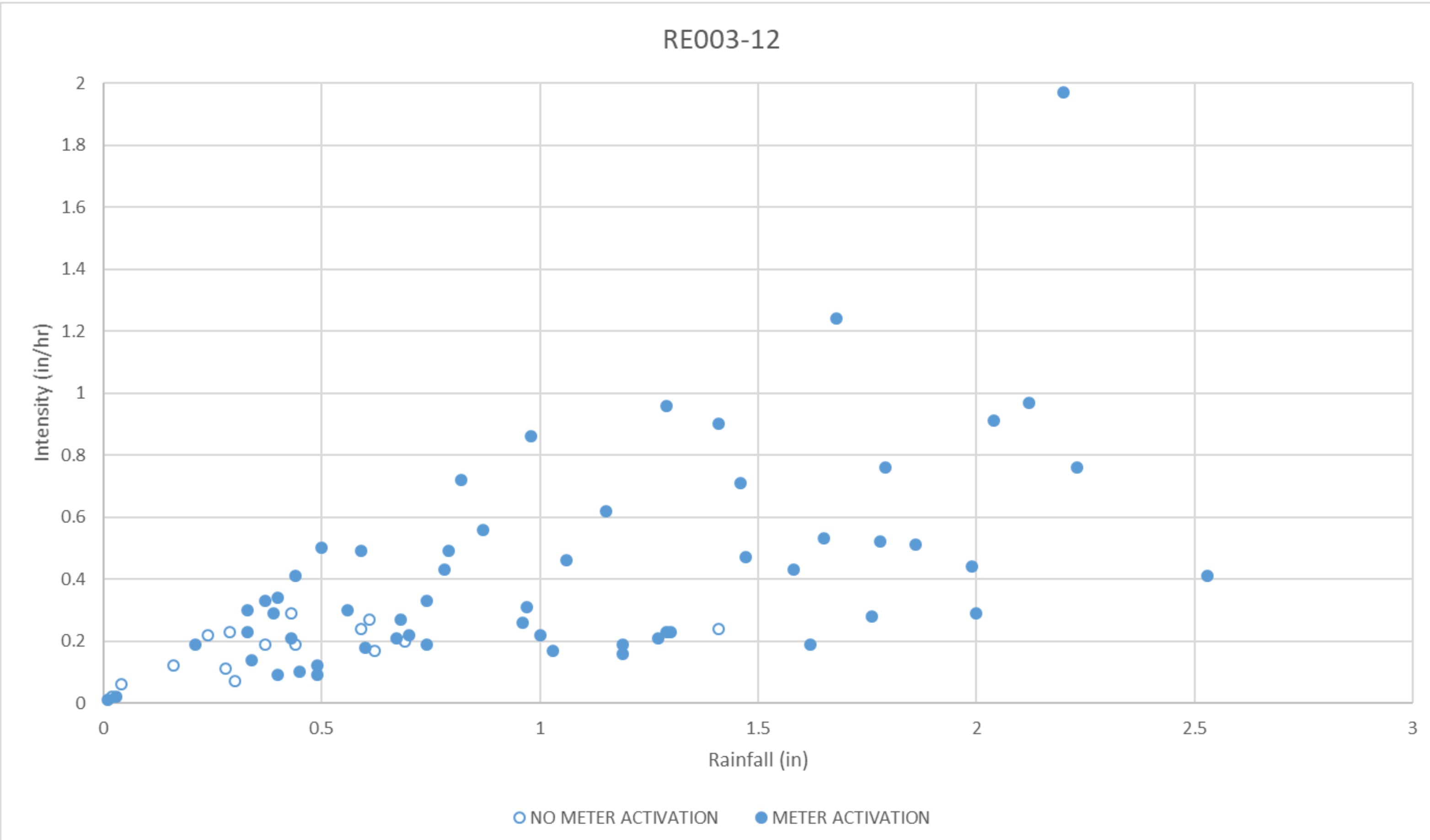
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS003
Regulator: RE03-7
Related Rain Gauge: 8

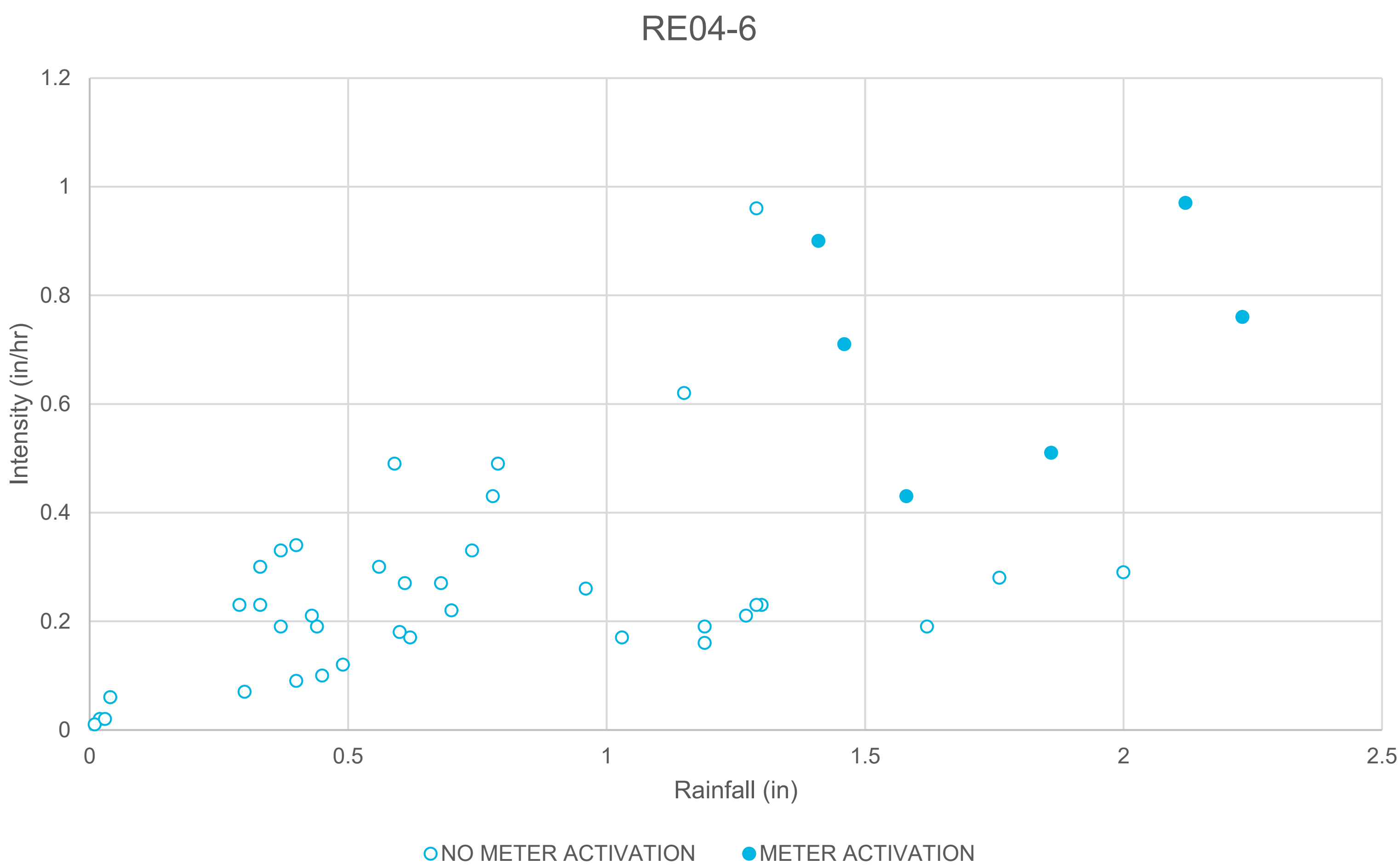


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS003
Regulator: RE03-12
Related Rain Gauge: 8

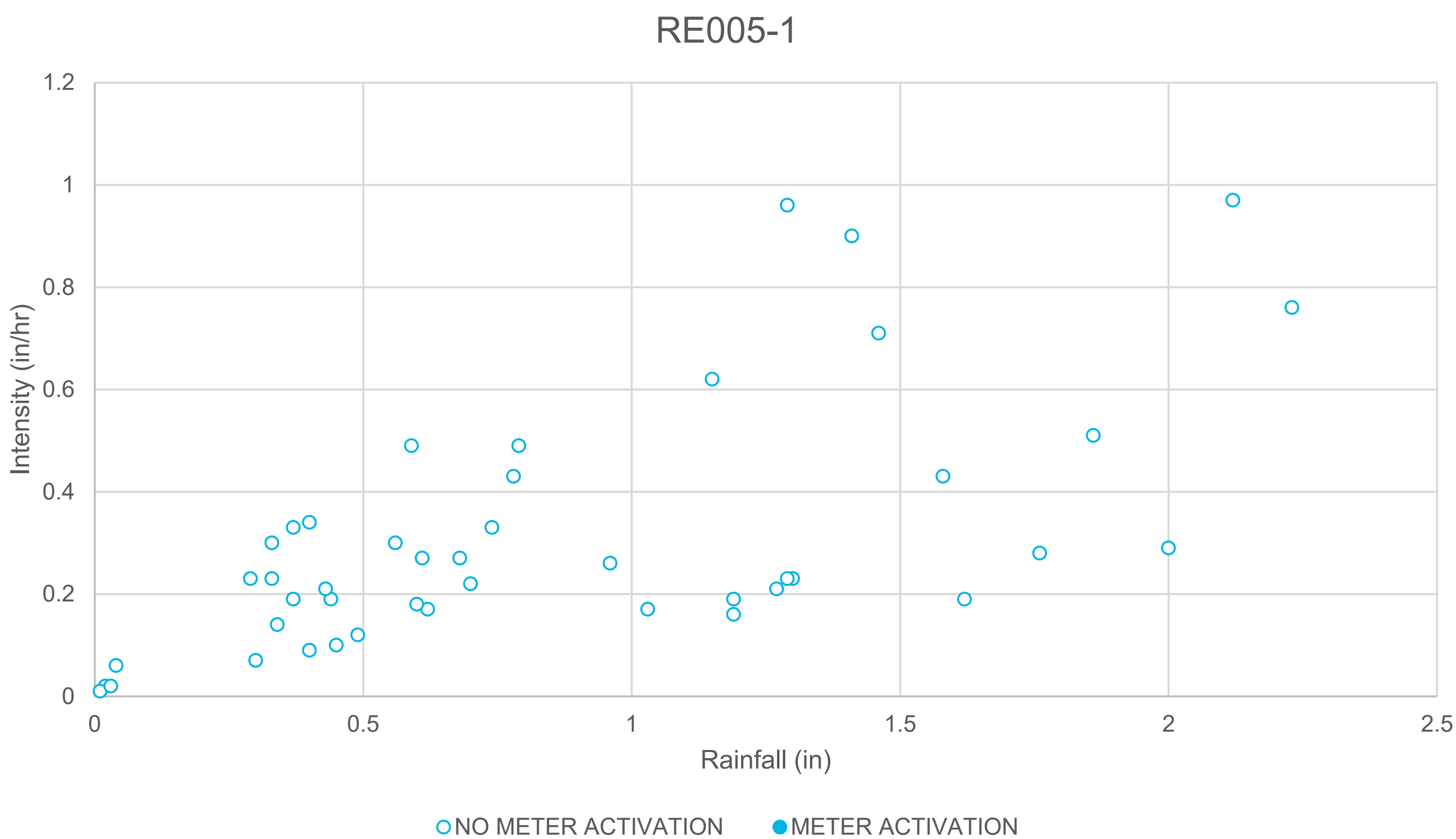


Outfall: BOS004
Regulator: RE04-6
Related Rain Gauge: 8



Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS005
Regulator: RE05-1
Related Rain Gauge: 8

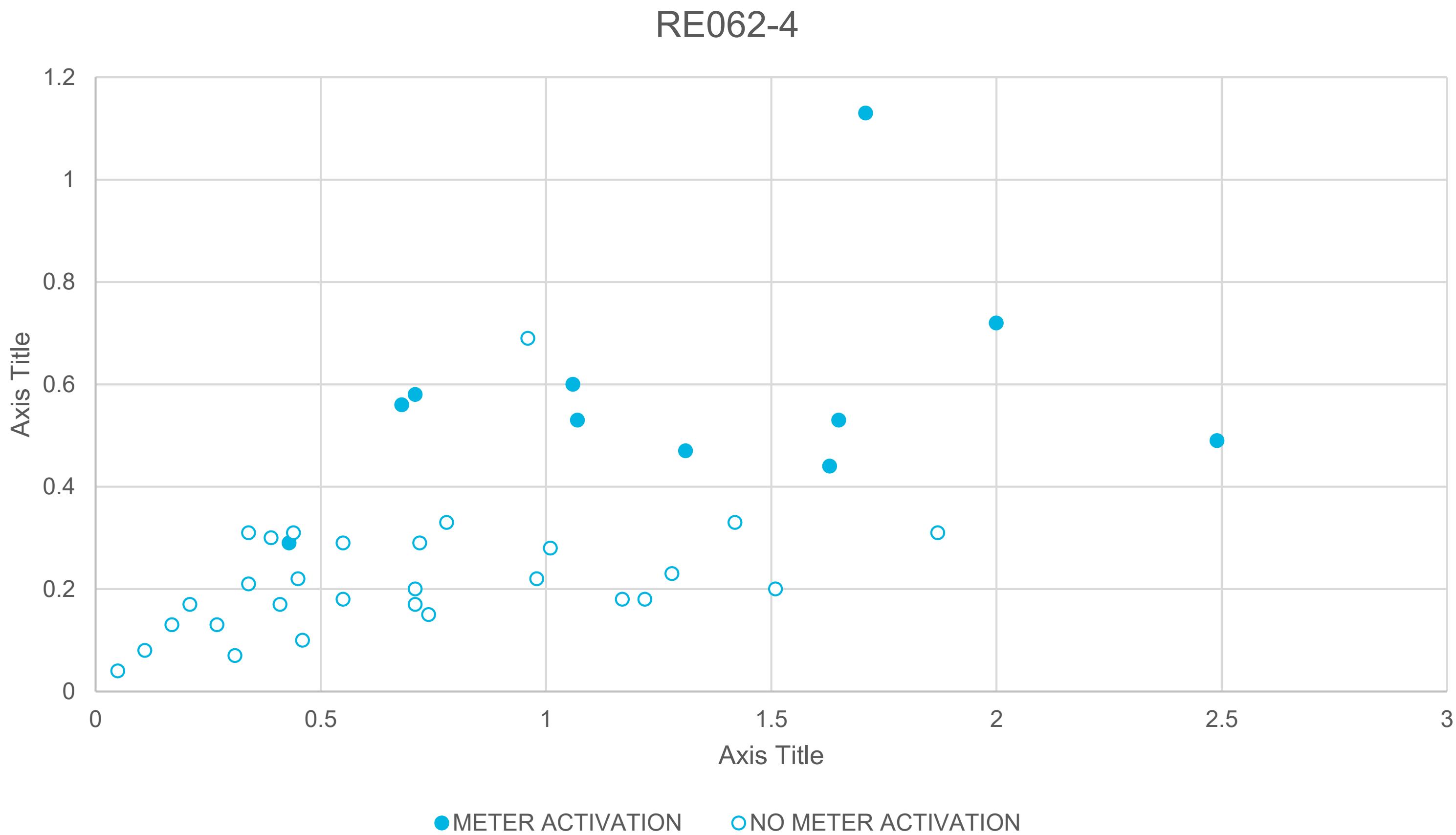


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Fort Point Channel

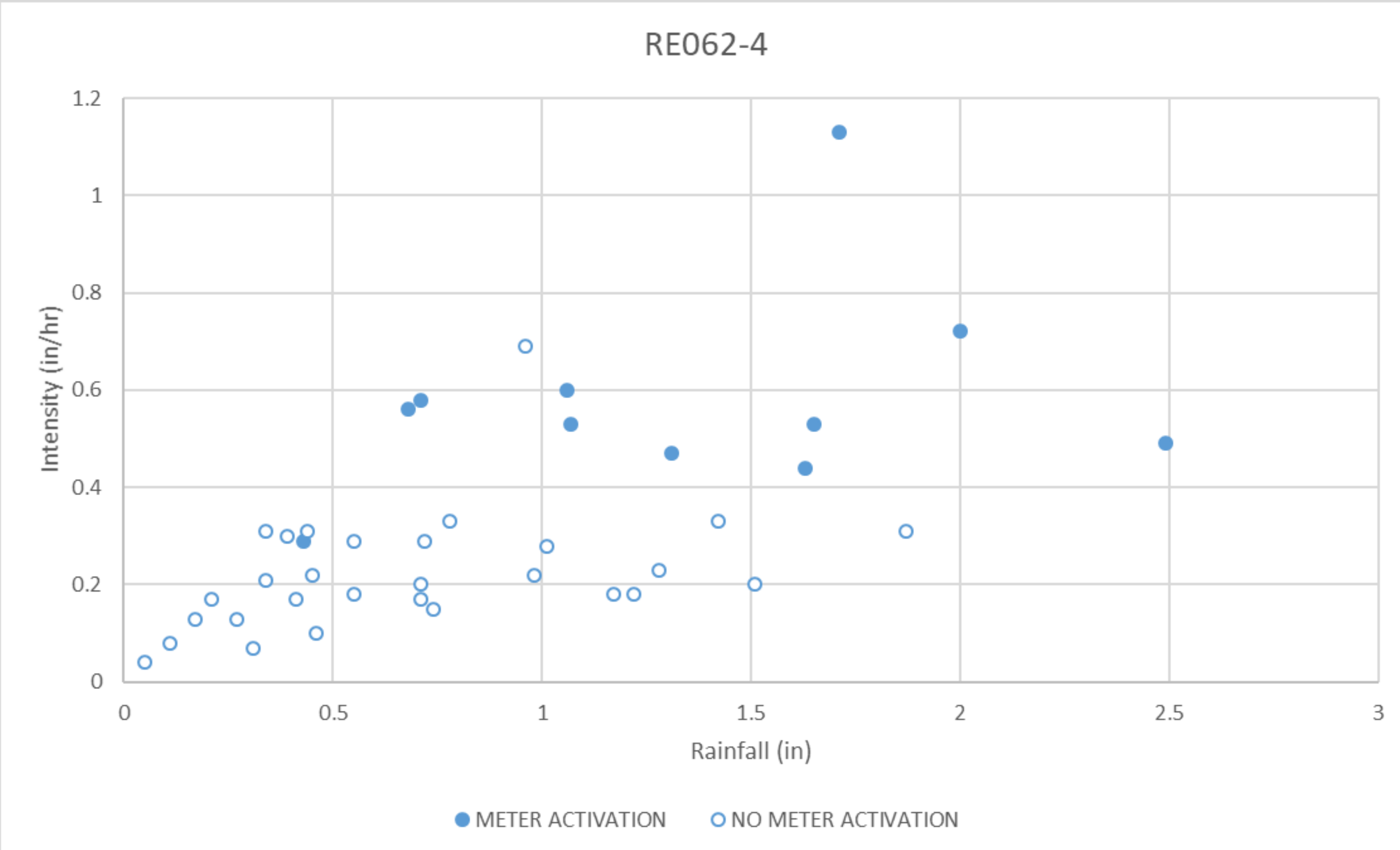
BOS062	RE062-4
BOS064	RE064-4
	RE064-5
BOS065	RE065-2
BOS068	RE068-1A
BOS070/DBC	RE070/8-3
	RE070/8-6
	RE070/8-7
	RE070/8-8
	RE070/8-13
	RE070/8-15
	RE070/9-4
	RE070/10-5
	RE070/7-2
MWR215 (Union Park)	
BOS070/RCC	RE070/5-3
BOS073	RE073-4

Outfall:BOS062
Regulator: RE62-4
Related Rain Gauge: 18



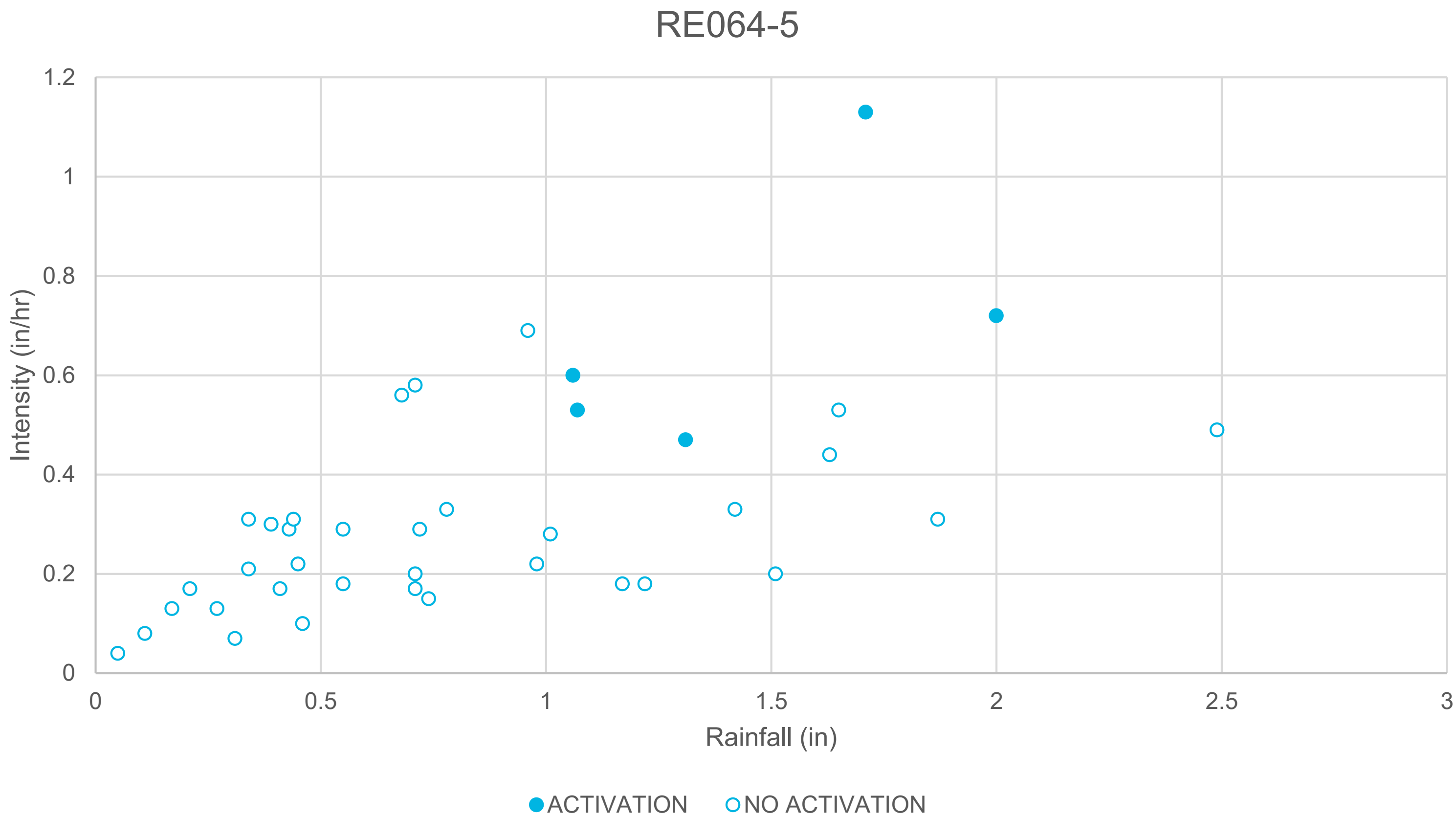
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall:BOS064
Regulator: RE64-4
Related Rain Gauge: 18



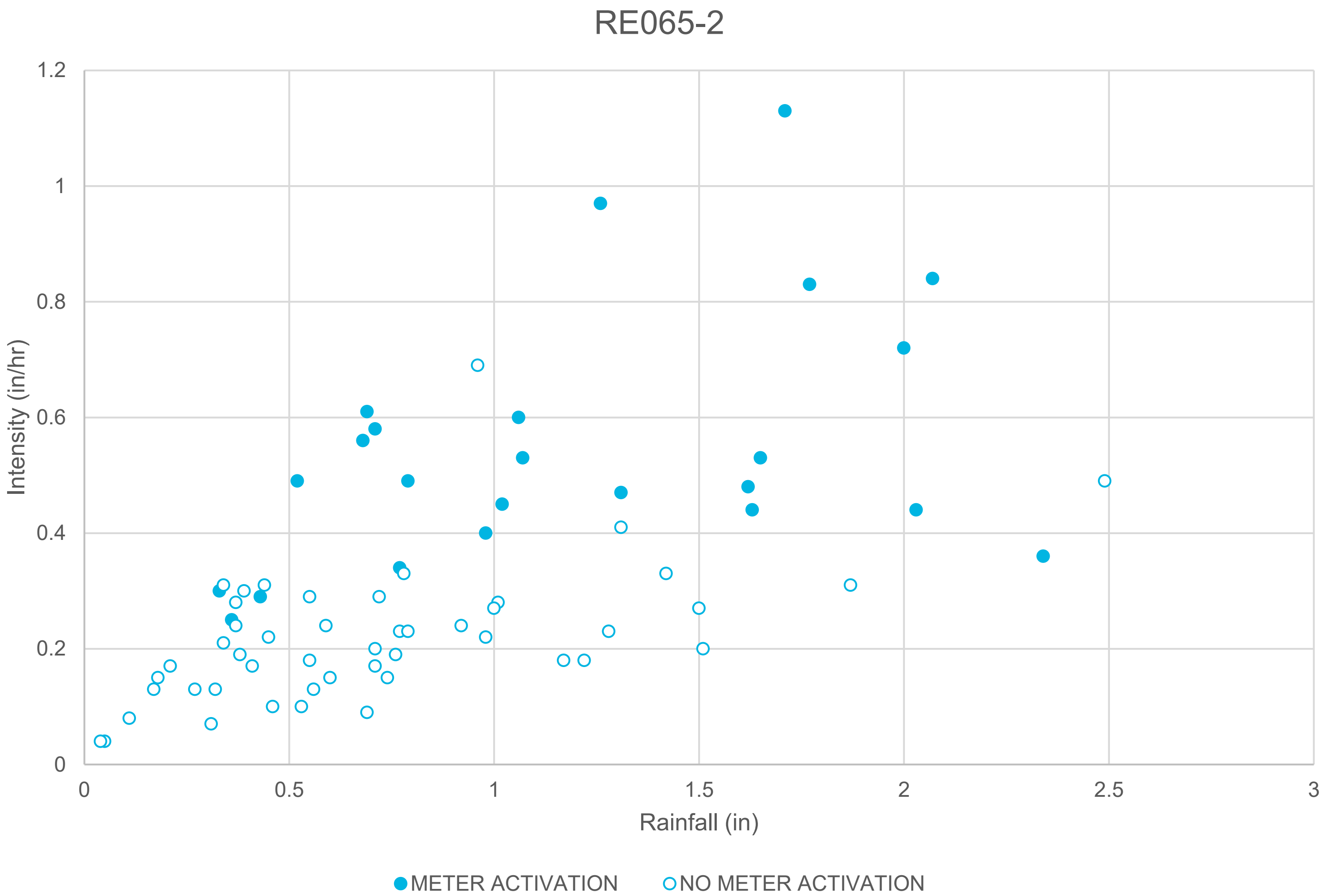
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall:BOS064
Regulator: RE64-5
Related Rain Gauge: 18

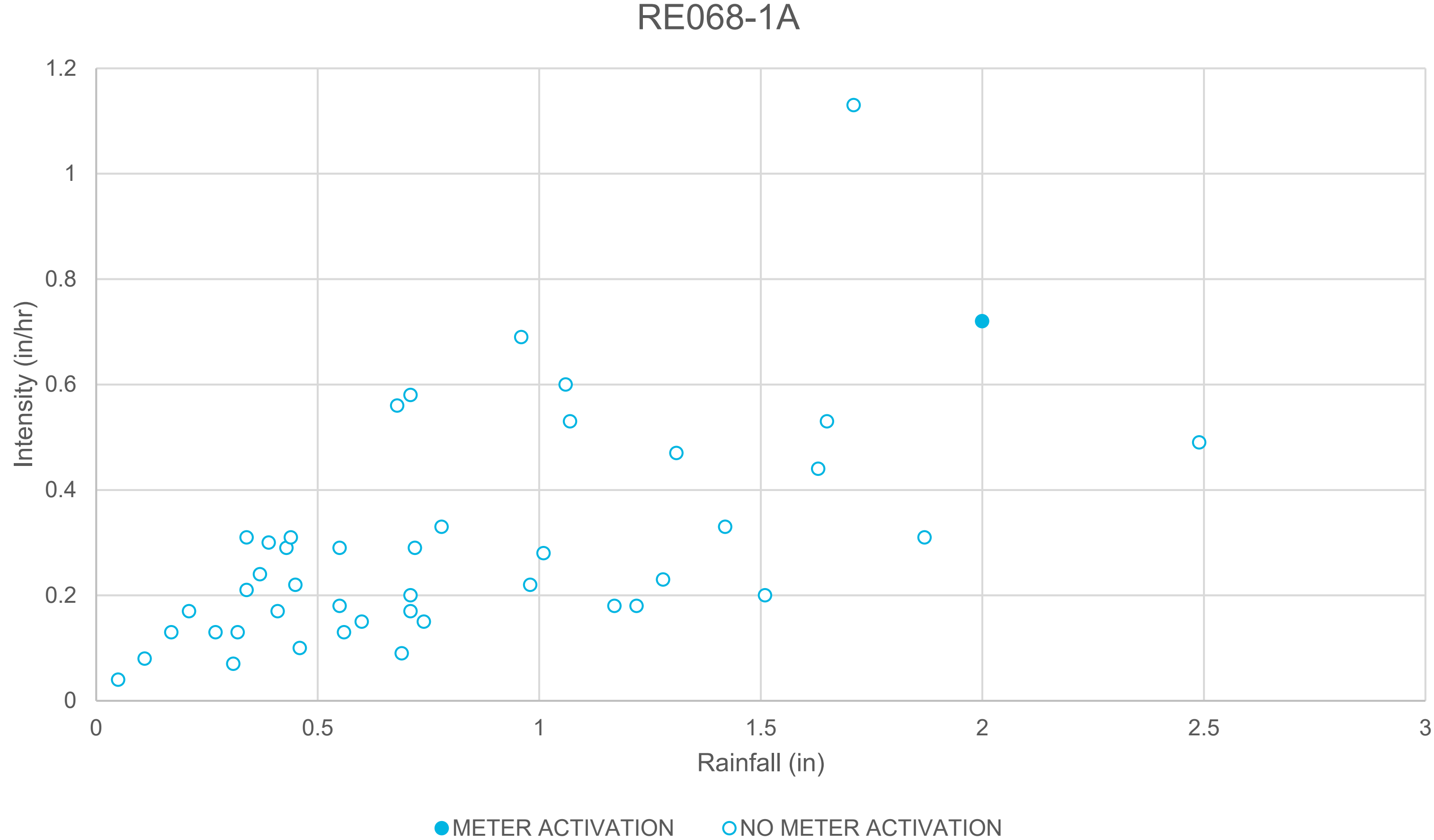


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall:BOS065
Regulator: RE65-2
Related Rain Gauge: 18

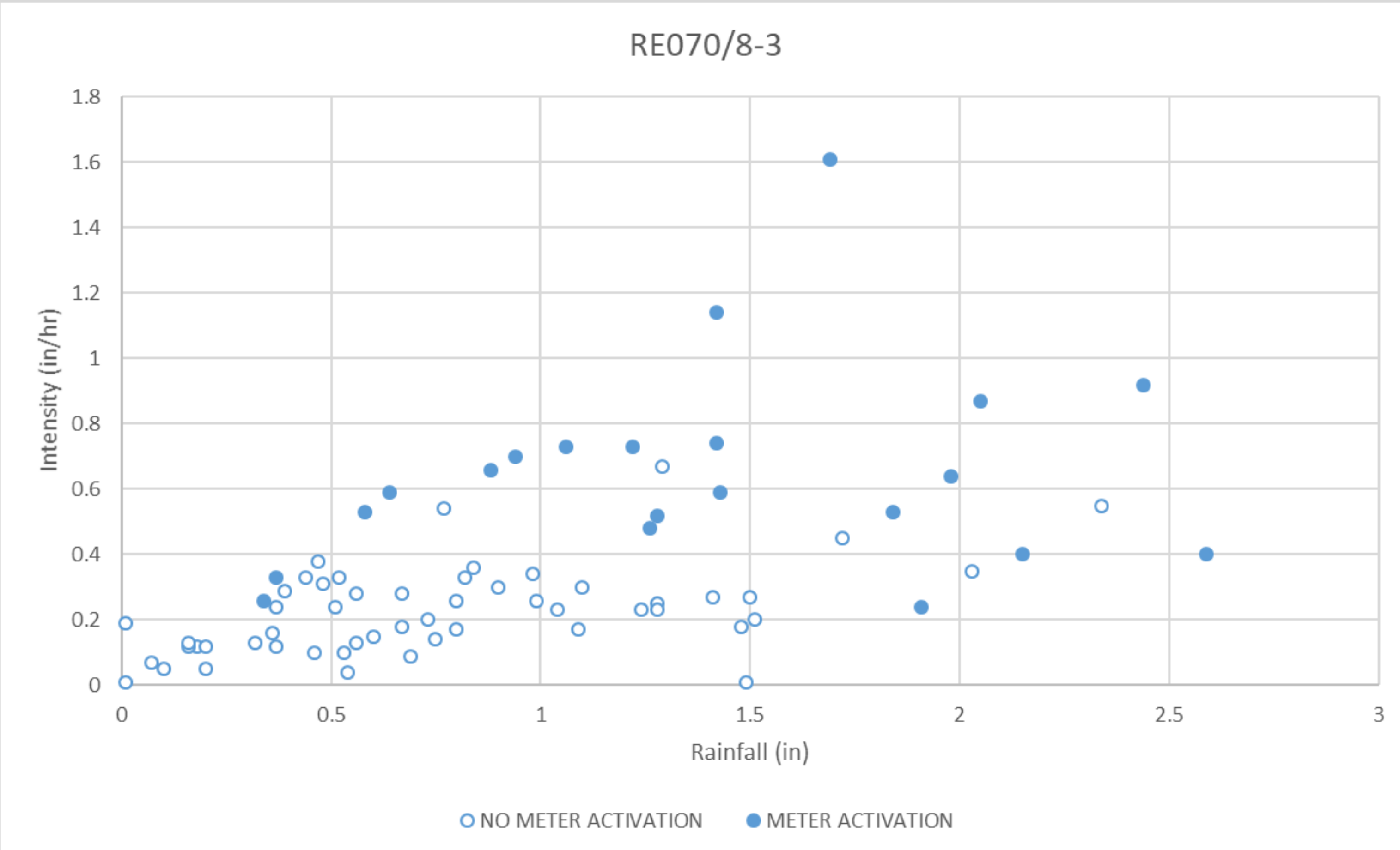


Outfall:BOS068
Regulator: RE68-1A
Related Rain Gauge: 18

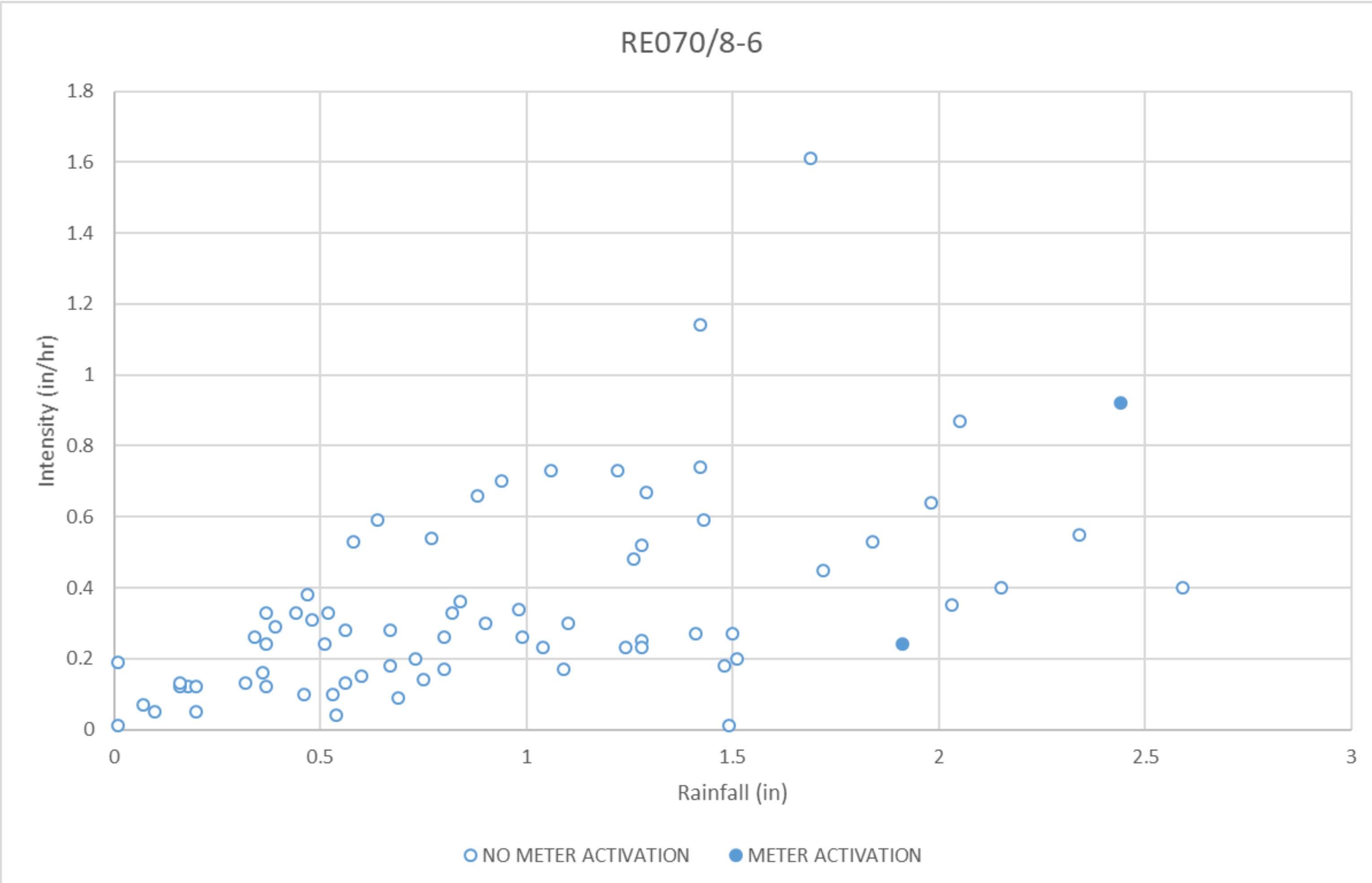


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

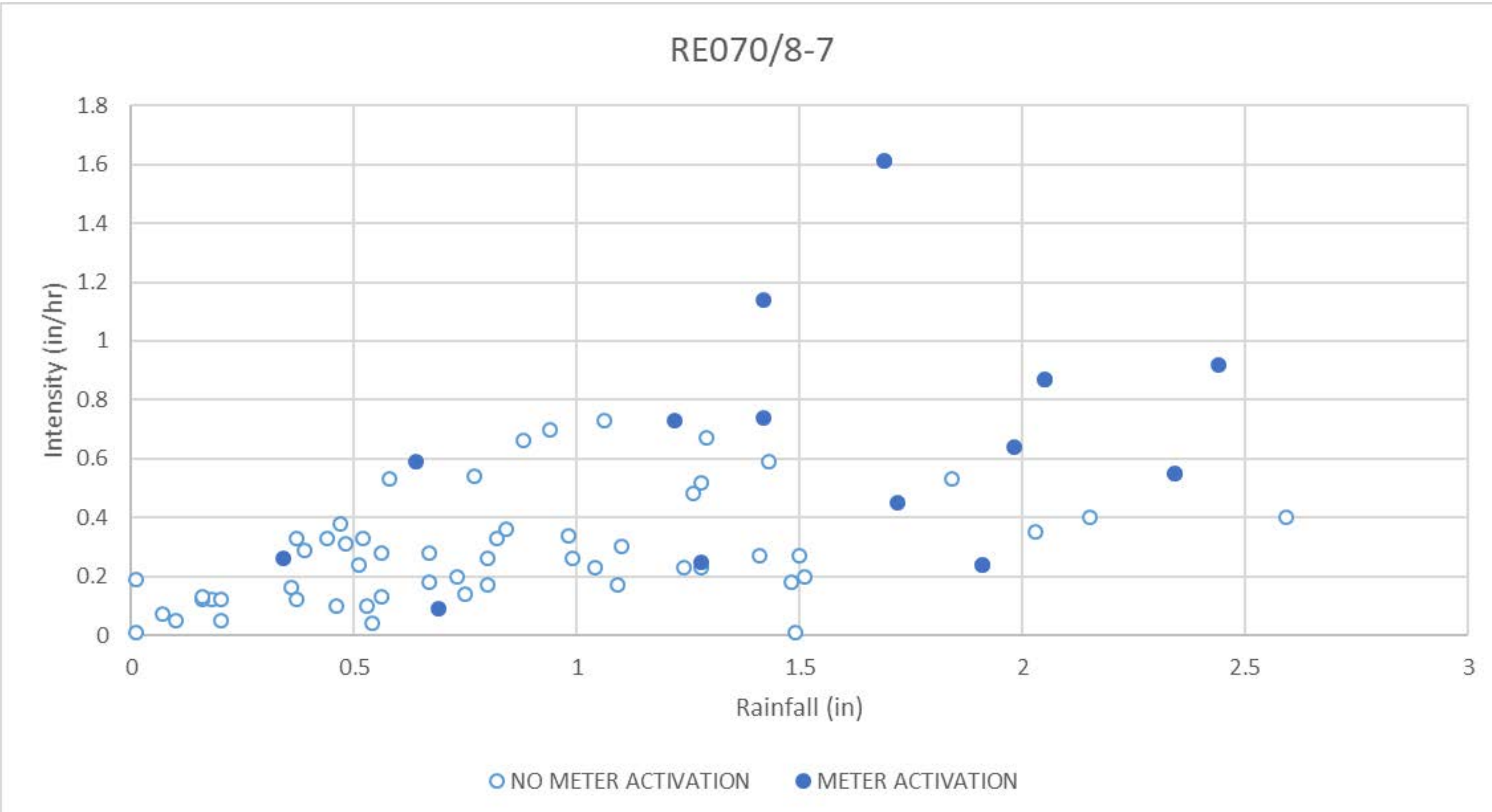
Outfall:BOS70/DBC
Regulator: RE070/8-3
Related Rain Gauge: 3



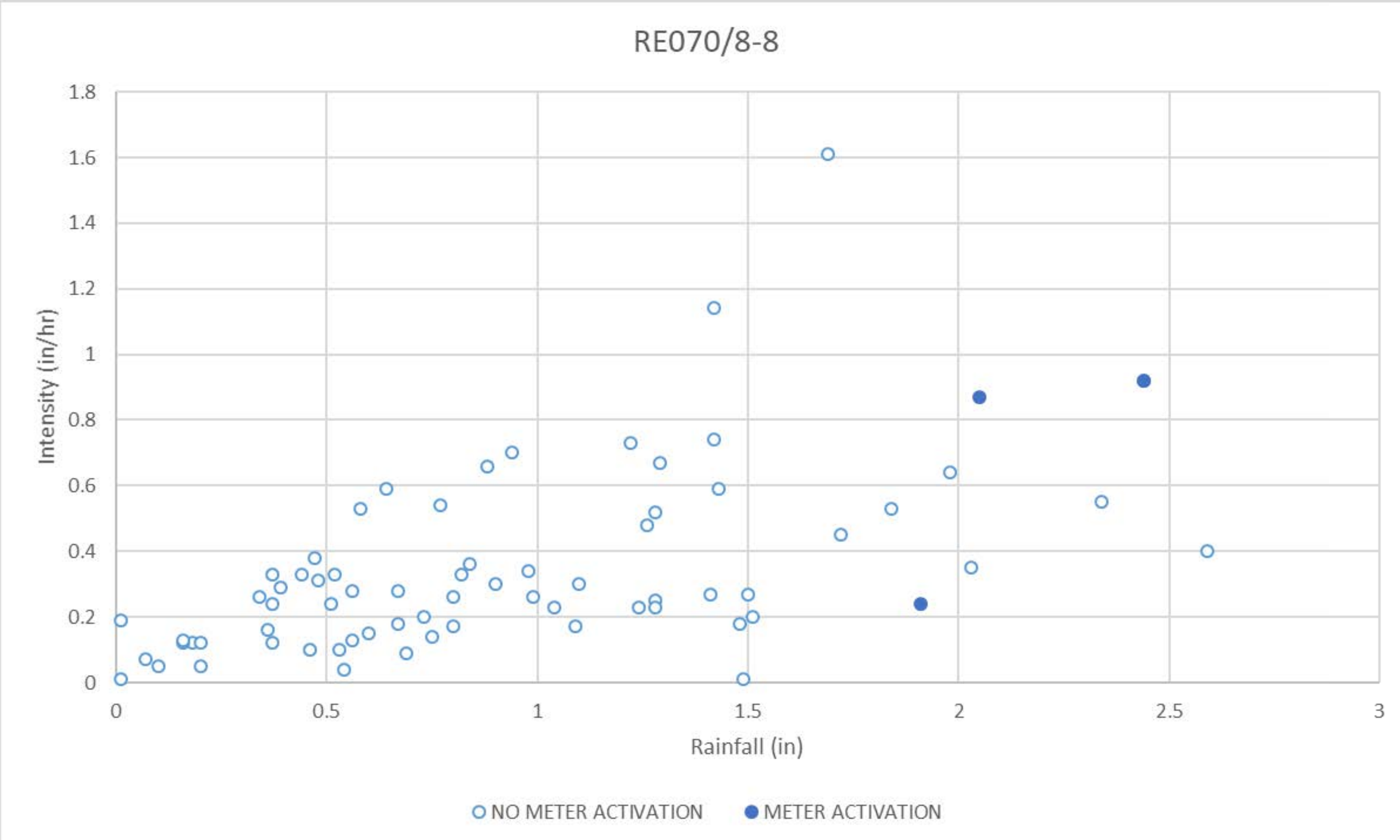
Outfall:BOS70/DBC
Regulator: RE070/8-6
Related Rain Gauge: 3



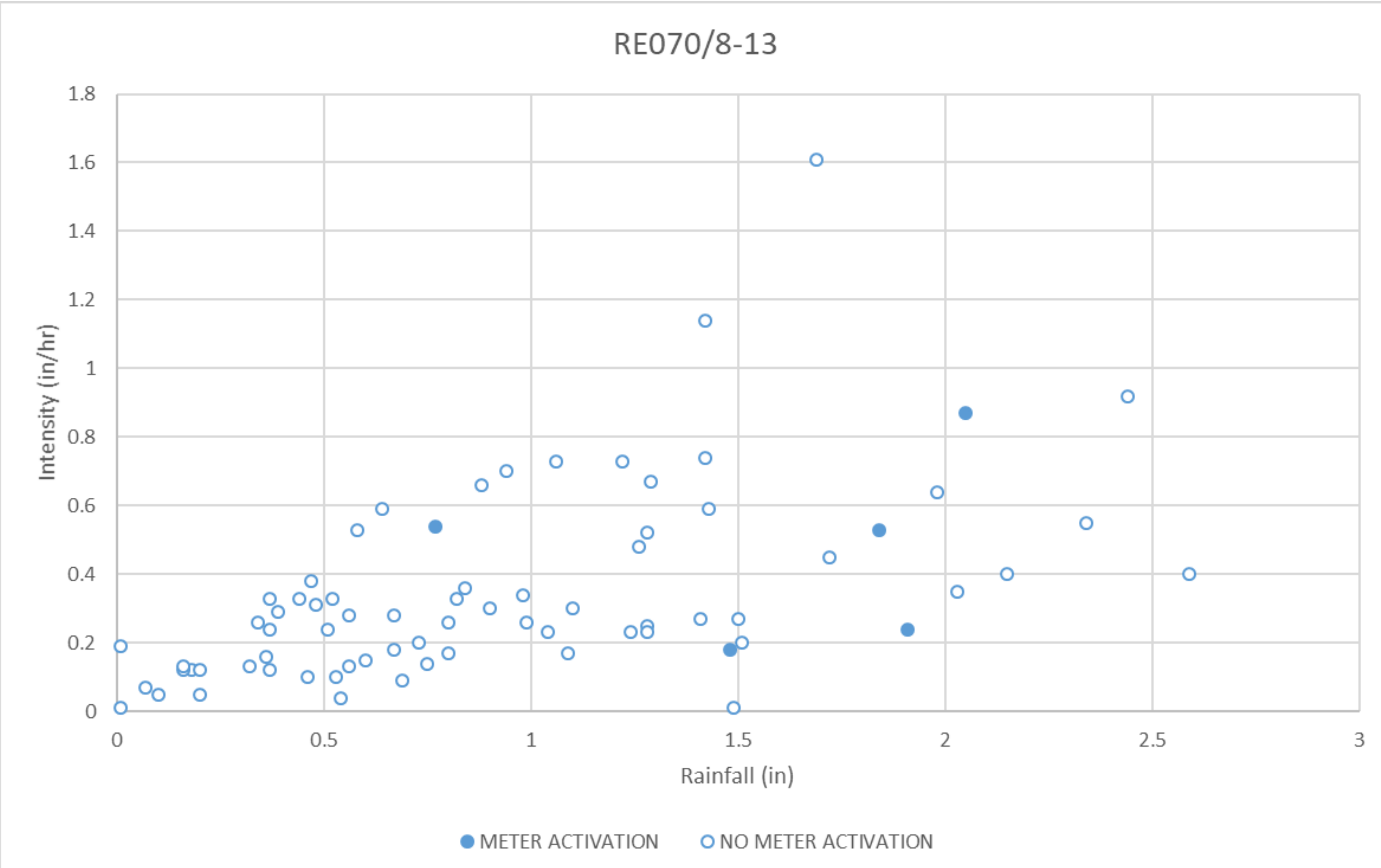
Outfall:BOS70/DBC
Regulator: RE070/8-7
Related Rain Gauge: 3



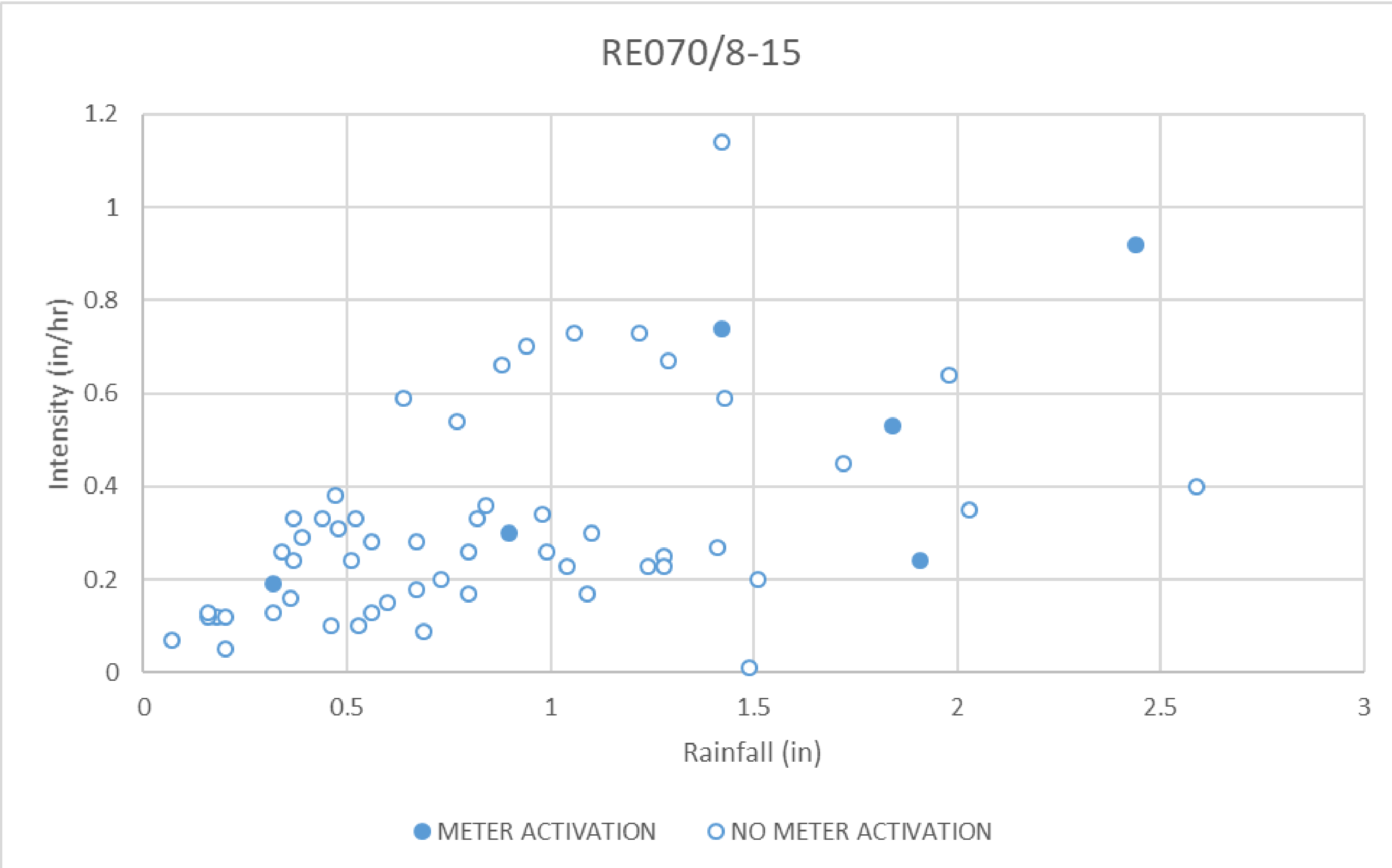
Outfall:BOS70/DBC
Regulator: RE070/8-8
Related Rain Gauge: 3



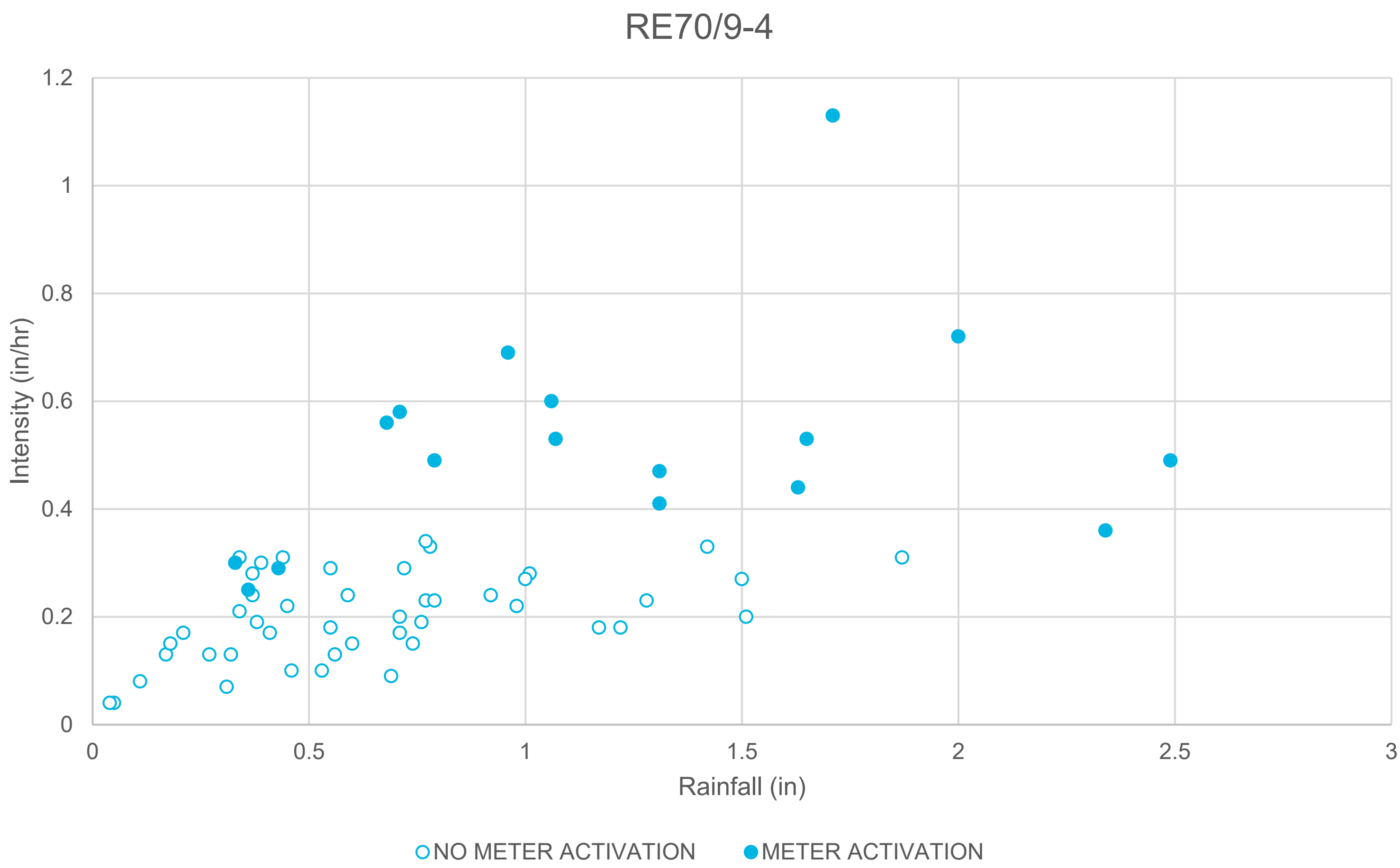
Outfall:BOS70/DBC
Regulator: RE070/8-13
Related Rain Gauge: 3



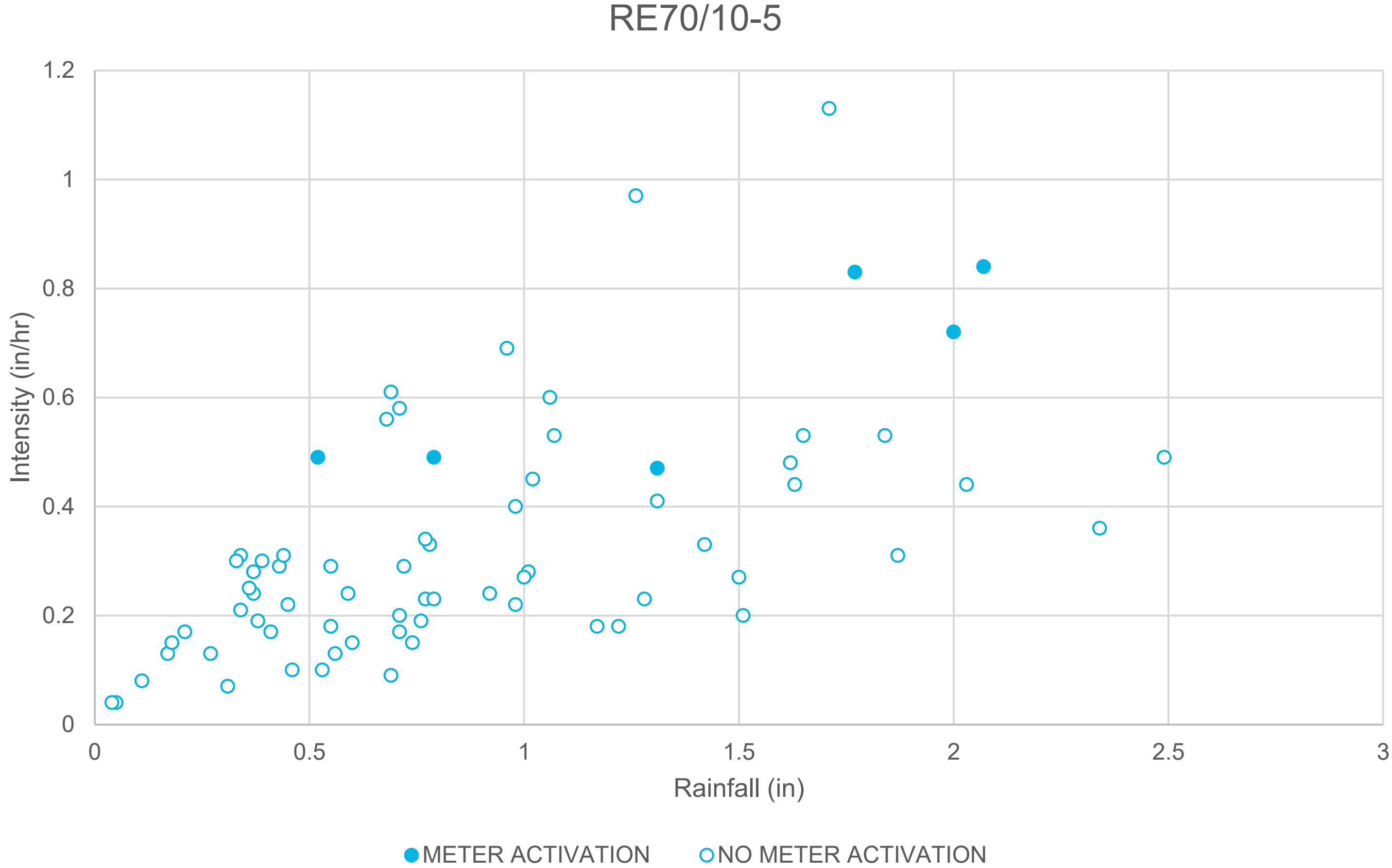
Outfall:BOS70/DBC
Regulator: RE070/8-15
Related Rain Gauge: 3



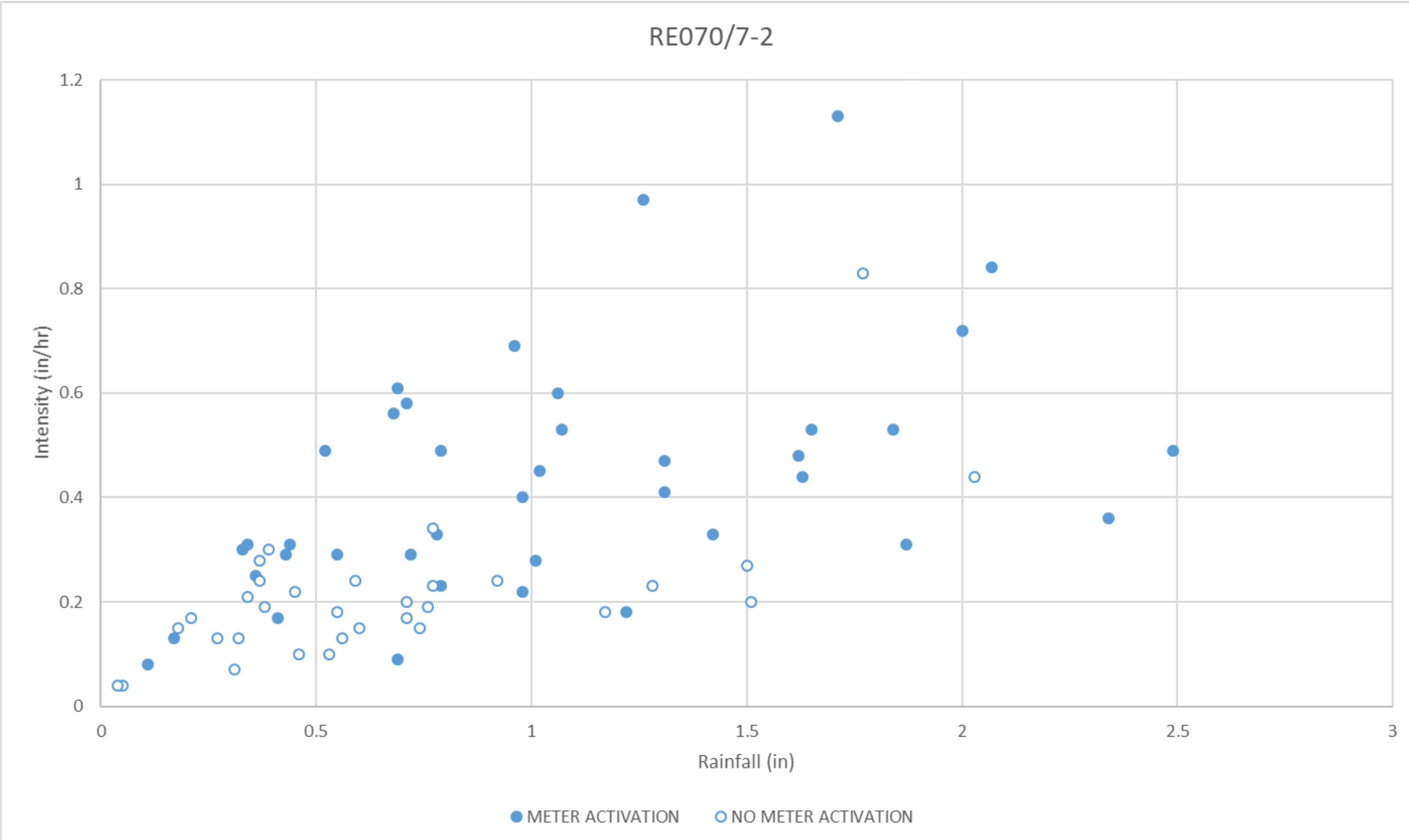
Outfall:BOS070/DBC
Regulator: RE70/9-4
Related Rain Gauge: 18



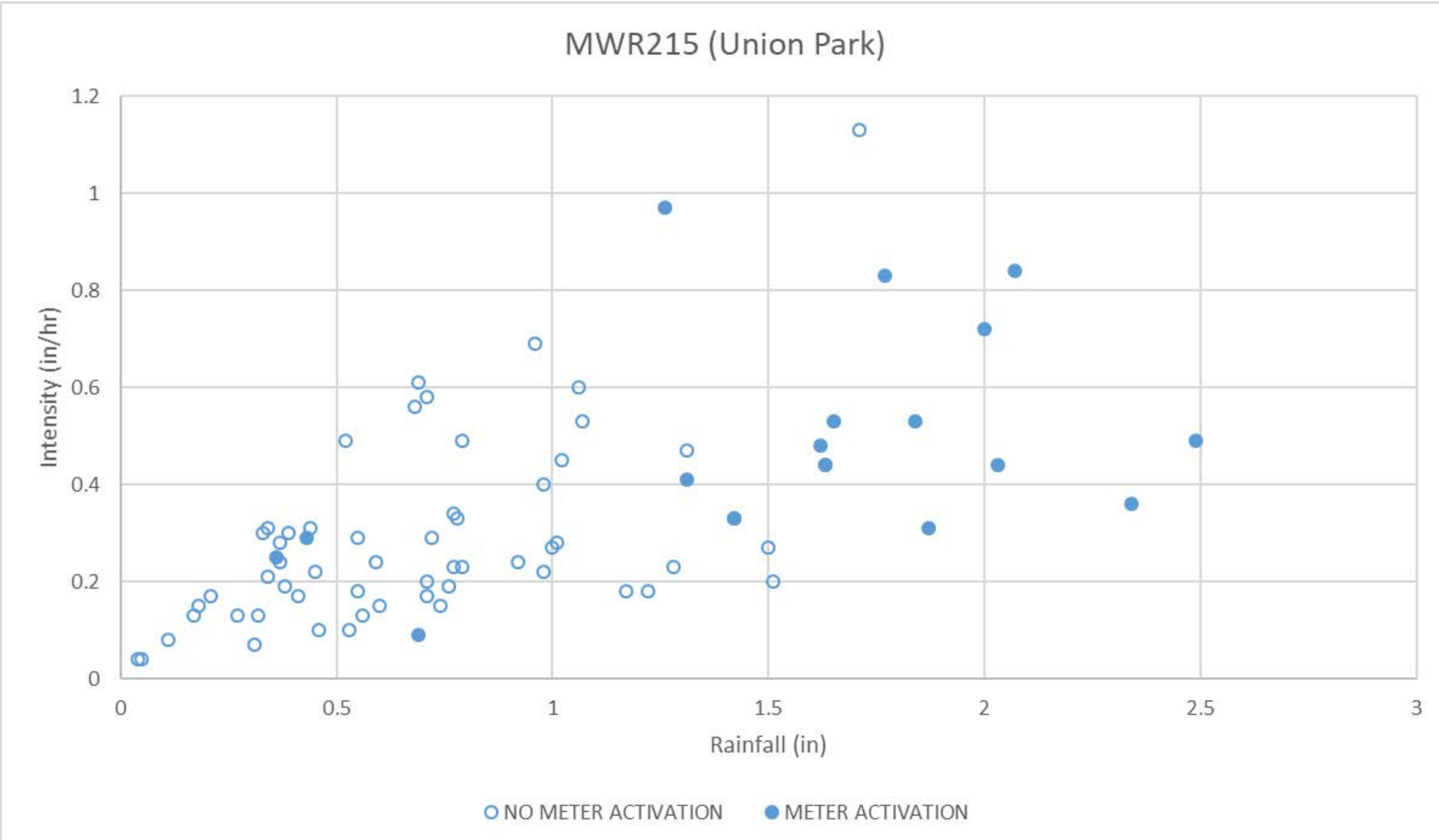
Outfall:BOS070/DBC
Regulator: RE70/10-5
Related Rain Gauge: 18



Outfall:BOS070/DBC
Regulator: RE70/7-2
Related Rain Gauge: 18

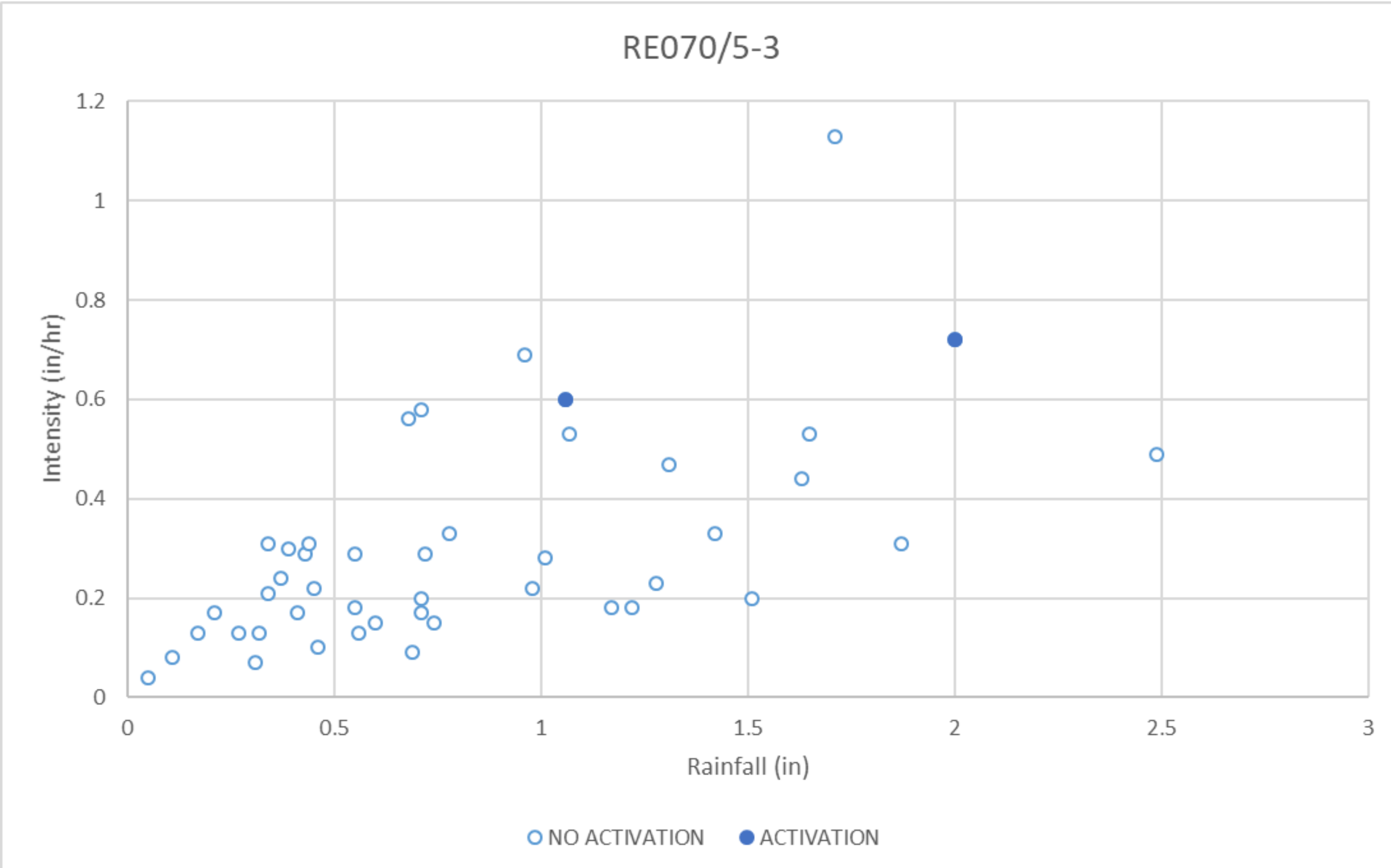


Outfall:MWR215 (Union Park)
Regulator: N/A
Related Rain Gauge: 18



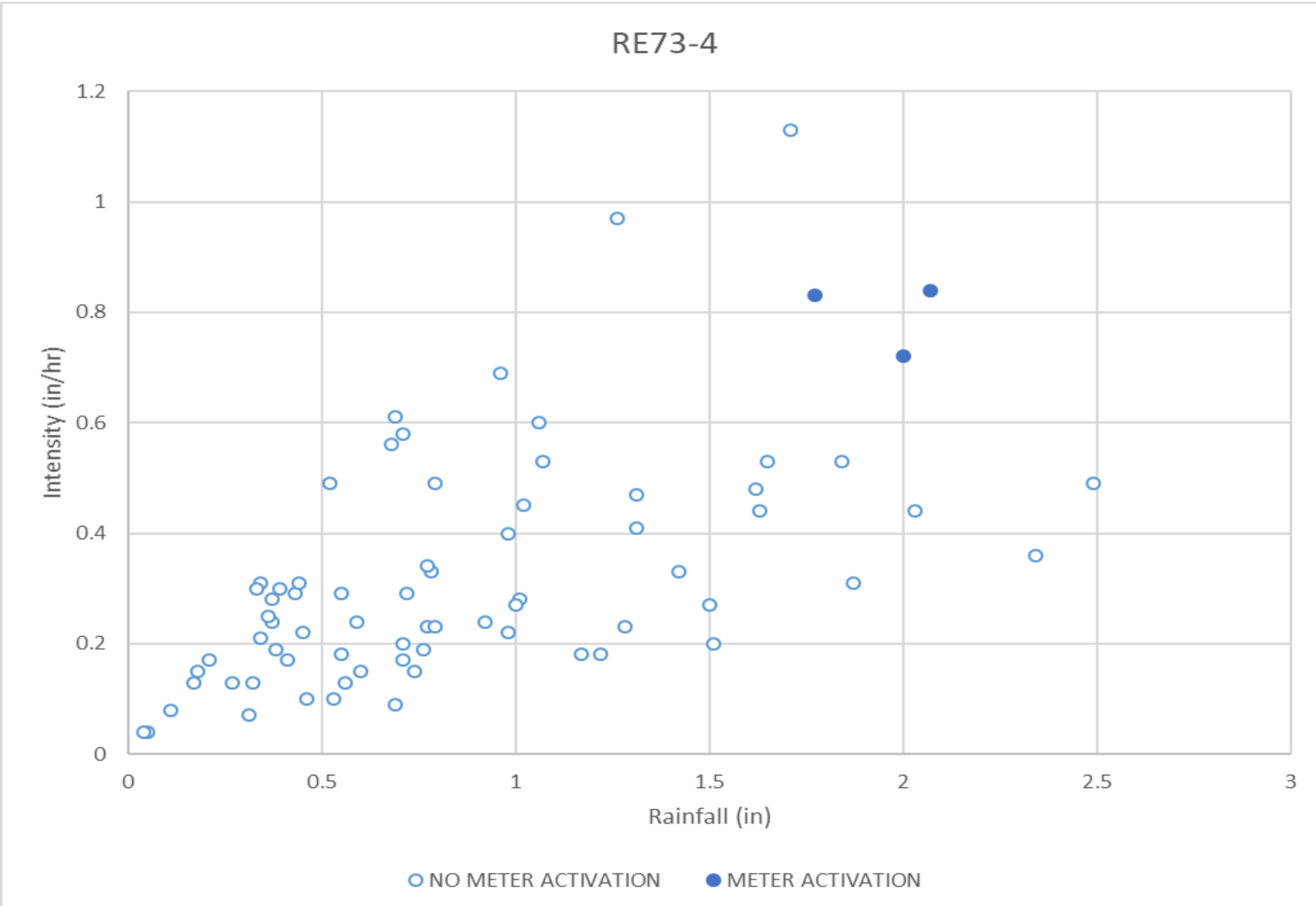
Meter activation represents an activation in which flow was discharged out of Union Park.

Outfall:BOS070/RRCC
Regulator: RE70/5-3
Related Rain Gauge: 18



Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

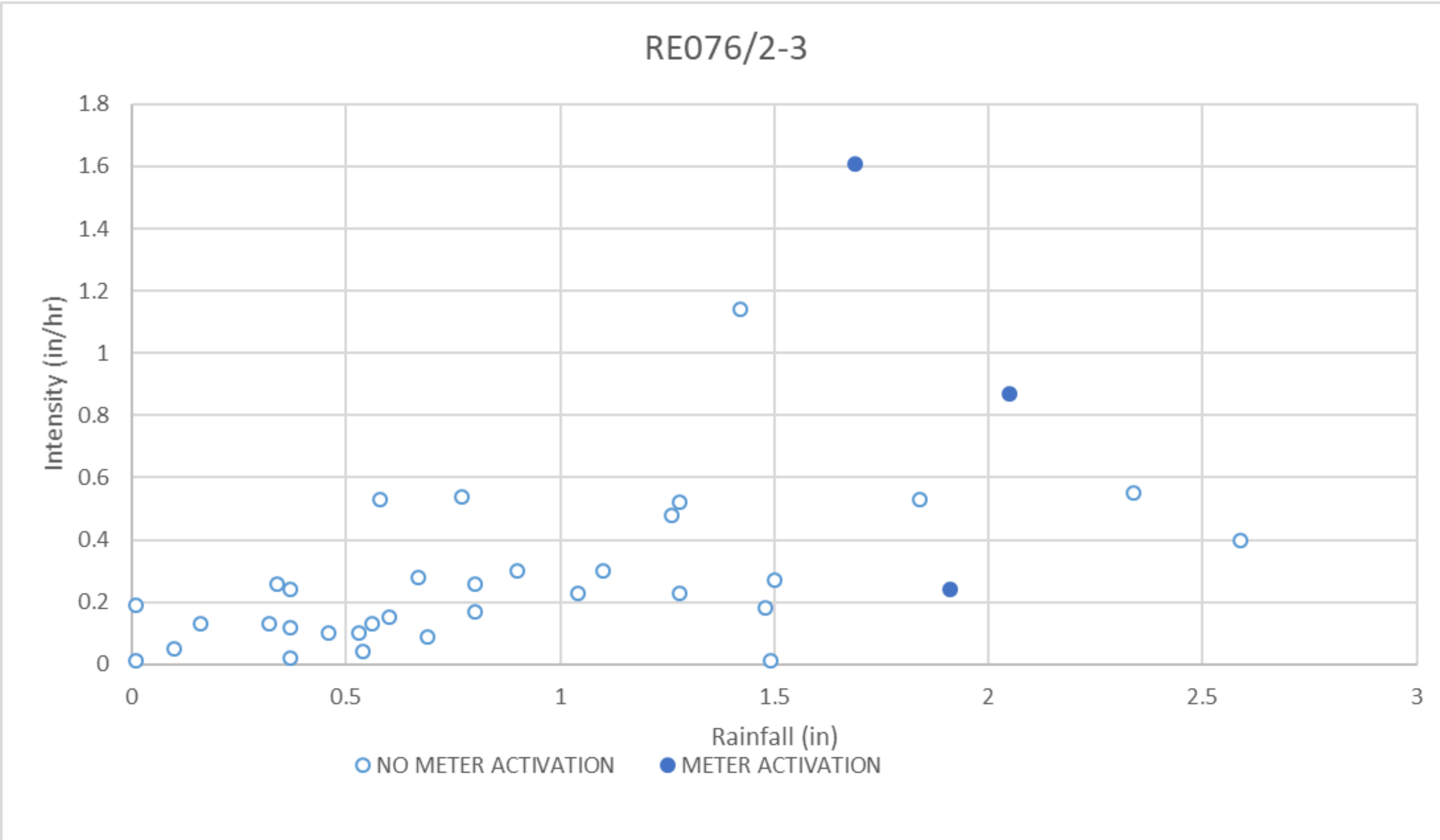
Outfall:BOS073
Regulator: RE073-4
Related Rain Gauge: 18



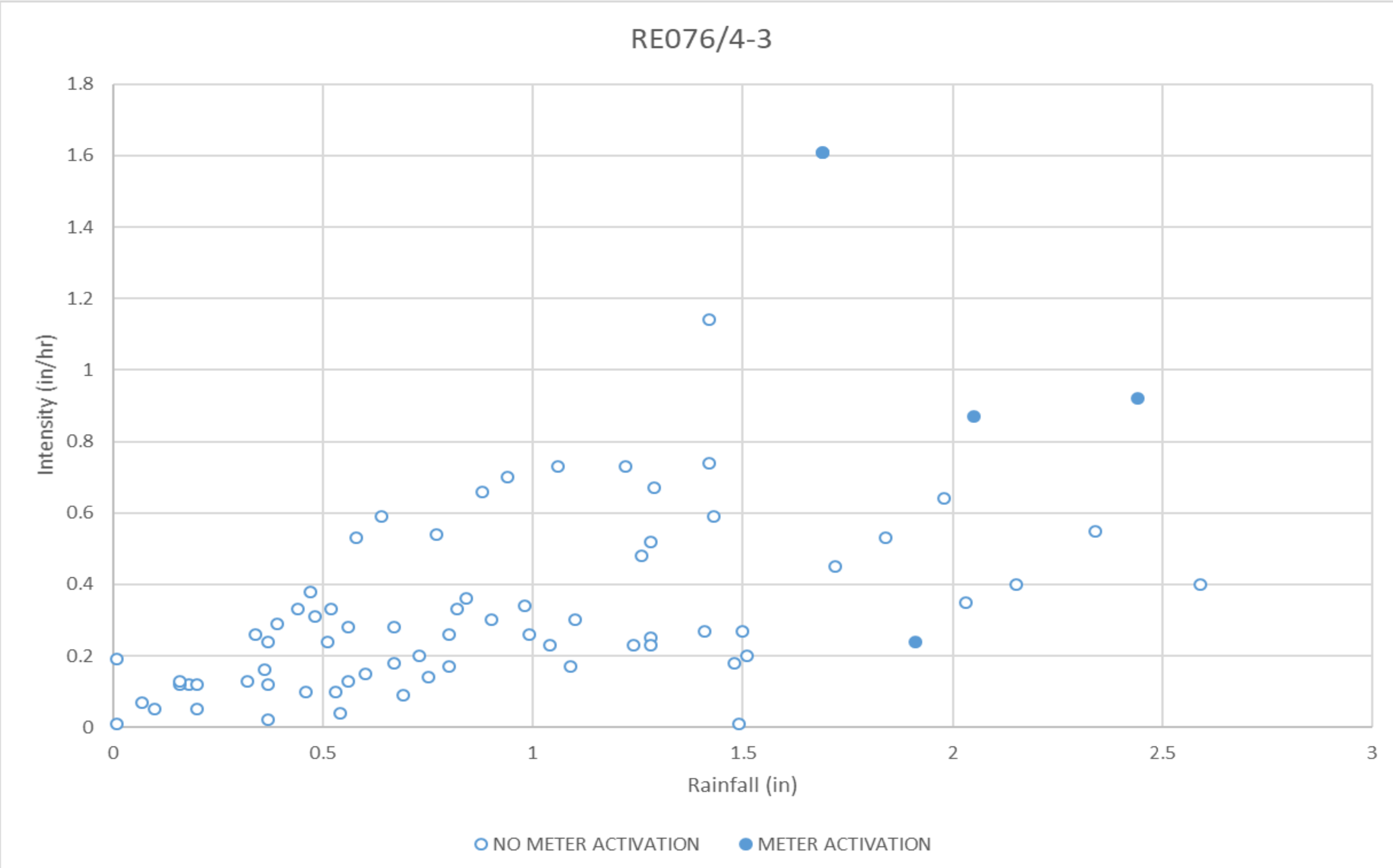
Reserved Channel

BOS076	RE076/2-3
	RE076/4-3
BOS078	RE078-1 RE078-2
BOS079	RE079-3
BOS080	RE080-2B

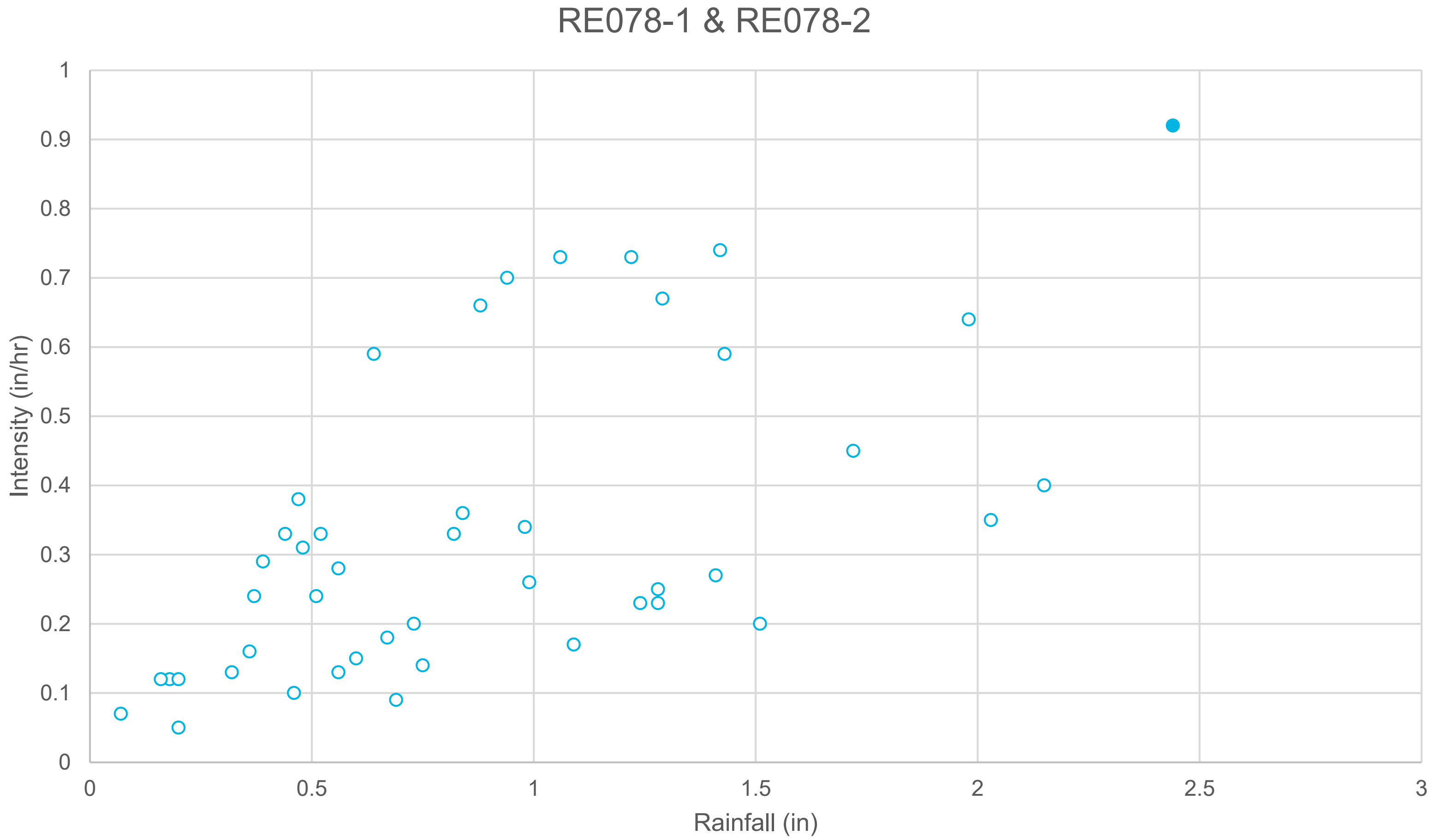
Outfall: BOS076
Regulator: RE076/2-3
Related Rain Gauge: 3



Outfall: BOS076
Regulator: RE076/4-3
Related Rain Gauge: 3

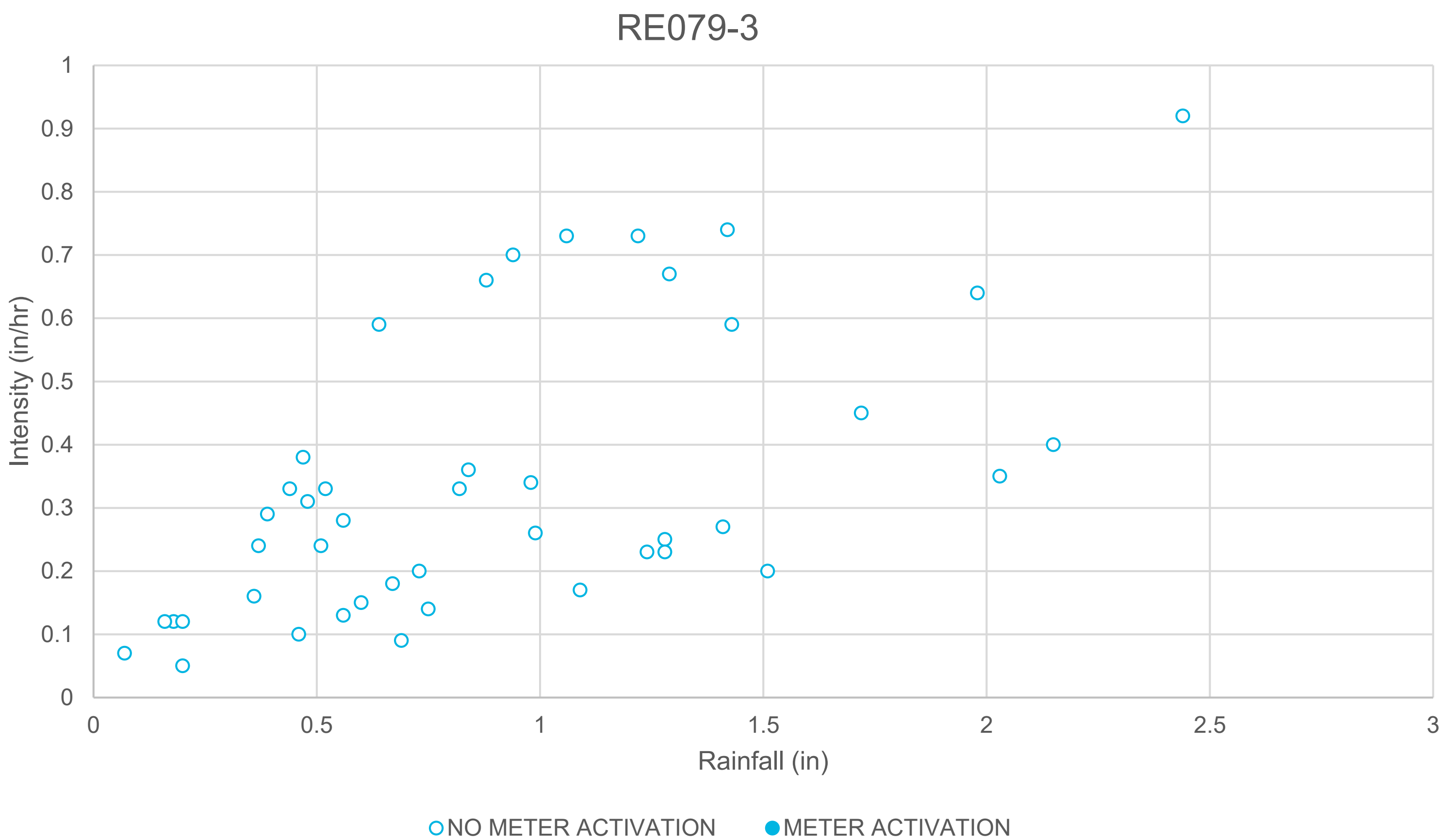


Outfall: BOS078
Regulator: RE078-1 & RE078-2
Related Rain Gauge: 3



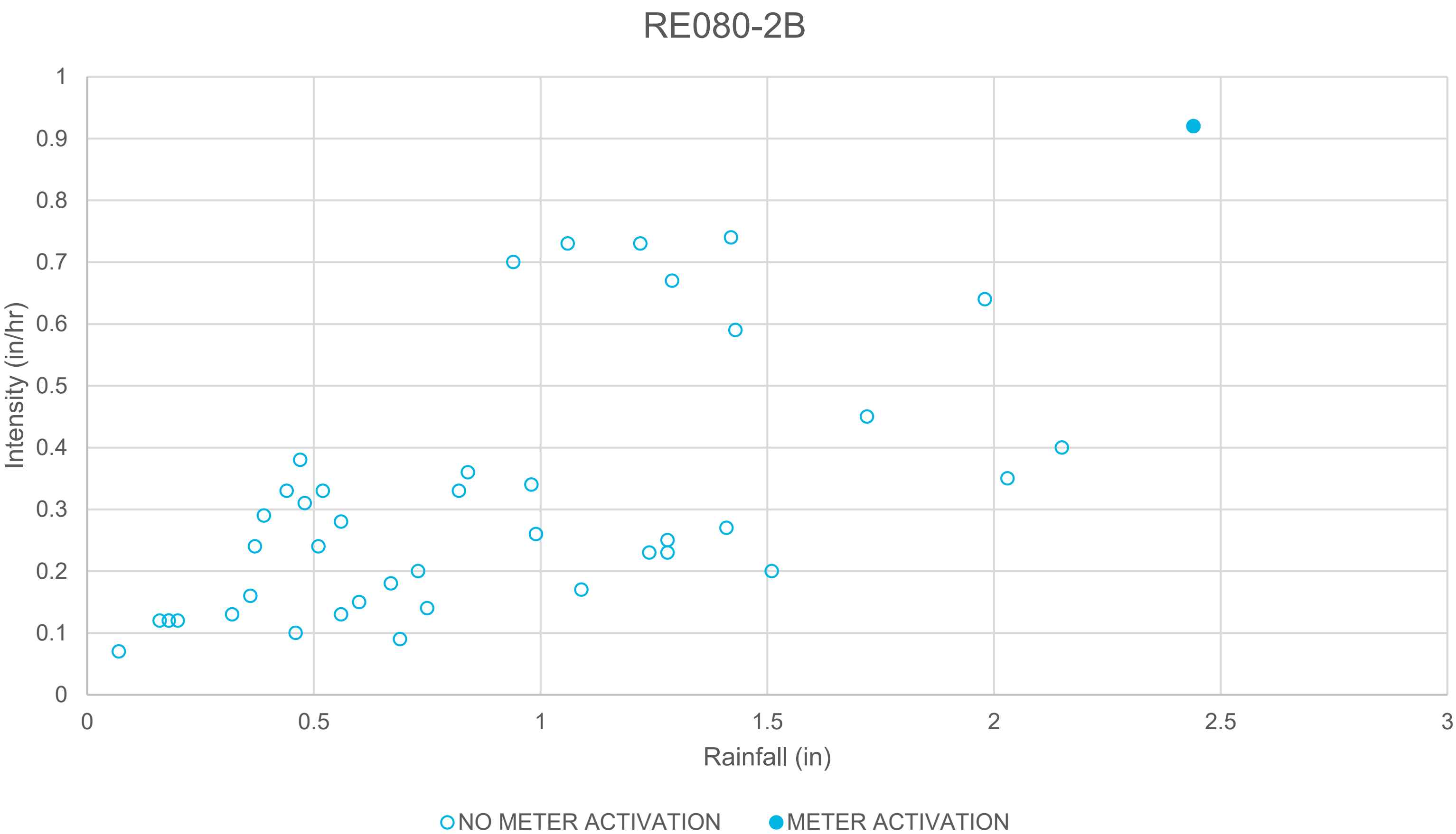
Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS079
Regulator: RE079-3
Related Rain Gauge: 3



Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

Outfall: BOS080
Regulator: RE080-2B
Related Rain Gauge: 3

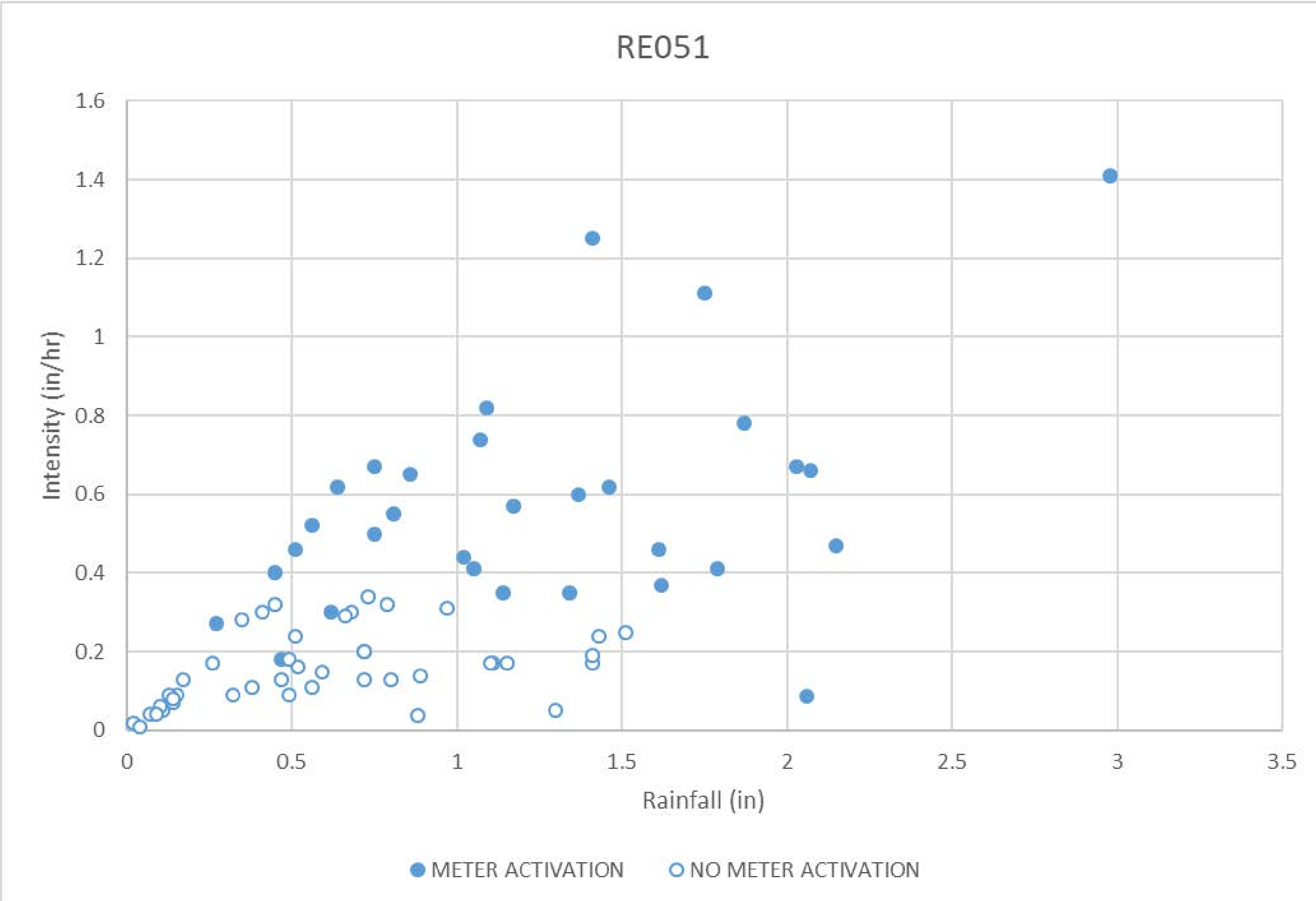


Meter was removed as of March 1, 2019. No activations were assessed following March 1, 2019.

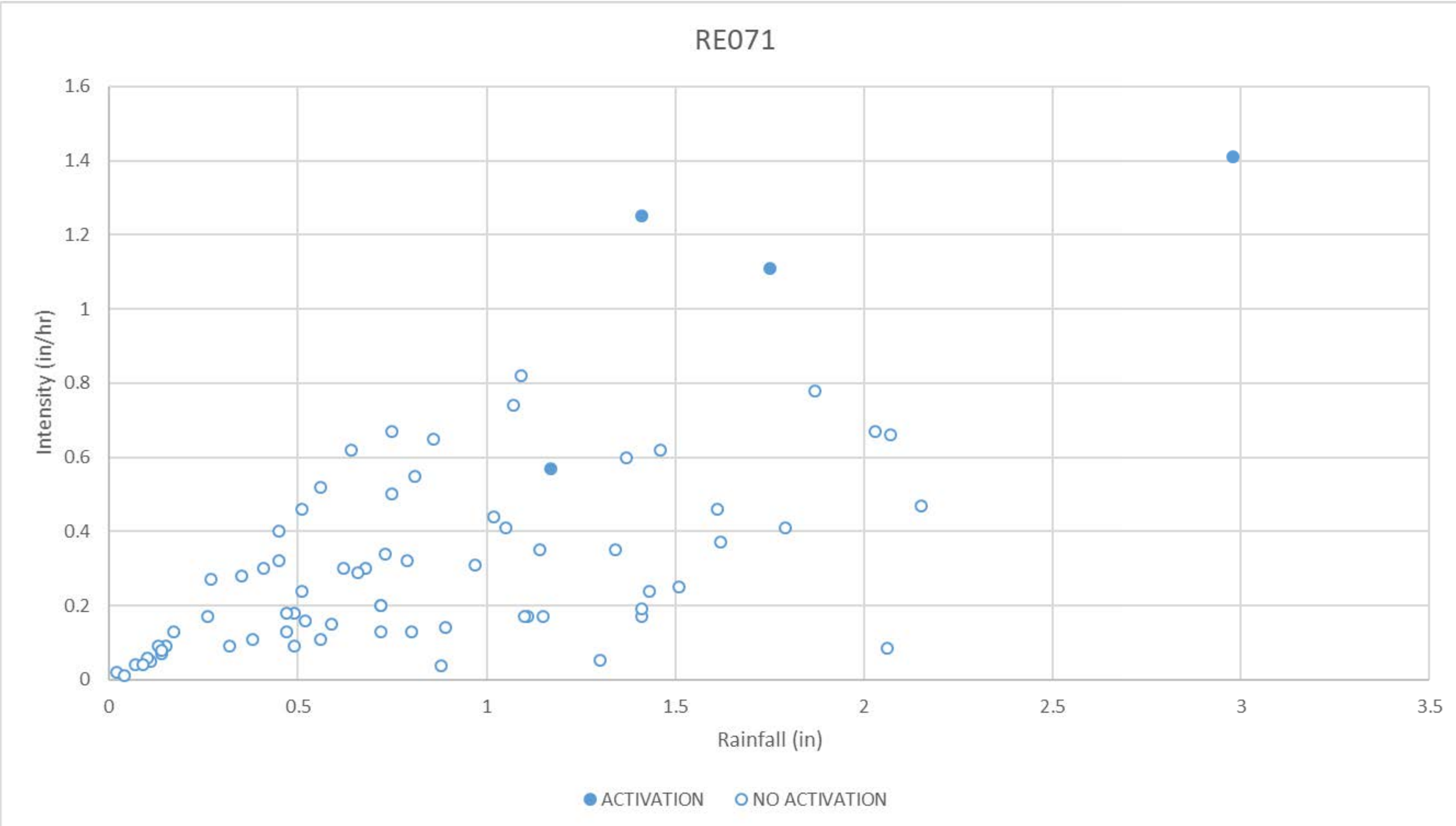
Upper Charles

CAM005	RE-051
CAM007	RE-071

Outfall:CAM005
Regulator: RE051
Related Rain Gauge: 19



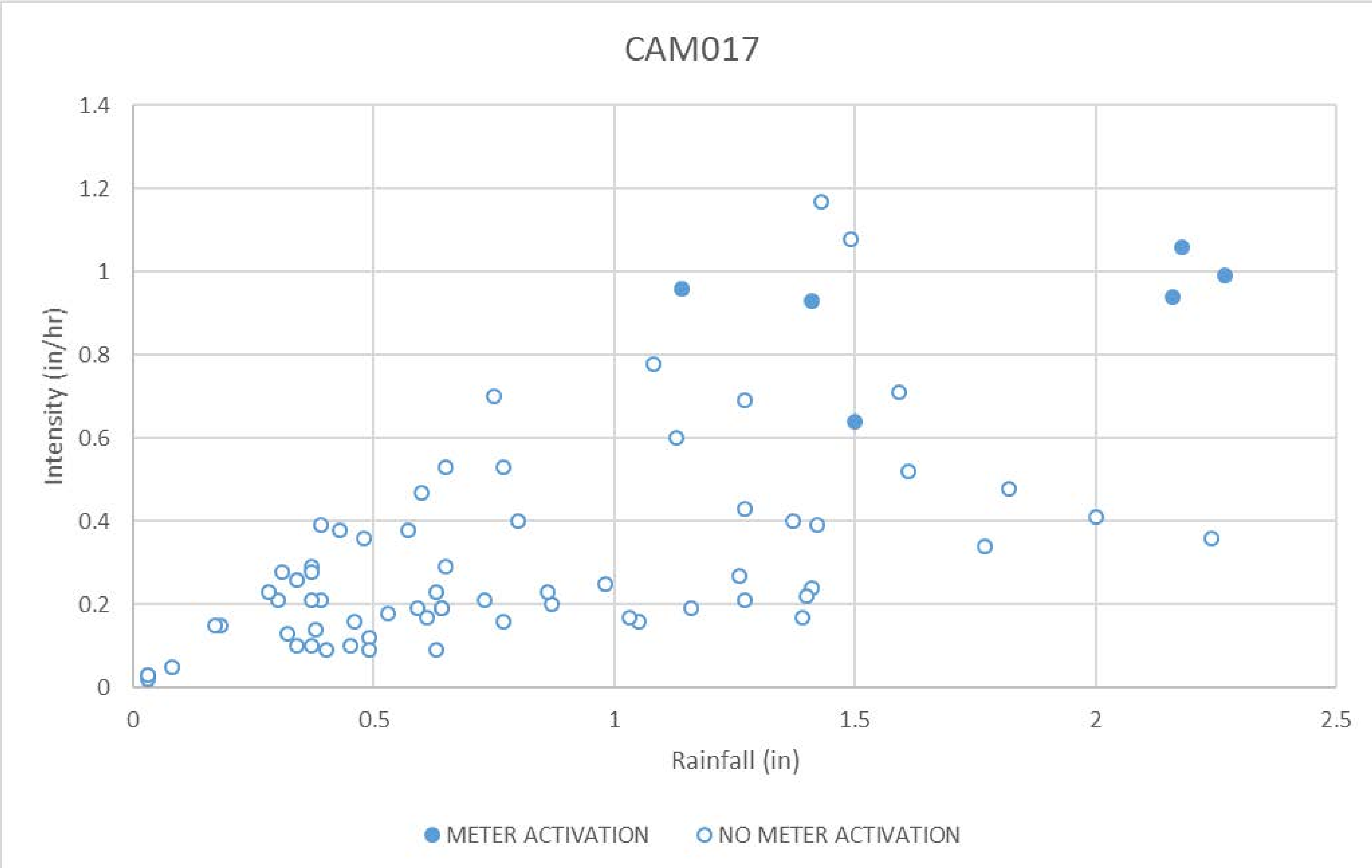
Outfall:CAM007
Regulator: RE071
Related Rain Gauge: 19



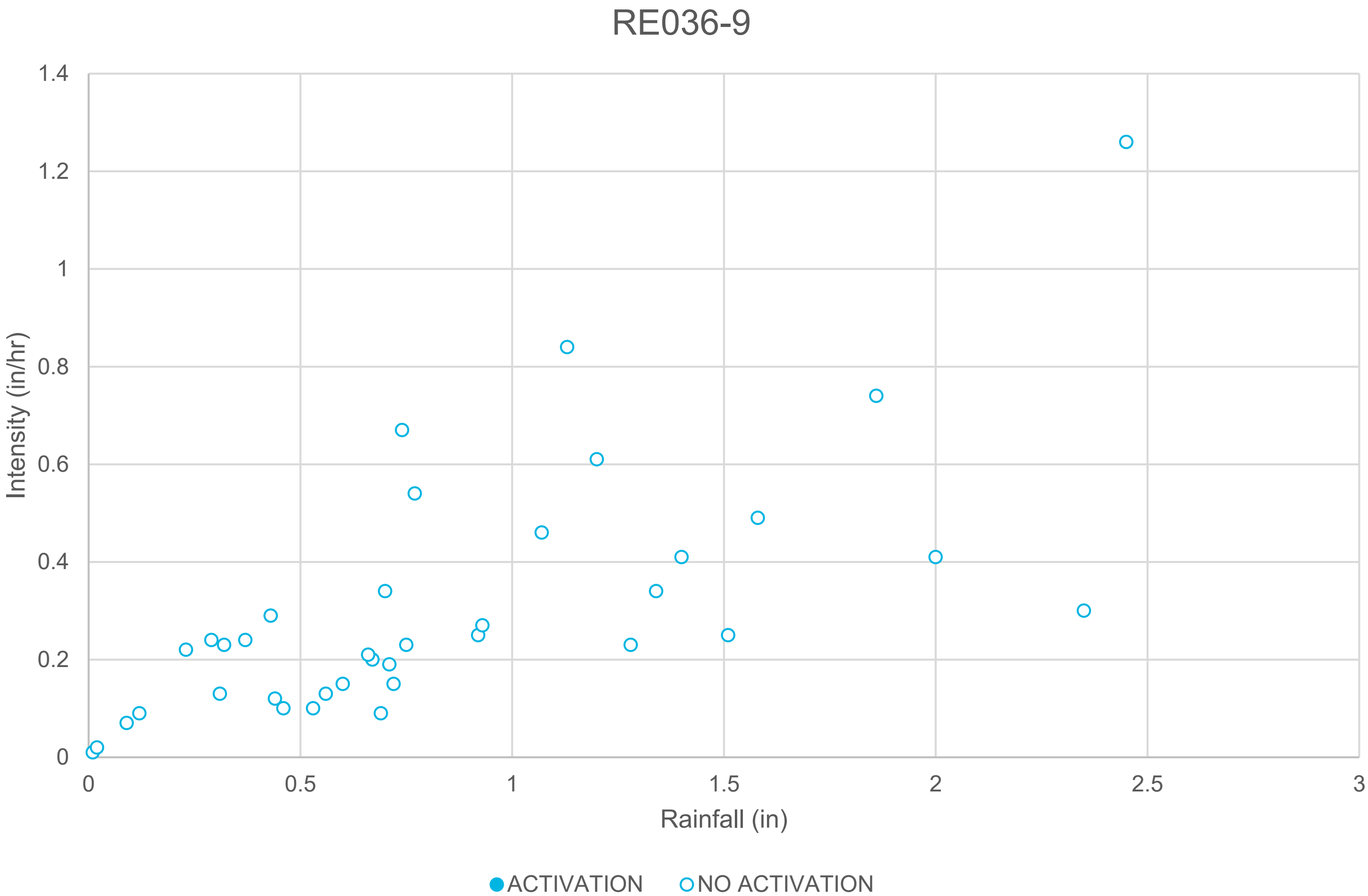
Lower Charles

CAM017	CAM017
MWR010	RE036-9
	RE037
MWR201	Cottage Farm
MWR023	RE046-19
	RE046-30
	RE046-50
	RE046-54
	RE046-55
	RE046-62A
	RE046-90
	RE046-100
	RE046-105
	RE046-381
	RE046-192

Outfall: CAM017
Regulator: CAM017
Related Rain Gauge: 4

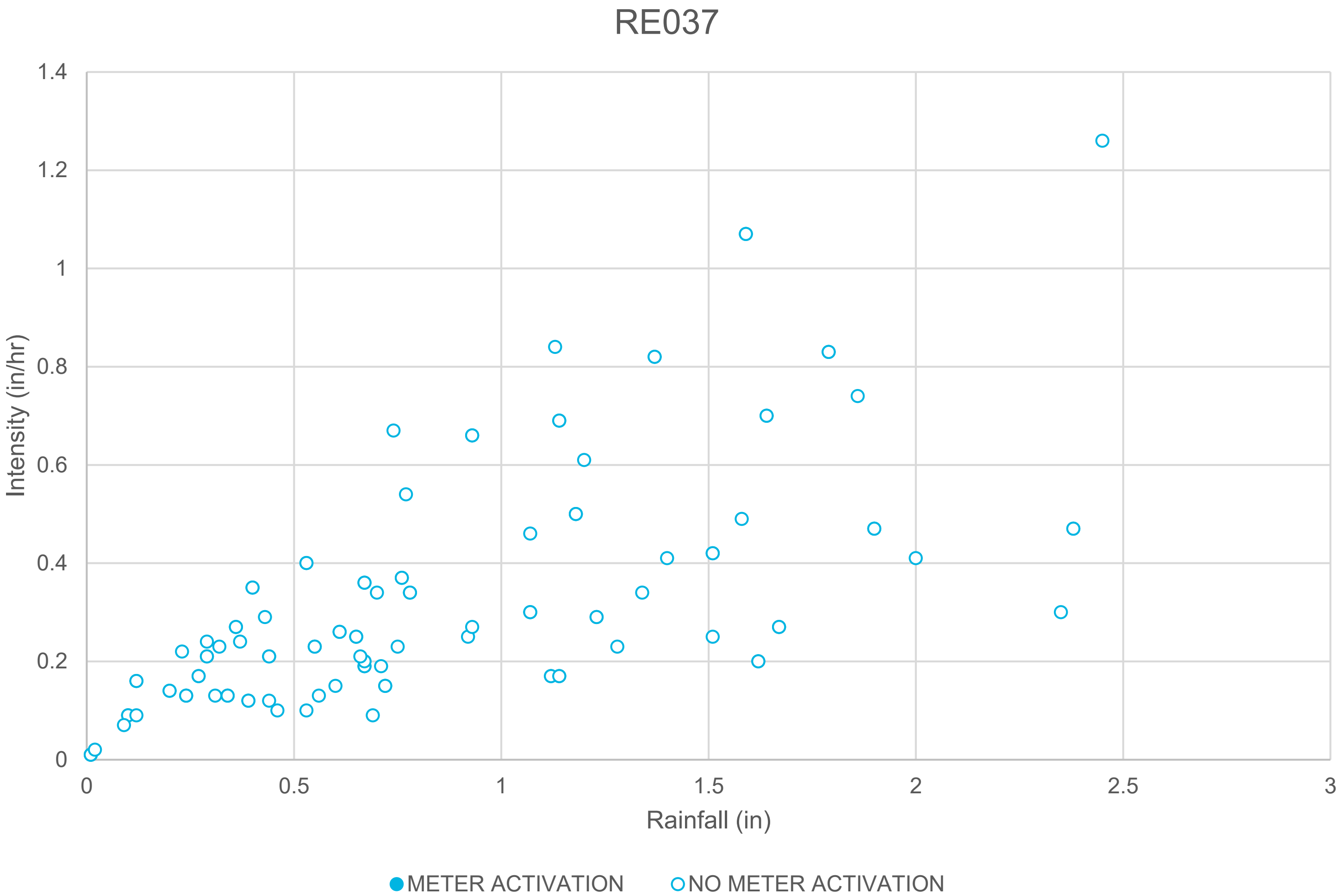


Outfall: MWR010
Regulator: RE036-9
Related Rain Gauge: 12

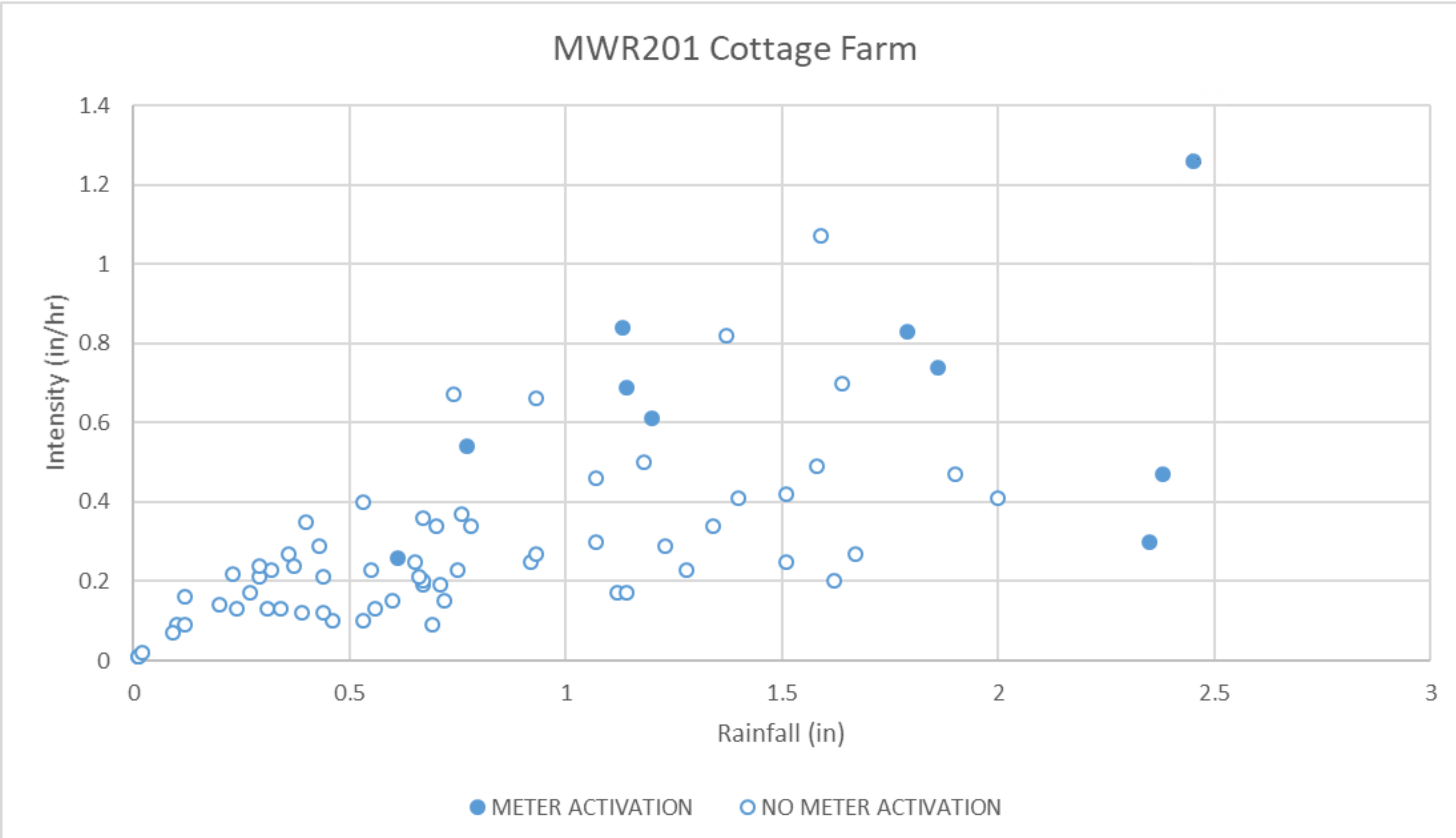


Metering data not available until December, 2018

Outfall: MWR010
Regulator: RE037
Related Rain Gauge: 12

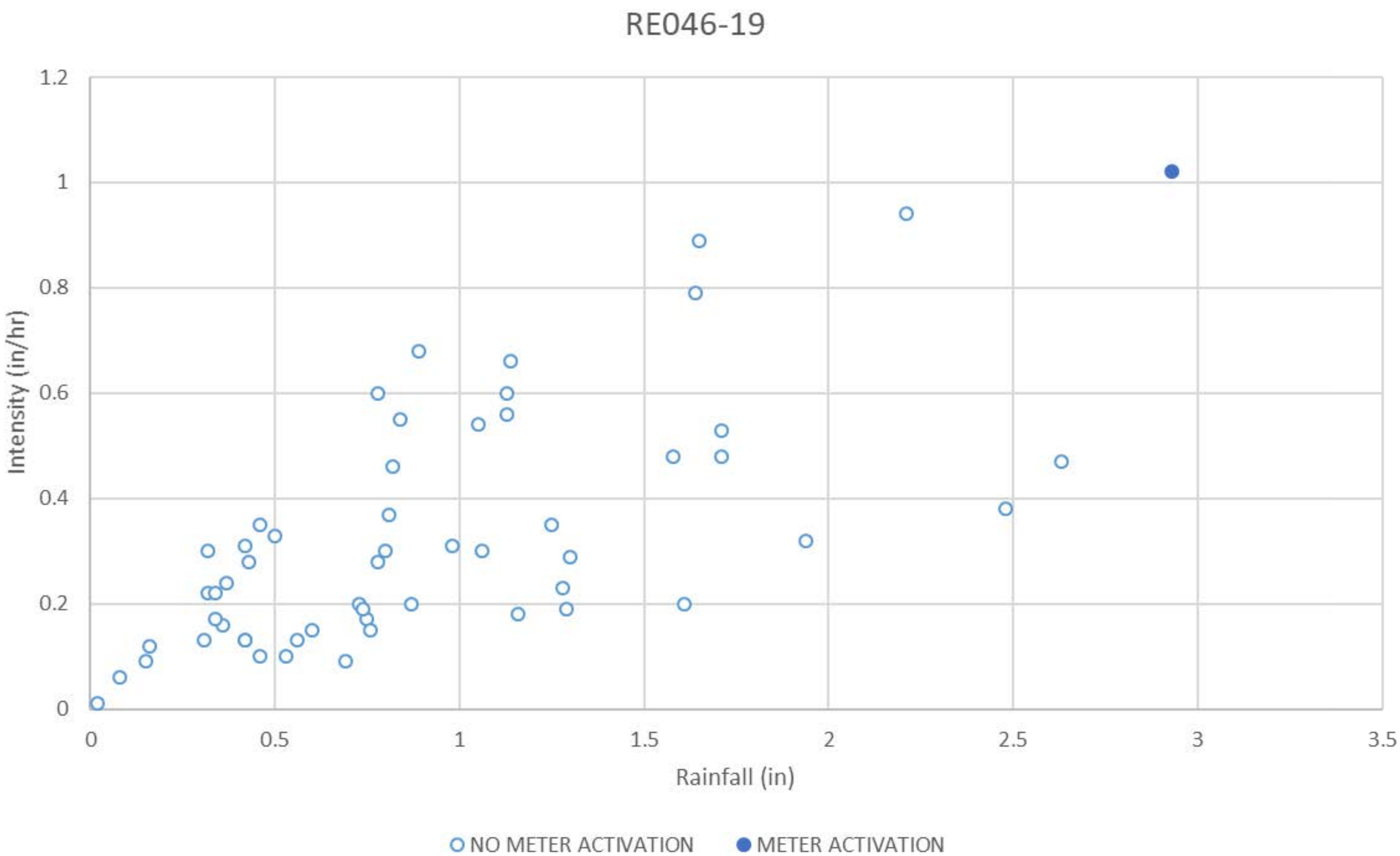


Outfall: MWR201 (Cottage Farm)
Regulator: RE042
Related Rain Gauge: 12

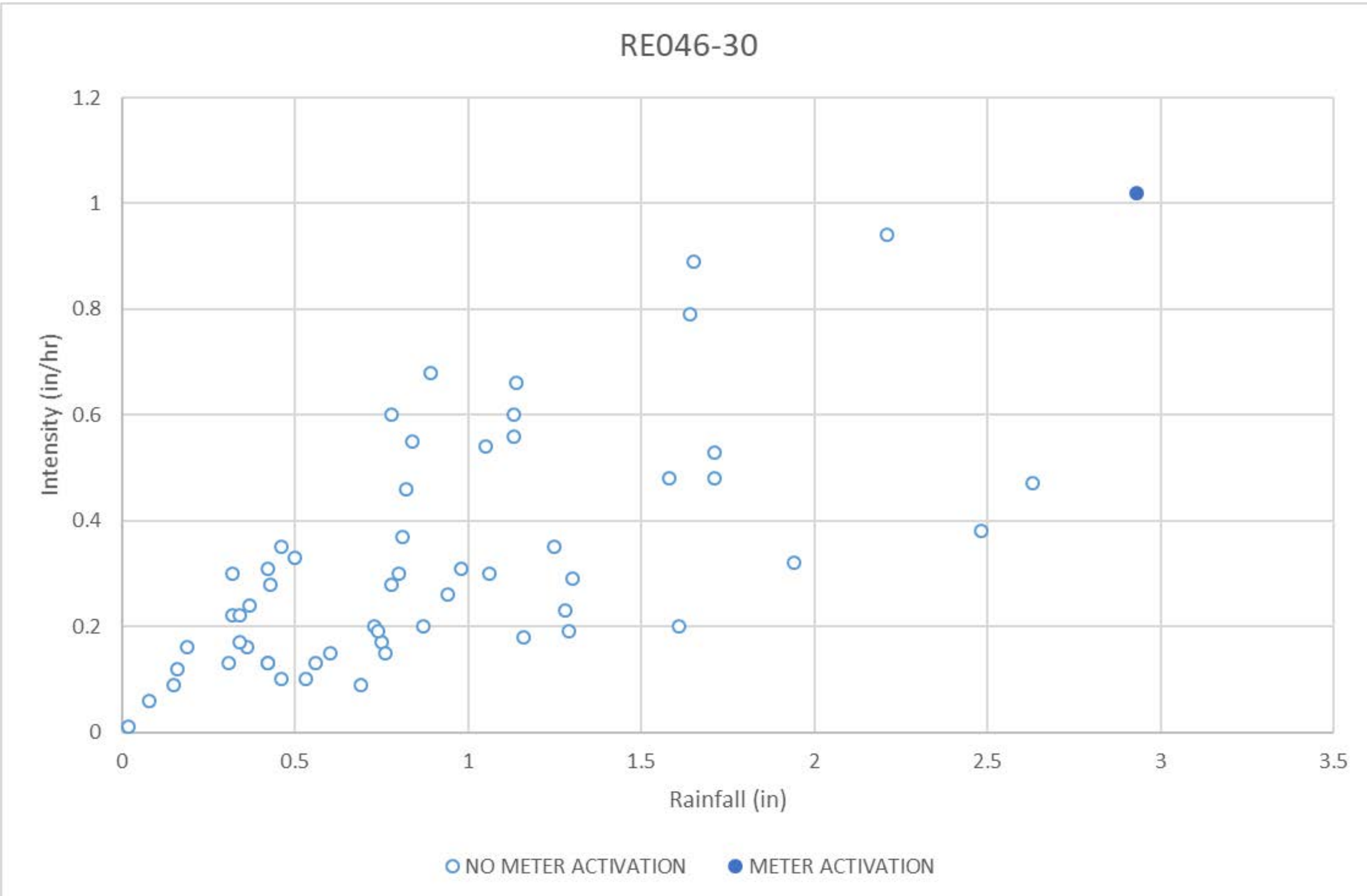


Meter activation represents an activation in which flow was discharged out of Cottage Farm

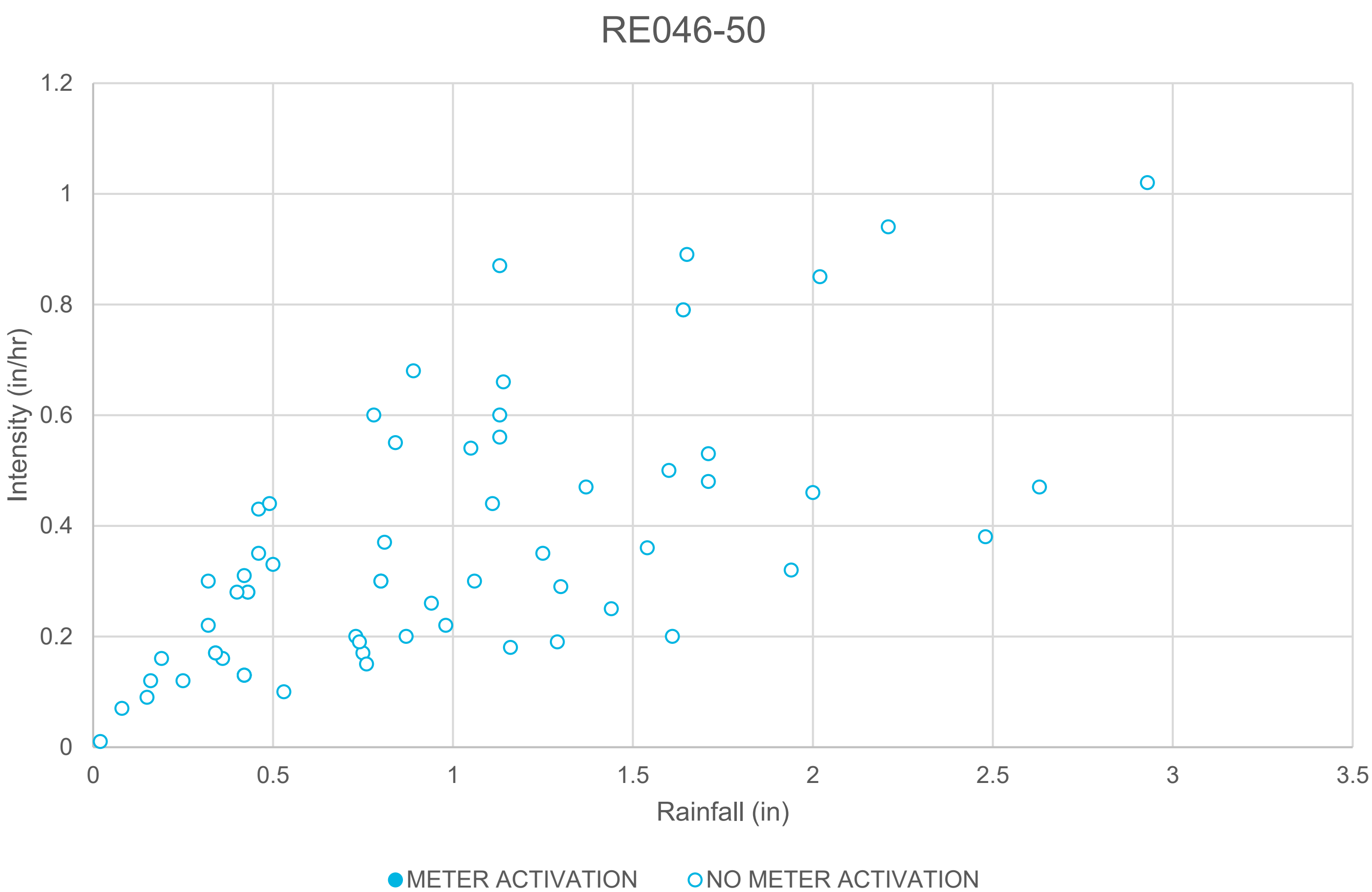
Outfall: MWR023
Regulator: RE046-19
Related Rain Gauge: 15



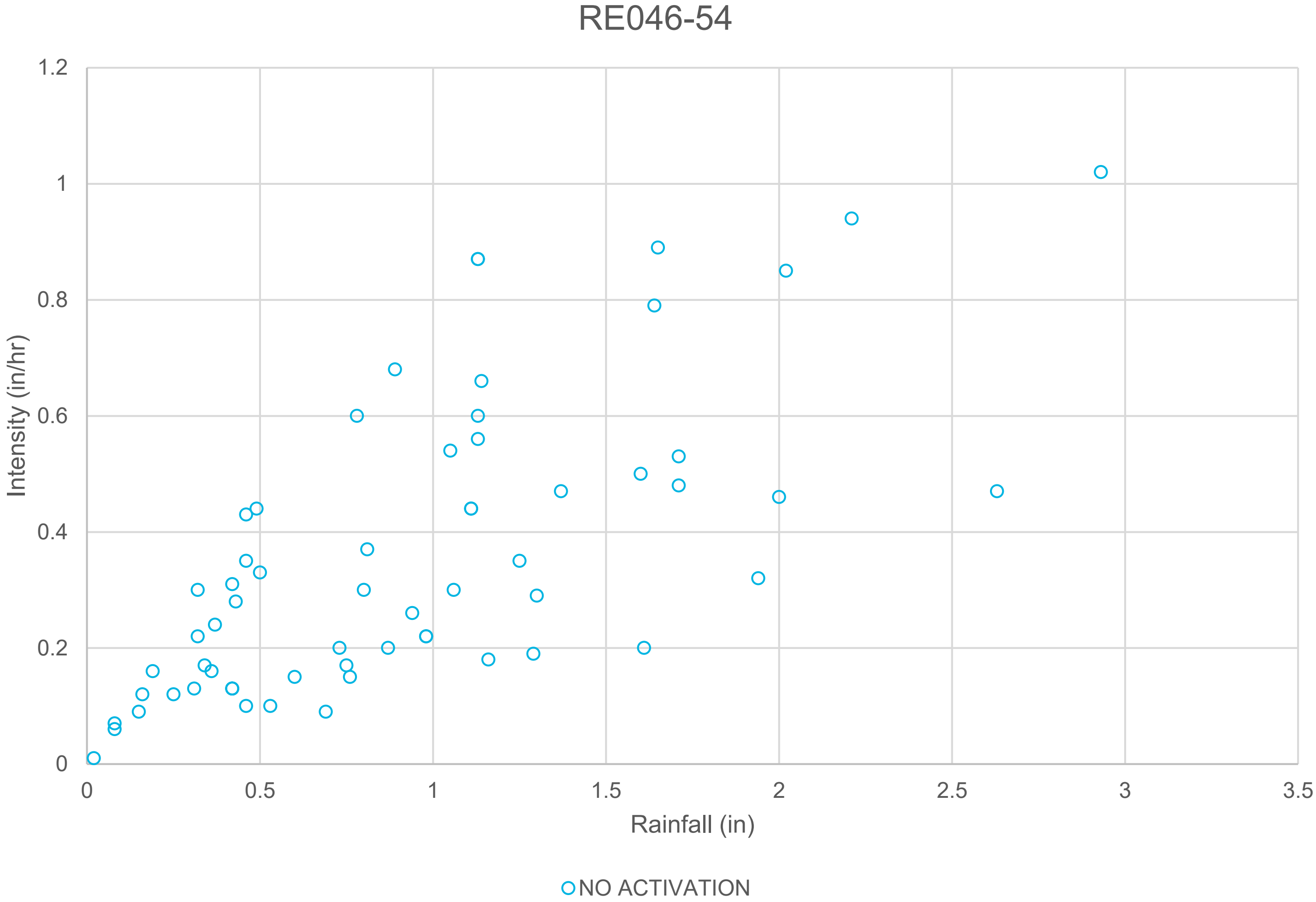
Outfall: MWR023
Regulator: RE046-30
Related Rain Gauge: 15



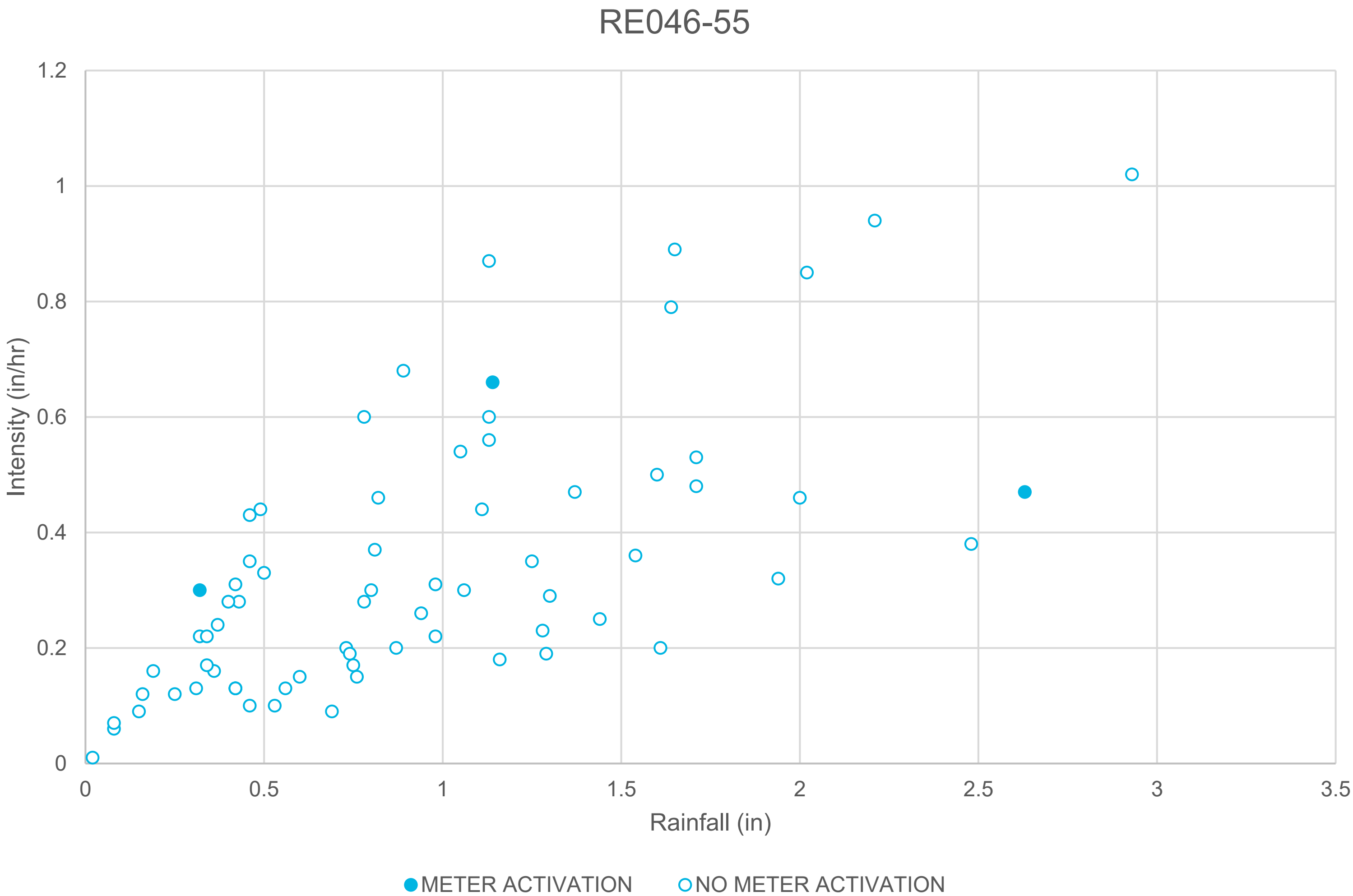
Outfall: MWR023
Regulator: RE046-50
Related Rain Gauge: 15



Outfall: MWR023
Regulator: RE046-54
Related Rain Gauge: 15

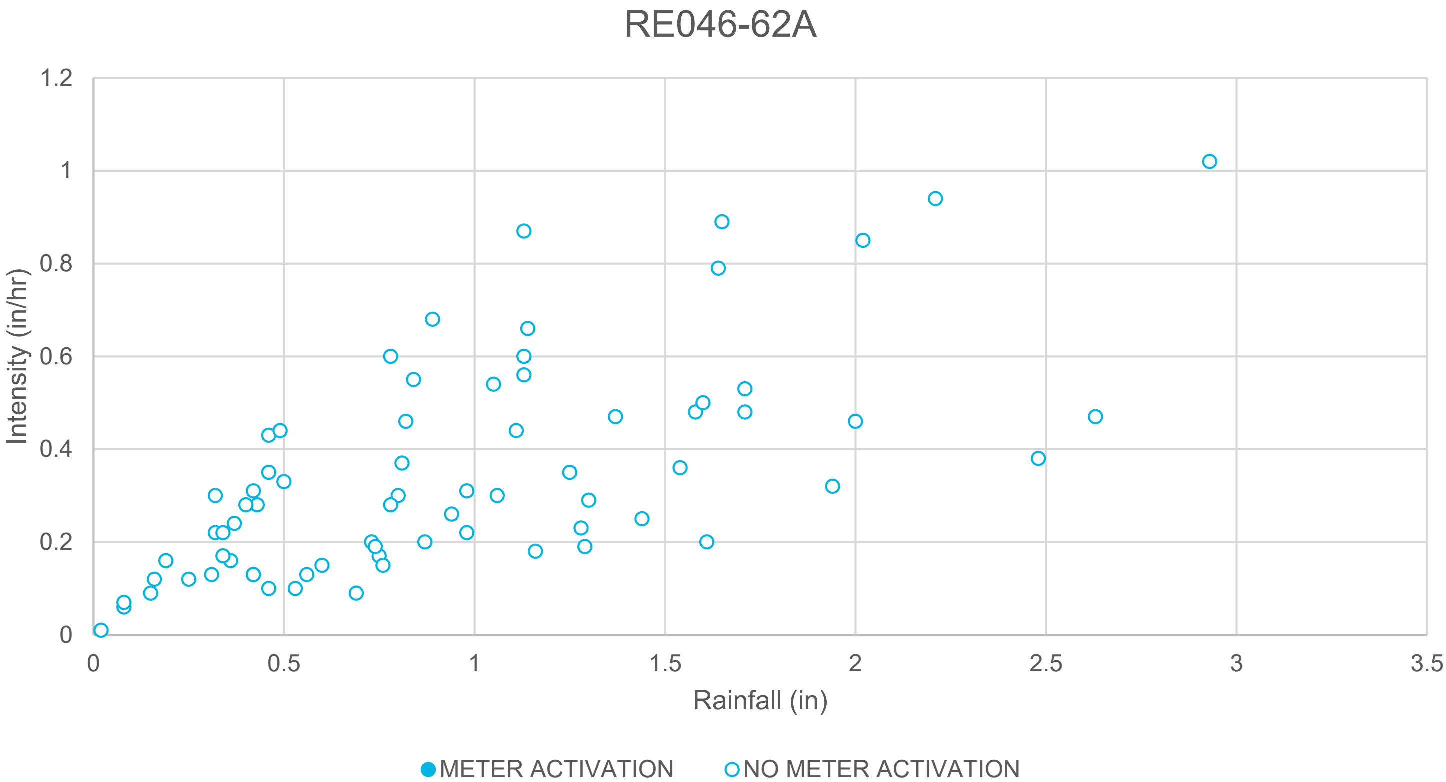


Outfall: MWR023
Regulator: RE046-55
Related Rain Gauge: 15

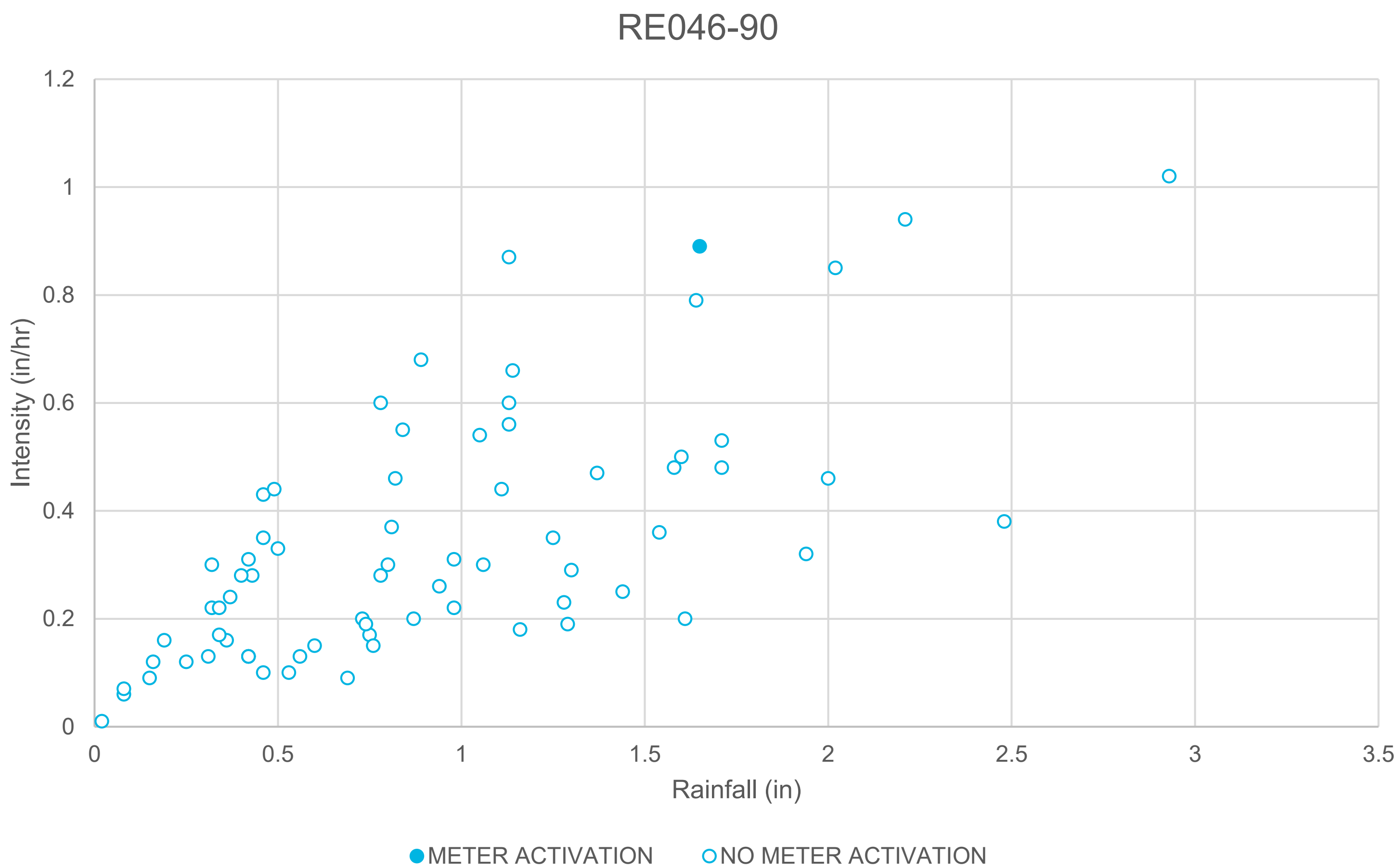


Blockage may have contributed to some activations prior to June 21, 2018.

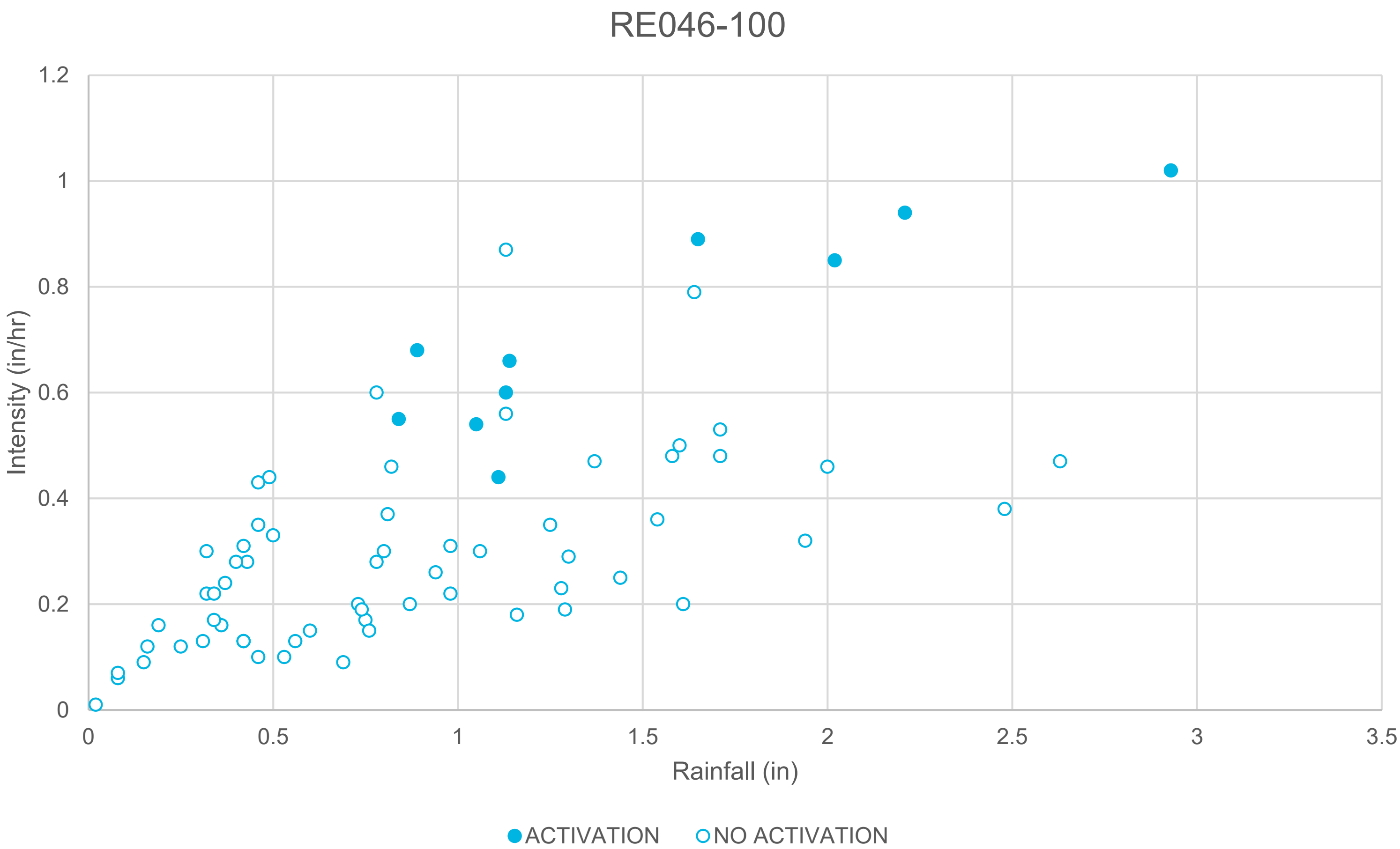
Outfall: MWR023
Regulator: RE046-62A
Related Rain Gauge: 15



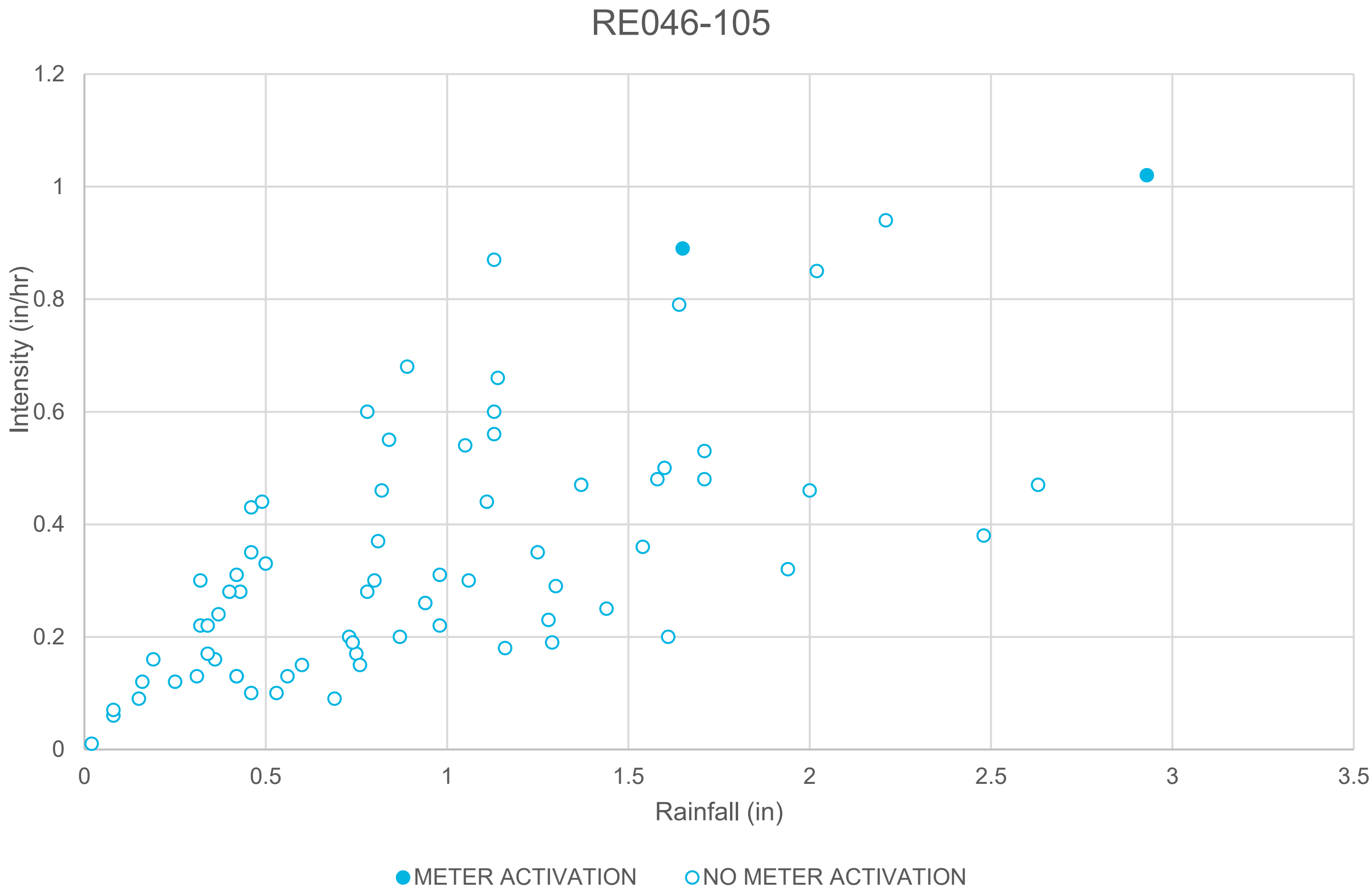
Outfall: MWR023
Regulator: RE046-90
Related Rain Gauge: 15



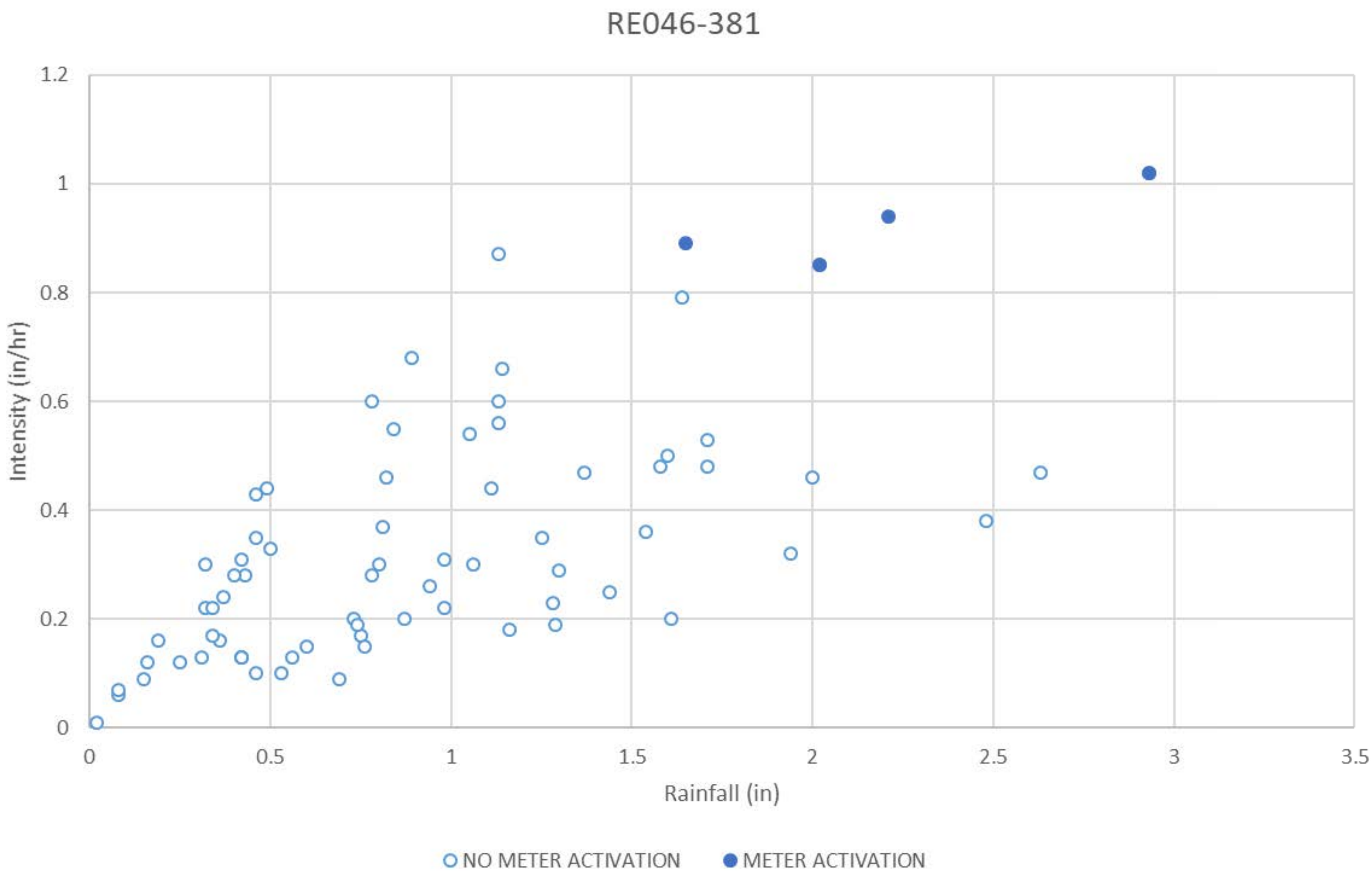
Outfall: MWR023
Regulator: RE046-100
Related Rain Gauge: 15



Outfall: MWR023
Regulator: RE046-105
Related Rain Gauge: 15



Outfall: MWR023
Regulator: RE046-381
Related Rain Gauge: 15



Outfall: MWR023
Regulator: RE046-192
Related Rain Gauge: 2