Task 6: Final CSO Post Construction Monitoring Program and Performance Assessment Report

MWRA Contract No. 7572

December 30, 2021

Project number: 60559027

Foreword

As we file this Final CSO Assessment Report, I am filled with gratitude and pride when I reflect on the accomplishments made over the past 30 plus years that have dramatically transformed the conditions of Boston Harbor, its tributary rivers and beaches. Faced with unacceptable water quality in the 1980s, the court plaintiffs understandably filed suit against MWRA's predecessor agency leading to the issuance of a Federal Court Order in what has been come to be known as the "Boston Harbor Case". With the dedication and diligence of our state and federal partners at MassDEP and EPA Region 1, the Conservation Law Foundation, the watershed advocacy groups, and MWRA's member communities as well as the many dedicated MWRA Board members and staff, we have gone from an estimated annual discharge of 3.3 billion gallons of Combined Sewer Overflows (CSOs) to the harbor and rivers in the late 1980s to 414 million gallons today, an 87% overall reduction with 93% of the remaining discharges treated. Although these improvements came at the high cost of approximately $911 million to implement the Long-Term Control Plan (LTCP) and make further improvements beyond the 35 projects required under the court order, it was money well spent when considering the revitalization of the waterfront neighborhoods and new recreational opportunities on or near these vastly cleaner natural resources. These investments will be appreciated for generations to come. As a reminder of what has been accomplished:

- Boston Harbor, once derided as the dirtiest harbor in America, has rebounded; seals, whales, and other wildlife are returning;
- Boston's beaches are considered the cleanest urban beaches in the country, providing residents with safe access to the seaside without the need to travel;
- The EPA and local watershed organizations have given the Charles River's Lower Basin, which had a failing grade of D in 1995, grades between B- to A- over the past five years, and there are considerations to opening it up to swimming once again;
- An innovative stormwater wetland in Cambridge has improved water quality in the Little River and Alewife Brook and created plant and wildlife habitats, recreational open space and educational opportunities;
- Water quality monitoring data show that bacterial contamination in the main stem of the Mystic River is very low on a regular basis and meets water quality standards in dry weather and most of the time in wet weather;
- The cleanup of Boston Harbor, its tributary rivers and its beaches has brought about a renaissance of recreational activity and waterfront development.

With advancement in the tools used to measure and understand how rainfall impacts collection system flows within the MWRA's and CSO communities' systems, MWRA has been able to refine its prediction of CSO discharge frequency and volumes. The assessment program implemented over the last four years utilized 64 meters at critical CSO regulators, which enhanced our work in building and calibrating a collection system model that would confidently predict CSO performance. As documented in the attached report, 70 of the 86 CSO outfalls known to be active 30 years ago are now achieving, or materially achieving, their established LTCP goals. This includes the closure of 35 outfalls (10 more than required under the LTCP) and the virtual elimination of CSO and stormwater discharges at five outfalls that had long polluted the South

Boston beaches prior to construction of the South Boston storage tunnel. With respect to the 16 outfalls where the Authority has not met the specific volume and/or activation goals, it is notable that the implementation of the LTCP and its 35 projects has significantly reduced both the frequency of activation and discharge volume and the Authority is near meeting the system-wide LTCP goal. With the current overall CSO volume prediction of 414 million gallons (MG) in a typical year, the Authority has reduced discharges in a typical year by 87%. This is very close to the overall LTCP goal of an 88% reduction established years ago.

MWRA will continue to focus its attention on these 16 remaining outfalls. MWRA is moving forward with projects to improve performance at six of the 16 CSO outfalls, and is either already in construction (BWSC East Boston sewer separation) or in design (CHE008, Somerville Marginal MWR205, SOM007A/MWR205A) to implement these improvements. These six outfalls are projected to meet LTCP goals after 2021, further reducing the overall CSO volume to approximately 384 MG in a typical year, 20 MG below the LTCP objective. For the remaining 10 outfalls, MWRA has identified, through hydraulic modeling, potentially feasible alternatives that are predicted to achieve LTCP volume and activation goals at four of the outfalls. MWRA will continue to conduct evaluations for these four as well as the remaining six outfalls, where the remaining, but small, CSO activation or volume exceedances have been particularly challenging to resolve.

A sophisticated receiving water quality model was developed and calibrated to better understand how pollutant sources, including stormwater, boundary sources and treated and untreated CSOs, continue to impair water quality standards for the Charles River, Alewife Brook, and Upper Mystic River. Water quality data continues to be collected, as has been done for over 30 years, within the Alewife Brook, Mystic River, Charles River, Neponset River, Chelsea Creek, Boston Harbor, Fort Point Channel, and Reserved Channel. These data have been evaluated to determine the water quality impact of the remaining CSOs within the areas where they still exist. In general, bacteria results show that under all weather conditions there have been improvements, although other sources of contamination, including stormwater, illicit connections and infrequent remaining CSOs, continue to impact these water bodies. Overall, water quality impacts are significantly higher from non-CSO sources. Under current conditions, CSOs alone would only contribute to annual non-attainment of the *E. coli* criterion less than 0.1% of the time for the Charles River, and approximately 2% of the time for the Alewife Brook/Upper Mystic River, consistent with the targets established in previous CSO planning efforts.

MWRA's ratepayers across the sewer service area have made a substantial investment in the elimination or control of CSO discharges to protect the environment and public health. MWRA continues to ensure the reliability of its collection and treatment systems, with many facility and collection system projects beyond CSO control totaling approximately $50 million a year in capital spending. In addition, all four CSO communities continue to make investments in system improvements that will further reduce CSO over the coming years. This includes further sewer separation work by the Boston Water and Sewer Commission in East and South Boston, continued sewer separation work by Chelsea as part of its master plan, sewer separation and flood control projects by Somerville, including the Union Square and Poplar Street Pump Station project, that will reduce flows to MWRA's system, and further sewer separation projects and flood control improvements by Cambridge.

MWRA and its combined sewer communities take pride in having accomplished what we set out to do so many years ago. We appreciate the support of our state and federal regulators, and are committed to making further CSO improvements over the next several years. However, achieving minimal water quality improvements must be weighed against the significant challenges and costs of further CSO reductions at the few remaining outfalls.

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MWRA Executive Director

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Definitions

Clean Water Act (CWA): Federal legislation that established the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters.

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 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.

SCADA: An acronym for 'supervisory control and data acquisition,' a computer system in which real time data is gathered and analyzed to control and monitor equipment.

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

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 Post Construction Monitoring and Performance Assessment Report

On November 8, 2017, the Massachusetts Water Resources Authority (MWRA) commenced a three-year study[1] to measure the performance of its $911 million long-term combined sewer overflow ("CSO") control plan (the "Long-Term Control Plan" or "LTCP"). The performance assessment was intended to comply with the last two scheduled milestones in the 36-year-old Federal District Court Order in the Boston Harbor Case (U.S. v. M.D.C., et al, No. 85-0489 MA).

From 1987 through 2015, MWRA addressed 182 CSO-related court schedule milestones, including completing the construction of the 35 wastewater system projects that comprised the LTCP by December 2015. With submittal of this performance assessment report, all of the court imposed deadlines have been met. The last two court milestones required MWRA to:

- Commence by January 2018 a three-year[1] performance assessment including post-construction monitoring in compliance with EPA's CSO Policy (59 Fed. Reg. 18688) (April 19, 1994); and
- Submit by December 2021[1] the results of its performance assessment to the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP) demonstrating that it has achieved the levels of CSO control specified in the LTCP.

These requirements were pursuant to 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"; see Section 1.2.1).

MWRA's CSO performance assessment included the following key scope elements:

- Inspections at all CSO regulators addressed in the LTCP to confirm closed or active status and confirm or update physical conditions;
- Extensive overflow data collection at remaining active CSO regulators;
- Upgrading and improving calibration of MWRA's hydraulic model of the wastewater system using recent inspection information and overflow data;
- Assessments of system performance for CSO control and the consideration of performance improvements; and
- Assessment of the water quality impacts of remaining CSOs and compliance with Massachusetts Water Quality Standards.

This Post Construction Compliance Monitoring report presents the results of field investigations and modeling assessments undertaken to assess the level of performance achieved by the MWRA's LTCP program and describes recent work that has been and will continue to be undertaken to further improve attainment with the LTCP goals. The report is organized into the following parts and chapters:

- **Chapter 1** - Purpose and scope of the Post Construction Compliance Monitoring Report, basis for performance goals, and overview of MWRA's CSO control accomplishments and benefits;

[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.

Part I, Key Findings – The four chapters in Part I present the key findings of the performance assessment in terms of attainment of the LTCP goals for CSO outfall activation and frequency, water quality impacts, and future activities to address outfalls that do not meet the LTCP goals.

- **Chapter 2** - Updated system performance assessment and comparison with LTCP levels of control;
- **Chapter 3** - Receiving water quality modeling and water quality assessments;
- **Chapter 4** - Recommendations and continuing work for outfalls currently forecast not to attain LTCP activation frequency and goals;
- **Chapter 5** - Summary and conclusions from key findings

Part II, Summary of Supporting Activities – The seven chapters in Part II provide details on supporting activities conducted during the performance assessment.

- **Chapter 6** - Summary of the CSO inspection program;
- **Chapter 7** -- Summary of the CSO metering program;
- **Chapter 8** - Summary of CSO meter data review and analysis for data collected;
- **Chapter 9** - Summary of rainfall data collection and analyses;
- **Chapter 10** - Summary of collection system model updates and calibration;
- **Chapter 11** - Summary of meter versus collection system model comparisons;
- **Chapter 12** - Summary of water quality model development and calibration.

During the course of the project MWRA documented the progress of the performance assessment in seven interim reports listed in Table 1-1. These reports provide additional detail on the items discussed above and are referenced in the chapters that follow.

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
2 - link	July 1 to December 31, 2018 (6 months)	Apr. 2019
3 - link	January 1 to June 30, 2019 (6 months)	Oct. 2019
4 - link	July 1 to December 31, 2019 (6 months)	Apr. 2020
5 - link	January 1 to June 30, 2020 (6 months)	Oct. 2020
6 - link	July 1 to December 31, 2020 (6 months)	Apr. 2021
7 - link	January 1 to June 30, 2021 (6 months)	Oct. 2021

1.2 Basis for Performance Goals

1.2.1 Second Stipulation and Goals for CSO Activation Frequency and Volume

MWRA's obligations for CSO control in the Court Order are set forth 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* (the "Second Stipulation") as amended in April 2008. The Second Stipulation, which replaced the 1987 First Stipulation by which MWRA originally assumed responsibility under the Court Order for CSO control, formalized agreements reached by EPA, DEP and MWRA in March 2006 over long-term levels of CSO control, the projects comprising the LTCP, and project implementation schedules. In exchange for MWRA agreeing to supplement the 1997 Charles River CSO plan with additional projects that would achieve a higher level of control, MWRA was allowed a five-year period (2015-2020) of no additional CSO obligations or related capital project spending beyond the LTCP that was then approved. With the agreement, MWRA assumed the obligation of conducting a post-construction monitoring program and performance assessment to assess attainment of the LTCP levels of control. With this agreement and associated approvals and court orders, MWRA gained greater certainty in managing its capital program and rate increases over the 15-year period through 2020.

The Second Stipulation requires MWRA to implement the CSO requirements on the Court's schedule, as well as meet the LTCP levels of control. In July 2006, the Court accepted and incorporated the approved schedule revisions as Schedule Seven. The approved LTCP levels of CSO control are set forth in Exhibit "B" to the Second Stipulation and reproduced below in Table 1-2. Pursuant to the Second Stipulation, MWRA accepted legal liability to undertake such corrective action at each CSO outfall within or hydraulically connected to MWRA's sewer system as may be necessary to implement the CSO control set forth in the Court schedules and related orders of the Court, and to meet the levels of CSO control (including as to frequency of CSO activation and as to volume of discharge) described in MWRA's Long-Term CSO Control Plan. With respect to all CSO outfalls owned and operated by the MWRA, including the CSO outfalls in Exhibit "B" identified with the prefix "MWR" and the Union Park CSO Treatment Facility CSO outfall, MWRA also accepted legal liability to undertake such future corrective action as may be necessary to meet the CSO control requirements of the Clean Water Act.

The performance goals established in the Second Stipulation were based on a "Typical Year" of rainfall that was defined in the Long-Term CSO Control Plan. The "Typical Year" is a 365-day design period that MWRA uses to evaluate CSO performance and was accepted by EPA and DEP as a key performance measure. This rainfall year was created during the development of the CSO LTCP to represent average annual rainfall in the CSO system. The rainfall from 1992 was selected and "typicalized" by adding and removing storm events to create a year that represented long-term averages from a 40-year rainfall record. The rainfall is used to estimate average CSO performance on an annual basis.

The Typical Year has been the basis for development, recommendation and approval of the levels of control in the LTCP; establishment of the federal court mandated levels of control; and assessment of system performance. Typical Year performance is measured and tracked with MWRA's wastewater system hydraulic model, which as part of this assessment program underwent a major calibration and was updated based on new flow meter data. The model update kept pace with changes to the MWRA system and the community systems to better represent CSO discharges. One of the objectives of the performance assessment was to improve the level of confidence in the model for predicting system conditions and CSO discharges so that the model could reliably be used to establish system performance for the Typical Year.

The long-term levels of CSO control recommended by MWRA with its LTCP, approved by EPA and DEP with the 2006 Agreement, and included in Exhibit B to the Second Stipulation are presented in Table 1-2.

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

CSO OUTFALL	LONG TERM CONTROL PLAN(1) 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**
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**

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

CSO OUTFALL	LONG TERM CONTROL PLAN[1] TYPICAL YEAR	
	Activation Frequency	Volume (MG)
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**
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**

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

CSO OUTFALL	LONG TERM CONTROL PLAN[1] TYPICAL YEAR	
	Activation Frequency	Volume (MG)
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**

Notes:
(1) This list has 84 outfalls. Currently MWRA reports CSO discharge activation frequency and volume at 86 locations including SOM002 and SOM006 which are not included in the Second Stipulation. Outfalls SOM002 and SOM006 had been closed prior to issuance of the Second Stipulation.

1.2.2 Attainment of Water Quality Standards

In addition to performance goals for CSO activations and volumes, the LTCP included goals for attainment with water quality standards. In 1998, when EPA and DEP issued their initial approvals of MWRA's 1997 recommended CSO plan, DEP also issued water quality standards determinations for some of the CSO affected water segments, and issued CSO variances for others. This brought the plan into compliance with state water quality standards. Table 1-3 shows current water quality standards classifications established by DEP for the waters covered by the MWRA's LTCP. As indicated in Table 1-3, the applicable water quality standards for the waters affected by the LTCP include Class B, Class SB, Class $B_{(CSO)}$, Class $SB_{(CSO)}$, and Class B (CSO Variance). Class B and Class SB waters are, respectively, inland and coastal/marine waters designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. Water meeting Class B or SB standards indicate that the water is “fishable and swimmable.” CSO discharges to Class B and Class SB waters are prohibited primarily to protect beaches and shellfish beds.

Table 1-3. Water Quality Standards and Required Levels of CSO Control

Water Quality Standard Classification	Receiving Water Segment	Required Level of CSO Control
Class B	Neponset River	CSO prohibited (25-year storm control for the South Boston beaches)
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 frequency and volume in the approved Long-Term Control Plan (LTCP)
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 (1998-2024)

In the Massachusetts Surface Water Quality Standards regulation, Class $B_{(CSO)}$ or $SB_{(CSO)}$ waters

> *…occasionally are subject to short-term impairment of swimming or other recreational uses due to untreated CSO discharges in a typical year, and the aquatic life community may suffer adverse impact yet is still generally viable. In these waters, the uses for Class B and Class SB waters are maintained after the implementation of long term control measures described in the approved CSO long term control plan, except as identified in such plan. The Department may designate a segment partial use, $B_{(CSO)}$ or $SB_{(CSO)}$, provided that a. a Department approved long term control plan provides justification for the overflows; b. the Department finds through a use attainability analysis and EPA concurs, that achieving a greater level of CSO control is not feasible for one of the reasons specified at 314 CMR 4.03(4); c. existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected; and d. public notice is provided …*[2]

DEP did not change the Class B designations for the Charles River and the Alewife Brook/Upper Mystic River at the time the LTCP was approved, but instead issued water quality standards variances to Class B standards for the impacts from CSO. DEP has since issued a series of multi-year CSO variances that allow MWRA and the CSO communities to continue to discharge CSO to these waters. In accordance

[2] Massachusetts Surface Water Quality Standards, 314CMR4 .06(1)(d)(10), December 6, 2013

with agreements MWRA reached with EPA and DEP in 2006, 2016 and 2019, DEP reissued, and the EPA approved, the Charles River and Alewife Brook/Upper Mystic River CSO variances through August 2024.

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 authorize limited CSO discharges to these receiving waters subject to conditions in the variances. Each variance extension, including the variances currently in effect, acknowledges that it would not be feasible to fully attain the Class B bacteria criteria and associated recreational uses for these receiving waters within the variance period.

The variances include conditions that MWRA and the CSO communities have complied with for these waters. The latest conditions include, but are not limited to:

- Implementation of the LTCP;
- Continued implementation of operation and maintenance measures that can minimize CSO discharges and impacts;
- Dissemination of public information on CSO discharges and potential public health impacts;
- Rapid public notifications of CSO discharges to the Charles River and to Alewife Brook or the Upper Mystic River;
- Continuation of MWRA's water quality monitoring program; and
- Annual reporting of rainfall events and estimates of CSO activations and discharge volumes at each outfall.

The variances currently in effect, from September 1, 2019 to August 31, 2024, include additional system optimization measures listed below:

- Alewife Brook Project - Alewife Brook Pump Station Optimization Evaluation Project (Notice to proceed April 2020. Study Report/Preliminary Design Submittal to MassDEP for review and approval April 2021);
- Mystic River Watershed Project - MWR205 & SOM007/MWR205A Somerville Marginal CSO Reduction Project, Study and Preliminary Design (Notice to proceed December 2020. Study Report/Preliminary Design Submittal to MassDEP for review and approval December 2021);
- CSO System Optimization for Alewife Brook and Lower Charles River Basins Project Study and Preliminary Design (Notice to proceed December 2020. Study Report/Preliminary Design Submittal to MassDEP for review and approval December 2022).

The variances have required continued implementation of CSO long-term control measures consistent with the LTCP and compliance with the Nine Minimum Controls defined in the EPA National CSO Policy. In compliance with the Nine Minimum Controls, MWRA maintains the conveyance capacity of its collection system and, with the cooperation of its CSO communities has improved the conveyance and treatment of wet weather flows through system optimization improvements. Examples of system optimization improvements include the raising of overflow weirs, the implementation of SCADA monitoring and control systems, optimized handling of flows at MWRA's Columbus Park and Ward Street headworks, and improved timing of the opening and closing of influent gates at MWRA CSO treatment facilities.

1.3 MWRA's CSO Control Accomplishments and Benefits

1.3.1 Three Decades of CSO Control Accomplishments and Benefits

MWRA's CSO control program began in 1987, when through a stipulation entered in the Boston Harbor Case (U.S. v. M.D.C., et al., No. 85-0489 MA) (the "First CSO Stipulation"), MWRA accepted responsibility for developing and implementing a region-wide plan to control CSOs hydraulically related to its wastewater system, including CSO discharges from its own outfalls and the outfalls permitted to and operated by the Boston Water and Sewer Commission (BWSC) and the cities of Cambridge, Chelsea and

Somerville. Since then, MWRA, with the cooperation of the CSO communities, has completed more than 180 CSO related milestones in the court ordered schedule (currently, “Schedule Seven”).

MWRA’s CSO efforts included development and implementation of projects to eliminate dry weather overflows and development of a first recommended CSO control plan (the Deep Rock Storage Tunnel Plan,[3] 1987-1991); development and implementation of more than 100 system optimization improvements that reduced average annual CSO discharge volume by nearly 25% (1992-96); development of the Long-Term CSO Control Plan (1992-97); reassessment and refinement of several CSO projects recommended in the 1997 plan, including the addition of several CSO projects to increase level of control for the Charles River (2006); and design and construction of the 35 CSO projects (1996-2015) in compliance with Schedule Seven. MWRA’s efforts also included additional system optimization strategies that further reduced CSO discharges, including enhancements to the operational protocols for the Cottage Farm, Prison Point and Somerville Marginal CSO treatment facilities (2007-08). MWRA has continuously tracked the effect of these improvements on system performance and CSO discharges.

Development and implementation of the LTCP closely followed and conformed to the requirements of the National CSO Policy[4] and EPA CSO-related guidelines, as well as Massachusetts DEP CSO Policy and CSO Guidance, even as these federal and state CSO policies were evolving. Through extensive inspections, system monitoring and modeling beginning in 1992-93, MWRA conducted a detailed characterization and performance assessment of its then-existing collection and treatment system, but also incorporating major capital improvements already planned. The 1992 performance assessment incorporated major capital investments in the sewer system already underway or planned by MWRA, including upgrades to the transport system, pumping stations, headworks and Deer Island treatment plant (“Early CSO Related Improvements" in Figure 1-1). In the period 1988 through 1992, total annual CSO discharge predicted for the Typical Year rainfall dropped from 3.3 billion gallons to 1.5 billion gallons, with approximately 51% of the remaining discharge treated at five MWRA CSO treatment facilities that were in operation at that time[5]. The Charles River especially benefited from these early system improvements.

[3] In 1990, MWRA recommended a Deep Rock Storage Tunnel for CSO control, at an estimated capital cost of $1.2 billion in 1990 dollars (approx. $2.5 billion today), that conformed to the 1989 EPA CSO Strategy. In 1992, with the prospect of a more flexible EPA CSO policy (the 1994 National CSO Policy), MWRA began a new planning effort that culminated in the current Long-Term CSO Control Plan.

[4] EPA’s Combined Sewer Overflow Policy, 59 Fed. Reg. 18688 (April 19, 1994)

[5] Since that time, MWRA has decommissioned the Constitution Beach, Commercial Point and Fox Point CSO facilities following completion of sewer separation projects, upgraded the Cottage Farm, Prison Point and Somerville Marginal CSO facilities, and brought into operation the newly constructed Union Park Detention and Treatment facility.

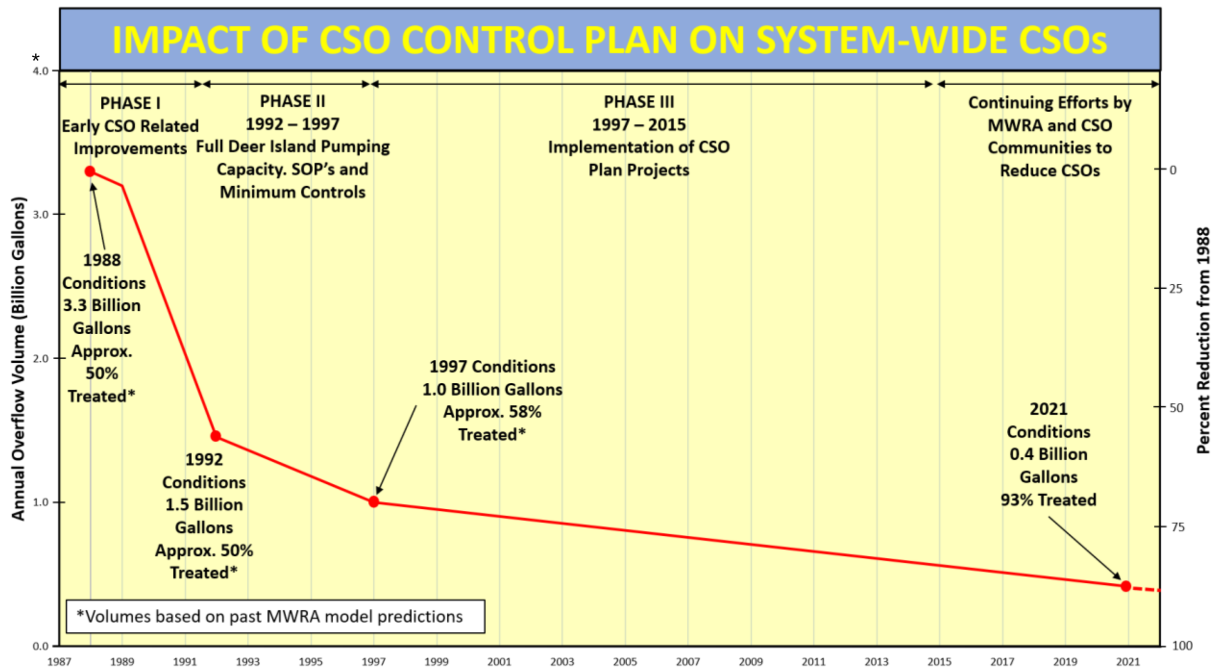


Figure 1-1. Wastewater System Improvement Contributions to CSO Control

EPA's National CSO Policy requires CSO permittees to develop and implement system optimization measures and reporting procedures intended in part to quantify, minimize and report CSO discharges in the short term, ahead of the implementation of a long-term control plan, as well as for the long term. These activities include detailed system characterization, system improvements that can reduce CSO, and optimized operations and maintenance. In 1993-1994, MWRA completed a System Optimization Plan ("SOP"), which recommended approximately 160 system modifications to maximize wet weather storage and conveyance. The SOP projects, which were fully implemented by MWRA and the CSO communities by 1997, further reduced CSO discharges by about 20 percent from the 1992 levels.

MWRA's CSO planning culminated in the recommendation of an extensive set of projects covering a range of control technologies to achieve long-term, site-specific CSO control goals using watershed-based assessments of receiving water impacts and uses. MWRA presented a conceptual plan of these improvements in 1994 and refined the recommendations in a *CSO Facilities Plan and Environmental Impact Report* issued in 1997. The long-term plan received initial federal and state approvals in early 1998, allowing MWRA to move the projects into design and construction.

As MWRA proceeded with implementation of the projects, it evaluated and recommended several adjustments and additions to the long-term plan in the period 1998 through 2006. These adjustments and additions responded to regulatory inquiries seeking higher levels of control (Charles River) or to new information about construction requirements, cost or CSO control performance (North Dorchester Bay, Reserved Channel, East Boston, and Alewife Brook). A final, comprehensive long-term control plan, comprising 35 wastewater system projects, shown in Figure 1-2, was approved by EPA and DEP in March 2006 and accepted by the Federal Court in April 2006 as part of the Second Stipulation, which replaced the 1987 First CSO Stipulation. Descriptions of the 35 projects and their individual CSO control benefits were presented in Section 2.4 of MWRA's Semiannual Report No. 1, November 30, 2018.

Figure 1-2. The 35 Long-Term Control Plan Projects

This approved plan and its recommended levels of CSO control were again updated by an amendment to the Second Stipulation in April 2008 that revised the long-term level of control at the Prison Point Facility. This update was based on hydraulic optimization MWRA incorporated into the operations of the facility in response to federal and state regulators' requests and in compliance with related milestones in Schedule Seven. The final approved plan called for reducing total annual CSO discharge in the Typical Year to 0.4 billion gallons (an 88% reduction from the 1988 level), with 93% of the remaining discharge to be treated at four MWRA CSO facilities: three CSO facilities providing detention/treatment with disinfection/dechlorination, and one CSO facility providing screening and disinfection/dechlorination.

MWRA began design and construction of the CSO projects in 1996 in compliance with milestones in the federal court schedule and with cooperation from its member communities with permitted CSO outfalls. MWRA executed memoranda of understanding ("MOUs") and financial assistance agreements with BWSC, the City of Cambridge and the City of Somerville in 1996 by which each municipality agreed to implement the projects within the Long-Term Control Plan involving facilities that would be owned and operated by each community, such as the new storm drain systems that would be constructed as part of sewer separation projects. MWRA agreed to fund the "eligible" costs: the costs of work to construct the facilities necessary to attain the long-term levels of CSO control.

In compliance with strict design and construction milestones in the court schedule, and within a timeframe of only 20 years, MWRA and the CSO communities completed the design and construction of all 35 projects (see Table 1-4). The capital (design and construction) cost of these projects ranged from less than $100,000 (for Prison Point CSO Facility Optimization) to $228.4 million (for the North Dorchester Bay CSO Tunnel).

Most of the projects were major undertakings involving the construction of new wastewater facilities or extensive new storm drain or sewer systems, all in historical, densely developed residential and commercial areas. In addition to the design and construction work, the projects also required extensive coordination with landowners, permitting agencies, transportation authorities and neighborhood residents. In some of the project areas, construction impacts were significant and unavoidable, and the collaboration, support and patience of residents and business owners should not be overlooked in understanding the effort borne by many parties to bring these projects to completion and achieve their benefits.

The MWRA and community CSO control efforts included the management of 125 contracts, including 82 construction contracts, 33 engineering contracts and 10 planning and technical support contracts, as well as financial assistance agreements with five communities that assisted in designing and constructing the plan (represented below) with total award value of $423 million, 46% of the total $911 million budget for CSO control in MWRA's Capital Improvement Program (CIP). MWRA, BWSC, the City of Cambridge and the Town of Brookline installed nearly 100 miles of new storm drain and sewer pipe with the sewer separation, interceptor relief, hydraulic relief, and storage projects in the LTCP. The sewer separation projects involved street-by-street separate storm drain and/or sewer construction that removed more than 4,300 acres of stormwater runoff from sewer systems in Boston, Brookline, and Cambridge.

Prior to 1988, treated and untreated CSO discharges occurred in every rainfall event, approximately 100 times a year. The LTCP was intended to reduce total CSO discharge volume in the Typical Year by approximately 87%, from 3.3 billion gallons a year to 0.4 billion gallons, and 93% (0.38 billion gallons) of this remaining discharge volume was estimated to be treated at MWRA's four new or upgraded CSO treatment facilities. Figure 1-3 shows the targeted CSO reduction for each of the receiving water segments addressed in the LTCP.

Table 1-4. Long-Term CSO Control Plan Project Implementation Schedules

Project		Capital Cost ($ millions)	Commence Design	Commence Construction	Complete Construction
North Dorchester Bay Storage Tunnel and Related Facilities		228.4	Aug-97	7-Aug	11-May
Pleasure Bay Storm Drain Improvements		3.2	Sep-04	Sep-05	Mar-06
Hydraulic Relief Projects	**CAM005 Relief**	1.1	Aug-97	Jul-99	May-00
	BOS017 Relief	1.2		Jul-99	Aug-00
East Boston Branch Sewer Relief		85.7	Mar-00	Mar-03	Jul-10
BOS019 CSO Storage Conduit		14.3	Jul-02	Mar-05	Mar-07
Chelsea Relief Sewers	**Chelsea Trunk Sewer Relief**	30	Jun-97	Sep-99	Aug-00
	Chelsea Branch Sewer Relief			Dec-99	Jun-01
	CHE008 Outfall Repairs			Dec-99	Jun-01
Union Park Detention/Treatment Facility		49.5	Dec-99	Mar-03	Apr-07
CSO Facility Upgrades and MWRA Floatables Control	**Cottage Farm Upgrade**	22.4	Jun-96	Mar-98	Jan-00
	Prison Point Upgrade			May-99	Sep-01
	Commercial Point Upgrade			Nov-99	Sep-01
	Fox Point Upgrade			Nov-99	Sep-01
	Somerville-Marginal Upgrade			Nov-99	Sep-01
	MWRA Floatables Control and Outfall Closings			Mar-99	Mar-00
Brookline Connection and Cottage Farm Overflow Interconnection and Gate		3.0	Sep-06	Jun-08	Jun-09
Optimization Study of Prison Point CSO Facility		0.05	Mar-06	Mar-07	Apr-08
South Dorchester Bay Sewer Separation		118.8	Jun-96	Apr-99	Jun-07
Stony Brook Sewer Separation		44.2	Jul-98	Jul-00	Sep-06
Neponset River Sewer Separation		2.5		Apr-96	Jun-00
Constitution Beach Sewer Separation		3.7	Jan-97	Apr-99	Oct-00
Fort Pt Channel Conduit Sewer Separation and System Optimization		11.9	Jul-02	Mar-05	Mar-07
Morrissey Boulevard Storm Drain		32.3	Jun-05	Dec-06	Jul-09
Reserved Channel Sewer Separation		70.6	Jul-06	May-09	Dec-15
Bulfinch Triangle Sewer Separation		9.1	Nov-06	Sep-08	Jul-10
Brookline Sewer Separation		24.7	Nov-06	Nov-08	Apr-13
Somerville Baffle Manhole Separation		0.4		Apr-96	Dec-96
Cambridge/Alewife Brook Sewer Separation	**CAM004 Stormwater Outfall and Detention Basin**	13.8		Apr-11	Apr-13
	CAM004 Sewer Separation	54.0	Jan-97	Jul 98/Sep-12	Dec-15
	CAM400 Manhole Separation	4.8	Oct-08	Jan-10	Mar-11
	Interceptor Connection Relief/Floatables Control at Outfalls CAM002, CAM401B and CAM001	2.9	Oct-08	Jan-10	Oct-10
	MWR003 Gate and Rindge Ave. Siphon Relief	3.8	Mar-12	Aug-14	Oct-15
	Connection Relief/Floatables Control at SOM01A	0.8	Mar-12	Sep-13	Dec-13
Region-wide Floatables Control and Outfall Closings		1.2	Sep-96	Mar-99	Dec-07

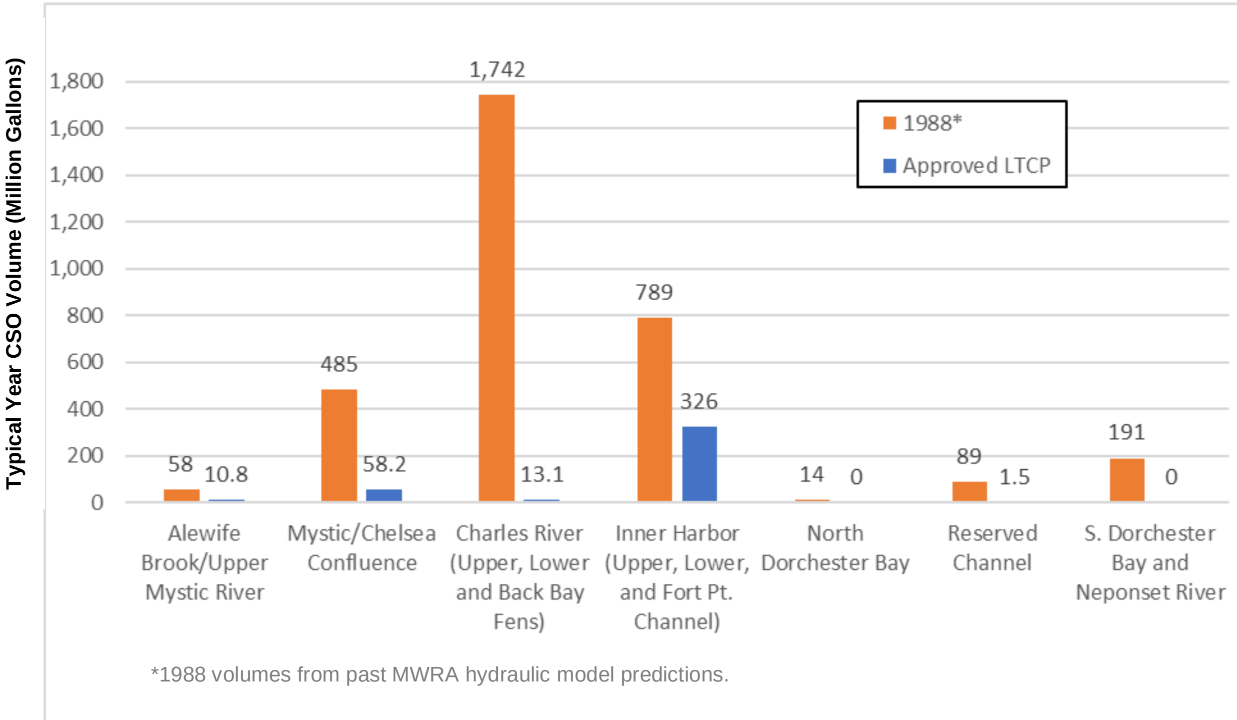


Figure 1-3. Region-wide CSO Discharge Volume Reduction by Receiving Water

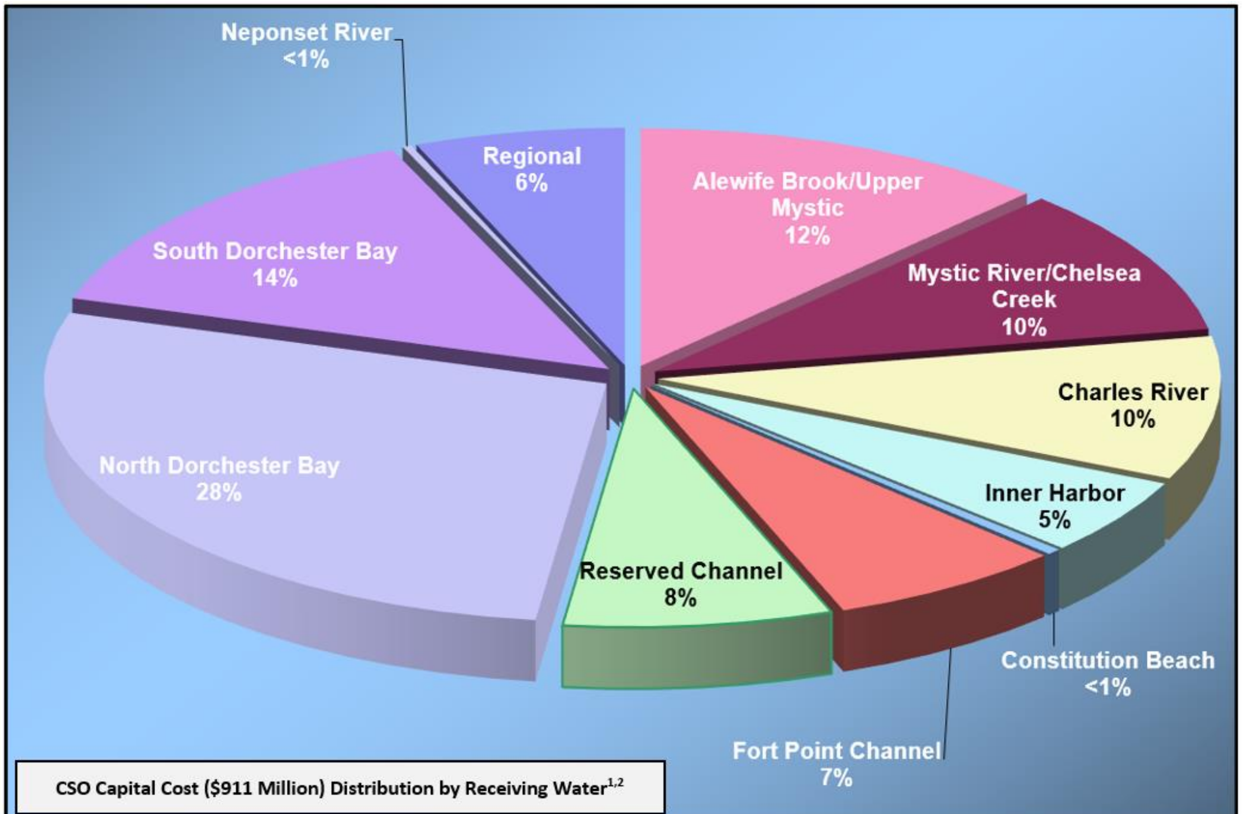
1.3.2 MWRA Ratepayers' Investment in CSO Control

MWRA's Capital Improvement Program (CIP) has spent $911 million for the CSO Control Program, including past planning, MWRA design and construction, financial assistance to communities to implement the LTCP projects resulting in facilities the communities own and operate, and the CSO performance assessment. The allocation of these dollars to CSO control projects and activities for the various receiving waters is shown in Figure 1-4 on the following page.

From 1987 through December 2018, MWRA spent approximately $903 million (99%) of the $911 million CSO Program budget, including $858 million for design and construction of the 35 LTCP projects. The remaining $8 million of CSO spending is for the following scheduled activities:

- $1.6 million for BWSC construction projects that will further reduce stormwater inflow from the Dorchester Interceptor system to minimize the risk of system flooding following the completion in 2007 of the South Dorchester Bay sewer separation project and the closing of related CSO outfalls.
- $5 million for MWRA's post-construction monitoring and performance assessment.
- $2.2 million for BWSC Phase 3 Sewer Separation in East Boston.

MWRA will also pay a $1.4 million share for rehabilitation of a large City of Somerville combined sewer for structural integrity and preservation of maximum in-system storage capacity within the upcoming year.



Notes:
1. "Regional" includes system optimization measures and area-wide planning, including the CSO Post Construction Monitoring Program and Performance Assessment.
2. "Charles River Basin" includes the Back Bay Fens.

Figure 1-4. CSO Cost Allocation by Receiving Water

In addition to the $911 million cost to MWRA for CSO control, BWSC, the City of Cambridge and the Town of Brookline incurred a total of more than $150 million of their own cost to successfully construct the LTCP projects they assumed responsibility for implementing pursuant to MOUs and financial assistance agreements with MWRA. The projects these communities managed primarily involved the construction of miles of new storm drains and sewers in dense residential neighborhoods. The neighborhoods were greatly affected by construction, and it was necessary to leave the construction areas, primarily neighborhood streets, in an improved condition for the long term. The successful construction of the CSO related work necessitated the provision of additional infrastructure and surface improvements for these neighborhoods.

1.3.3 Environmental Quality Improvement

The water quality of Boston Harbor, the Charles, Mystic and Neponset Rivers and Alewife Brook has steadily improved as MWRA and the CSO communities completed the CSO projects and as communities along these waters have implemented programs to control pollutant loadings from storm drains. Implementation of the LTCP has resulted in the elimination of CSO discharges to sensitive receiving waters used for swimming and shell fishing. These areas include the beaches of South Dorchester Bay, the Neponset River (Savin Hill, Malibu and Tenean beaches), and Constitution Beach in East Boston. For the South Boston beaches, MWRA's North Dorchester Bay CSO storage tunnel provides a 25-year storm level of CSO control and a 5-year storm level of separate stormwater control. As a result, beach closings due to high bacteria are relatively infrequent, allowing for swimming on most summer days at all beaches. There has been a marked reduction in samples failing to meet limits following start-up operation of the

CSO storage tunnel in May 2011. The fraction of days failing to meet the bacteria limit at one or more South Boston beaches has dropped from an average of 18% in the five years prior to start-up of the storage tunnel to an average of 4% in the five years following start-up. The few remaining water quality violations and related beach closings are not CSO related (as there has been no CSO discharge since the storage tunnel opened), and may be caused by environmental factors such as near-field overland stormwater runoff contaminated with pet waste or bird droppings.

Over the 10 years of tunnel operation through Q3-2021, stormwater discharged to the beaches in only four large storms, including Hurricane Irene in August 2011, the December 9, 2014 storm (4.47 inches of rain), the March 2, 2018 storm surge and coastal flooding event, and Tropical Storm Ida on September 1-2, 2021 (5 inches of rain). The tunnel has prevented more than 2 billion gallons of CSO and stormwater from discharging to the beaches since May 2011.

MWRA's major improvements to its collection and treatment systems and its completed CSO control projects have removed CSO as a major source of pollution to the Boston Harbor and its tributaries, and have the potential to enhance environmental conditions and promote safe public use. The benefits of these complementary pollution control programs are most evident in the Charles River. Tremendous water quality improvement has been observed and measured in the Charles River Basin, where average annual CSO discharge has been drastically cut from about 1.7 billion gallons in 1988 to 12.5 million gallons in 2021, a greater than 99% reduction. Approximately 73% of this remaining overflow is treated at MWRA's Cottage Farm CSO facility.

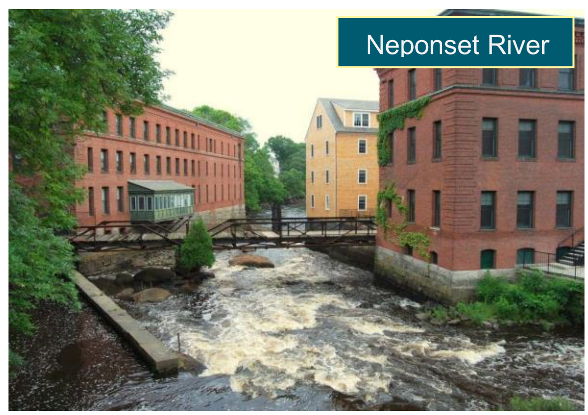
These improvements are the result of major wastewater system projects, most notably the Deer Island Wastewater Treatment Plant and related conveyance and pumping systems, as well as the completed CSO control projects. MWRA and the CSO communities along the Charles River completed a set of improvements in the late 1980s that eliminated dry weather sewage overflows at CSO outfalls. They also completed a set of system optimization projects in the mid-1990s that maximized the wastewater system's hydraulic performance and lowered CSO discharges. MWRA and the communities also completed seven CSO control projects along the Charles River: Cottage Farm Facility Upgrade (2000), CAM005 Hydraulic Relief (2000), Independent Floatables Controls and Outfall Closings Project (2001), Stony Brook Sewer Separation (2006), Cottage Farm Brookline Connection and Inflow Controls (2009), Bulfinch Triangle Sewer Separation (2010), and Brookline Sewer Separation (2013). The City of Cambridge also completed the Cambridgeport Partial Sewer Separation Project in 2020, further reducing treated discharges at the Cottage Farm facility.

In the same period, communities along the Charles River have continued programs aimed at reducing pollution in separate stormwater discharges, including identifying and removing illicit sewer connections to storm drains. The CSO and stormwater related improvements have contributed to significant and steady water quality improvement in the Charles River Basin during dry and wet weather conditions.

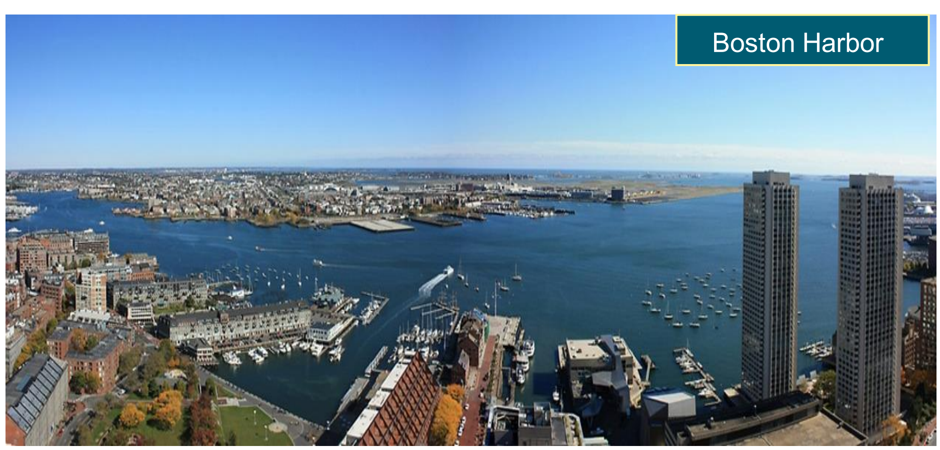
In the Upper Mystic River, direct discharge of untreated CSO has been eliminated, and MWRA sampling has typically shown more than 90% of samples meet standards in dry weather in recent years. While conditions worsen in heavy rain events, these rainfall conditions are relatively infrequent.

In Alewife Brook, despite significant CSO discharge reductions with completion of the LTCP, bacteria counts in the brook continue to frequently fail to meet swimming limits in both dry and wet weather, and water quality is particularly poor after heavy rain. During development of the LTCP, MWRA receiving water modeling predicted that the LTCP projects and their CSO reduction benefits would have limited impact on attainment of water quality standards due to bacteria loadings from separate stormwater discharges. More recent sampling and the analyses conducted as part of the performance assessment support this conclusion.

The water quality of the Neponset River has substantially improved, although the magnitude of improvements varies by river segment, with upstream locations showing the most significant change, particularly at the Baker Dam. CSO discharges were eliminated in 2000 with completion of the Neponset River sewer separation project. Prior to the project, CSO flows were discharged at two BWSC outfalls in the lower Neponset, downstream of Granite Avenue Bridge. Water quality data show improvement downstream of these former CSOs and further upstream at the Baker Dam, which shows improvement in dry as well as wet weather conditions. Bacteria levels generally meet swimming standards at the mouth of the Neponset River in all but heavy rainfall conditions.



Improvement in the quality of Boston Inner Harbor waters is also seen in the changes to *Enterococcus* bacteria counts from the time period before improvements (1989-1991) to data collected after most improvements described above were completed. As shown in Figure 1-5 on the following page, water quality conditions have improved beginning with the significant increase in wastewater transport and treatment capacity (delivery to the Deer Island Treatment Plant) in the early 1990s. This



increase in delivery capacity greatly reduced CSO discharges at most outfalls. Wet weather conditions continued to improve with implementation of the CSO projects. By 2008, MWRA and the CSO communities had completed many of the CSO control projects that further reduced or eliminated discharges at most CSO outfalls, including outfalls to the Charles River, Mystic River, and Chelsea Creek. In the same period, community efforts to control urban stormwater pollution were underway, and these efforts have continued.

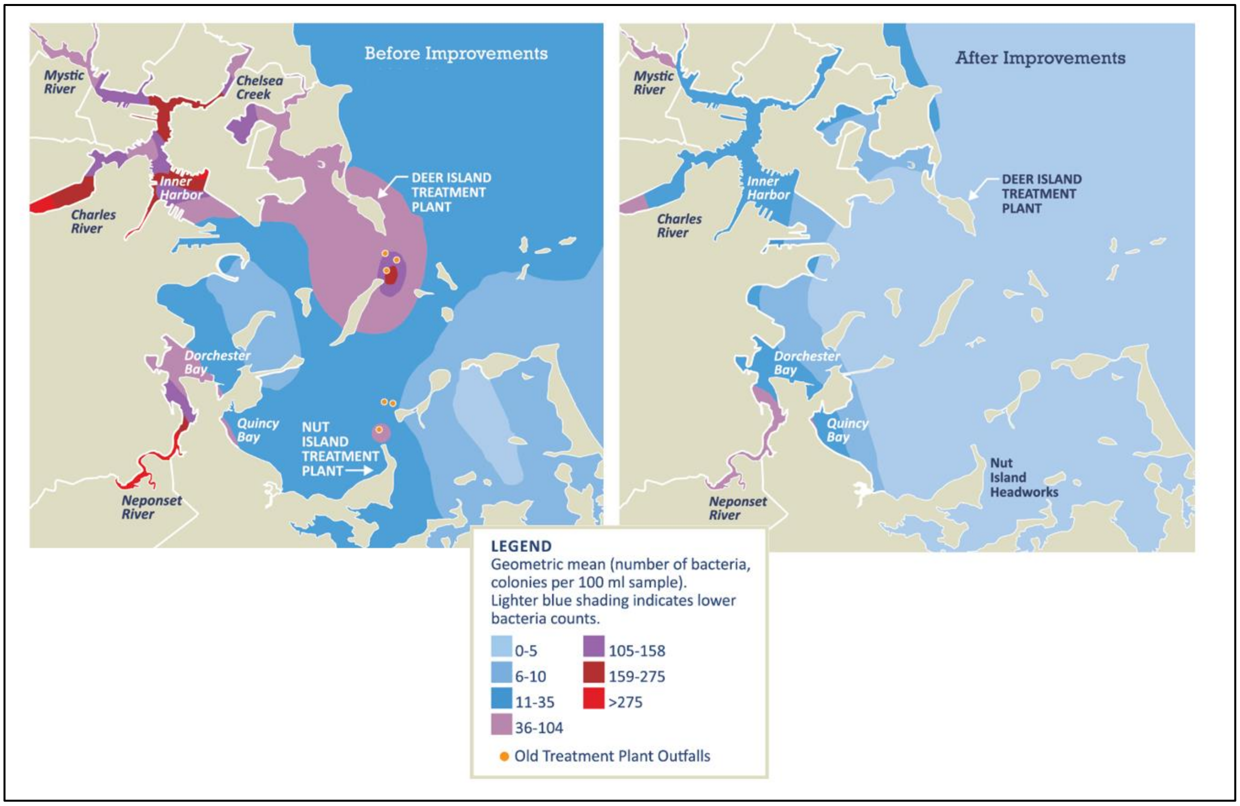


Figure 1-5. Changes in Boston Harbor *Enterococcus* Bacteria in Wet Weather

1.3.4 Continuing Improvements During Performance Assessment Period

While the CSO projects required to be implemented in the LTCP were completed by 2015, the MWRA and the CSO communities continue to evaluate and implement additional projects that have resulted or may result in further CSO reductions. Table 1-5 summarizes projects that were either fully implemented or implementation was initiated during the course of the performance assessment. These projects are further described in subsequent chapters of this report.

Table 1-5. Additional Projects Planned and/or Implemented by MWRA and CSO Communities

Project	Implemented By	CSO Outfalls Affected or Potentially Affected	Status as of Fall 2021
CAM401B Sediment Removal	City of Cambridge	CAM401B	Completed
Cambridgeport Partial Sewer Separation(1)	City of Cambridge	Cottage Farm (MWR201)	Completed
Willard Street Separation/CAM005 Outfall Cleaning	City of Cambridge	CAM005	In Planning
Union Square Flood Protection Project	City of Somerville	Somerville Marginal (MWR205) and Prison Point (MWR207)	Design/Construction
Davis Square/Tannery Brook Drainage Improvements	City of Somerville	SOM001A	In Planning
Raise Weir at CHE004	City of Chelsea	CHE004	Completed
Raise Weir at BOS010	BWSC	BOS010	Completed
East Boston Sewer Separation Contracts 1-3	BWSC	BOS003, BOS09, BOS010, BOS012, BOS014	Contracts 1 and 2 completed; Contract 3 construction in progress;
South Boston Sewer Separation Contracts 1 to 5	BWSC	BOS070, BOS065	Contract 1 construction started; Contract 2 in design
South Boston Sewer Cleaning	BWSC	BOS070	Completed
BOS017 Tide Gate Repair	BWSC	BOS017	Completed
Stormwater Separation near Rutherford Ave./ Middlesex St.	BWSC	BOS017	Completed
Somerville Marginal Gate Operation Modifications	MWRA	Somerville Marginal (MWR205)	Completed
Somerville Marginal Tide Gate Repair	MWRA	Somerville Marginal (MWR205)	Construction in progress

Notes:

(1) The LTCP took into account the completion of sewer separation in Cambridge, as proposed and fully funded by the City of Cambridge. Cambridge has proposed and MWRA accepted on a trial basis, the implementation of partial sewer separation which is further explained in Section 4.2.2.

Part I Key Findings

2. Typical Year Discharges: Updated System Performance Assessment and Comparison with LTCP Levels of Control

2.1 CSO Performance Assessment Relative to Attainment of LTCP Goals

The performance objectives of MWRA's approved LTCP include annual frequency and volume of CSO discharge at each outfall based on "Typical Year" rainfall. The Court Order - specifically Exhibit B to the Second Stipulation – sets forth 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 previously submitted to and accepted by DEP and EPA, are listed in Exhibit A to the Second Stipulation and presented in Table 2-1.

Hydraulic modeling has historically served as the basis for evaluating performance of the CSO system. As described in Chapters 10 and 11 of this report, the model has been continually updated as part of the post construction monitoring program. With the completion of the calibration of the collection system model in 2019, MWRA began to report comparisons of Typical Year model results to the 1992 system conditions and the LTCP goals using the most current version of the model available. The reporting started with Semiannual Report No. 4, which presented Typical Year performance based on Q3Q4-2019 system conditions (*i.e.* as of December 2019.) Each subsequent semiannual report presented updates to the performance in six-month increments. The reports described changes to the MWRA's system and/or changes/updates to the collection system model that had been incorporated since the previous semiannual report, and summarized the progress made towards meeting the LTCP goals.

The most current version of the collection system model available for this performance assessment report was the Q4-2021 system conditions model (*i.e.* December 2021.) The Q4-2021 model is based on the Q1Q2-2021 model, previously presented in Semiannual Report No. 7, with recent system updates including raising the weir at CHE004 to elevation 109.91 and incorporating Contract 2 of the BWSC's East Boston Sewer Separation project which was substantially completed in November 2021.

This chapter summarizes the system performance under Typical Year rainfall based on the Q4-2021 system conditions model. Table 2-2 presents a full accounting of the status and Typical Year overflow activity as of Q4-2021 System Conditions 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-1980s. Table 2-2 also presents the LTCP Typical Year levels of control and previously modeled CSO discharge levels for 1992 system conditions. In Table 2-2, Q4-2021 System Conditions activations or volumes that are greater than the LTCP goals are shaded in grey.

Table 2-1. MWRA Long-Term CSO Control Plan Facilities Planning Documentation (Page 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	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 supplement 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	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 2-1 MWRA Long-Term CSO Control Plan Facilities Planning Documentation (Page 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

Table 2-2. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals (Page 1 of 3)

Outfall currently achieves LTCP activation and volume goals.			Outfall is forecast to achieve LTCP goals after Dec 2021.			
Outfall investigations continue for forecast of LTCP attainment potential.			Model prediction is greater than LTCP value.			
OUTFALL	1992 SYSTEM CONDITIONS (1)		Q4-2021 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	0.61	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	5	0.66	5	1.61
CAM401B			4	0.50	7	2.15
SOM001A(8)	10	11.93	8	4.47	3	1.67
SOM001	0	0.00	Closed	N/A	Closed	N/A
SOM002	0	0.00	Closed	N/A	N/I(3)	N/I(3)
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**		**6.26**		**7.29**
UPPER MYSTIC RIVER						
SOM007A/MWR205A(7)	9	7.61	5	4.50	3	3.48
SOM006	0	0.00	Closed	N/A	N/I(3)	N/I(3)
SOM007	3	0.06	Closed	N/A	Closed	N/A
TOTAL		**7.67**		**4.50**		**3.48**
MYSTIC/CHELSEA CONFLUENCE						
MWR205(7) (Somerville-Marginal CSO Facility)	33	120.37	30	99.71	39	60.58
BOS013*	36	4.40	8	0.27	4	0.54
BOS014(7)	20	4.91	8	1.44	0	0.00
BOS015	76	2.76	Closed	N/A	Closed	N/A
BOS017(8)	49	7.16	6	0.34	1	0.02
CHE002	49	2.51	Closed	N/A	4	0.22
CHE003	39	3.39	0	0.00	3	0.04
CHE004	44	18.11	2	0.08	3	0.32
CHE008(7)	35	22.35	6	1.94	0	0.00
TOTAL		**185.96**		**103.78**		**61.72**
UPPER INNER HARBOR						
BOS009(7)	34	3.60	10	0.73	5	0.59
BOS010	48	11.83	1	0.07	4	0.72
BOS012	41	7.90	0	0.00	5	0.72
BOS019	107	4.48	1	0.07	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	1.33	1	0.43
BOS058	17	0.29	Closed	N/A	Closed	N/A
BOS060*	64	2.90	2	0.47	0	0.00
MWR203 (Prison Point Facility)*	28	261.85	17	248.33	17	243.00
TOTAL		**307.56**		**251.00**		**246.04**

Table 2-2. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals (Page 2 of 3)

OUTFALL	1992 SYSTEM CONDITIONS (1)		Q4-2021 SYSTEM CONDITIONS		LONG TERM CONTROL PLAN (2)	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
LOWER INNER HARBOR						
BOS003(7)	28	18.09	9	5.93	4	2.87
BOS004	34	3.43	0	0.00	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**		**5.94**		**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)	8	4.15	5	1.26	1	0.01
BOS064*	14	0.99	1	0.01	0	0.00
BOS065(8)	11	3.08	1	0.62	1	0.06
BOS068	4	0.62	0	0.00	0	0.00
BOS070/DBC(8)	4	281.62	7	6.18	3	2.19
MWR215 (Union Park Facility)			10	26.64	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**		**34.71**		**73.89**
RESERVED CHANNEL						
BOS076	65	65.94	1	0.10	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**		**0.10**		**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	0 / 25 year	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**
UPPER CHARLES						
BOS032	4	3.17	Closed	N/A	Closed	N/A
BOS033	7	0.26	Closed	N/A	Closed	N/A
CAM005(8)	6	41.56	8	0.75	3	0.84
CAM007*	1	0.81	1	0.47	1	0.03
CAM009(4)	19	0.19	Closed	N/A	2	0.01
CAM011(4)	1	0.07	Closed	N/A	0	0.00
TOTAL		**46.06**		**1.22**		**0.88**

Table 2-2. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals (Page 3 of 3)

OUTFALL	1992 SYSTEM CONDITIONS (1)		Q4-2021 SYSTEM CONDITIONS		LONG TERM CONTROL PLAN (2)	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
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(8)	2	3.18	2	1.11	0	0.00
MWR019(8)	2	1.32	2	0.47	0	0.00
MWR020(8)	2	0.64	2	0.46	0	0.00
MWR021	2	0.50	Closed	N/A	Closed	N/A
MWR022	2	0.43	Closed	N/A	Closed	N/A
MWR201(8) (Cottage Farm Facility)	18	214.10	2	9.09	2	6.30
MWR023(5)	39	114.60	1	0.03	2	0.13
SOM010	18	3.38	Closed	N/A	Closed	N/A
TOTAL		**342.98**		**11.28**		**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 – Boston GH1(5)	2	5.25	1	0.10	2	5.38
BOS046 – Boston GH2(6)			0	0.00		
TOTAL		**5.25**		**0.10**		**5.38**
Total Treated		**698**		**384**		**381**
Total Untreated		**759**		**30**		**23**
GRAND TOTAL		**1457**		**414**		**404**

*Model predicted activation and volume for Q4-2021 System Conditions has decreased since 1992 levels to a level believed to achieve anticipated water quality improvements. The inability to precisely meet activation and/or volume goals at these locations is considered immaterial.

(1) 1992 System Conditions include completion of Deer Island Fast-Track Improvements, upgrades to headworks, and new Caruso and DeLauri pumping stations. Estimated 1988 Grand Total Typical Year CSO volume (prior to these improvements) was 3,300 million gallons.
(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) N/I: Outfall is not included in Exhibit B to the Second CSO Stipulation.
(4) Tentatively closed pending additional hydraulic evaluation by City of Cambridge.
(5) BOS046 (Gatehouse 1) is primarily a stormwater discharge but may contain CSO if the upstream regulators overflow. The upstream regulators are monitored directly. Gatehouse 1 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 it is estimated that 25% of the CSO from the upstream regulators discharges at outfall MWR023 (Charles River) and 75% discharges at outfall BOS046 (Back Bay Fens).
(6) BOS046 (Gatehouse 2) contains a gate which may also be overtopped in extreme wet weather; this gate was added to the model after the Q1-2021 system conditions model run per new field information.
(7) See Table 2-3 below for outfalls forecast to attain LTCP after 2021.
(8) See Table 2-4 below for site-specific investigations underway where attainment of LTCP goals cannot yet be forecast.

2.1.1 Closed CSO Outfalls

As set forth in Table 2-2, MWRA and the CSO communities have eliminated CSO discharges at all 25 outfalls that were required to be closed pursuant to the Second Stipulation. In addition, eight outfalls that were not specified for closure in the Second Stipulation are in either a permanently or temporarily closed condition. Finally, as discussed in Note (1) to Table 1-2, two additional CSO outfalls (SOM002 and SOM006) were closed prior to the issuance of the Second Stipulation, and appropriately were not listed in the Second Stipulation. The total of 10 additional outfalls that were closed beyond the 25 listed in the Second Stipulation are as follows:

- SOM002 on Alewife Brook and SOM006 on the Upper Mystic River, closed by the City of Somerville in the 1980s and 1990s;
- CHE002 on the Mystic/Chelsea Creek Confluence, closed by the City of Chelsea in 2014;
- BOS006 and BOS007 in East Boston, closed by BWSC in 2008;
- BOS072 on Fort Point Channel, closed by BWSC in 2014;
- BOS083 and BOS087 on the South Boston beaches, closed by MWRA in 2011 with construction of the South Boston CSO storage tunnel; and
- CAM009 and CAM011 on the Charles River, which were closed by the City of Cambridge in 2007 on an interim basis. The City of Cambridge maintains CAM009 and CAM011 in a closed condition while it continues to evaluate hydraulic conditions in the local sewer system before making a decision to close them permanently.

Accordingly, as of the date of this report, the MWRA and the CSO communities have closed a total of 35 CSO outfalls. In a closed condition where activation and discharge of *any* volume of CSO is currently impossible, the only reasonable conclusion is that MWRA has, as to these 35 CSO outfalls, demonstrated compliance with the levels of control specified in the CSO LTCP. Moreover, with the exception of CAM009 and CAM011 where the City of Cambridge is currently evaluating whether to close these outfalls permanently, the balance of the 33 CSO outfalls described in this section are now permanently closed and effectively terminated.

2.1.2 Outfalls along the South Boston Beaches

For the South Boston beaches (North Dorchester Bay), MWRA's CSO storage tunnel provides a 25-year storm level of CSO control and a 5-year storm level of separate stormwater control. As such, in addition to closing CSO outfalls BOS083 and BOS087 as described above, MWRA has "effectively eliminated" CSO discharges at the remaining five outfalls along the South Boston beaches: BOS081, BOS082, BOS084, BOS085 and BOS086. Since May 2011, when MWRA brought the South Boston CSO Storage Tunnel and related facilities online, no CSO has discharged to the beaches, compared with an average of 20 CSO discharges per year prior to tunnel completion. Accordingly, as is the case with the closed outfalls summarized above, for all remaining CSO outfalls along the South Boston beaches, MWRA has demonstrated compliance with the levels of control specified in the CSO LTCP.

The storage 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 10 years of tunnel operation through October 2021, stormwater discharged to the beaches in only four large storms, including (1) Hurricane Irene in August 2011; (2) the December 9, 2014 storm (4.47 inches of rain); (3) the March 2, 2018 storm surge and coastal flooding event; and (4) Tropical Storm Ida on September 1-2, 2021 (5.03 inches of rain). Since May 2011, the tunnel has prevented more than 2 billion gallons of CSO and stormwater from discharging to the beaches.

2.1.3 Outfalls Where Difference between Q4-2021 Performance and LTCP Goals is Considered Immaterial

For the six outfalls noted in the asterisk footnote in Table 2-2, while the predicted activation frequency and/or volume exceeds the LTCP goal, the performance at these outfalls has improved since 1992 to a level believed to achieve water quality goals. In each of the six cases, the difference between the Q4-2021 performance and the LTCP goal is relatively nominal, and the inability to precisely meet the activation and/or volume goals at these locations is not material. Additionally, for these six outfalls water quality is not impaired by the deviation from the LTCP goals.

At two of the outfalls (BOS013 and BOS064) activations exceed the LTCP frequency goal, but such activations are of immaterial volumes (<0.05 MG). At the four other outfalls (BOS057, BOS060, MWR203 and CAM007), the annual volume discharge has either been reduced by greater than 84%, is within 2% of the LTCP goal, or exceeds the LTCP goal by an immaterial amount (<0.5 MG). Moreover, five of the six outfalls (BOS057, BOS060, MWR203, BOS064 and CAM007) either meet the LTCP frequency activation or have had >90% of activations eliminated since 1992.

Finally, for five of the outfalls (BOS013, BOS057, BOS060, MWR203 and BOS064), the receiving water at the MWRA monitoring station nearest the outfall has consistently achieved a quality report grade of B- or better (and in many instances as high as A+, see Figure 3-6 and Table 3-14), supporting MWRA's assessment that these remaining CSO discharges do not adversely impact water quality goals. For the remaining outfall (CAM007) a receiving water quality model is being used to assess the impacts of remaining CSO discharges. The model demonstrates that this CSO discharge, combined with all the other CSO discharges to the Charles River, contributes very little to the exceedance of the water quality standards for bacteria (E. *coli*), no more than 0.1% of the time in a Typical Year (see Table 3-12).

2.2 Forecasted CSO Performance

2.2.1 Attainment of the LTCP Goals at Remaining Active Outfalls as of Q4-2021 Conditions

In Table 2-2 above, each CSO outfall is color-coded based on status of attainment with the LTCP goals, as follows:

- Dark blue indicates outfalls that achieve the LTCP goals under the Q4-2021 conditions.
- Light blue indicates outfalls that are forecast to achieve the LTCP goals after December 2021.
- No color indicates outfalls for which investigations continue to assess the potential to achieve the LTCP goals.

As indicated in Table 2-2, of the 46 outfalls that remain active (i.e. are not physically closed or associated with the North Dorchester Bay CSO Storage Tunnel), 30 outfalls meet the LTCP goals as of Q4-2021 conditions. Of the remaining 16 outfalls, six are projected to meet the LTCP goals after December 2021, and ten outfalls continue to be investigated.

2.2.2 Outfalls Forecast to Attain LTCP Activation and Volume Goals after December 2021

The site-specific investigations summarized in Chapter 4 have identified system improvement recommendations that are predicted by MWRA's hydraulic model to result in attainment of the LTCP goals but are scheduled or expected to be implemented by MWRA and the CSO communities after 2021. The outfalls, locations, recommended system improvements, entity implementing the work, and tentative scheduled completion dates are listed in Table 2-3.

Table 2-3. Outfalls Forecast to Attain LTCP Goals After 2021

OUTFALL	LOCATION	SYSTEM IMPROVEMENT(S)	TO BE IMPLEMENTED BY	TENTATIVE SCHEDULED COMPLETION
MWR205	Somerville Marginal CSO Facility	Construct new connection from the facility influent conduit to the interceptor and replace tide gate.	MWRA	2024
SOM007A/ MWR205A				
BOS003	East Boston	Complete BWSC Sewer Separation Contract 3, including upgrade of interceptor connection at regulator RE003-12.	BWSC	2023
BOS009				
BOS014		Construct new interceptor connection		
CHE008	Chelsea Creek	Replace/upgrade interceptor connection	MWRA	2022

2.2.3 Outfalls Currently Not Forecast to Attain LTCP Activation and/or Volume Goal

MWRA has continued to track CSO performance and the causes of higher overflow activity at locations where Typical Year CSO activation and/or volume exceed the LTCP goals and no additional system improvement has yet been recommended. MWRA has identified candidate projects or system adjustments that may further mitigate CSO discharges to bring activations and volumes to or closer to the LTCP goals. Table 2-4 lists the outfall locations where site specific investigations continue. For four of the ten CSO outfalls listed in Table 2-4, MWRA has developed concept designs which are predicted to meet LTCP goals if implemented. MWRA is working with BWSC to evaluate the constructability and cost for these projects. Information on the progress of these evaluations is presented in more detail in Chapter 4.

Table 2-4. Locations of Outfalls Where Site-Specific Investigations (Page 1 of 2)

OUTFALL	Q4-2021 SYSTEM CONDITIONS MODEL		LONG TERM CONTROL PLAN		FUTURE CONDITION		OUTFALLS WITH MODELED CONCEPT DESIGNS PREDICTED TO ATTAIN LTCP GOALS	OUTFALLS PRESENTING SIGNIFICANT CHALLENGES
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)		
ALEWIFE BROOK								
SOM001A	8	4.47	3	1.67	TBD*	TBD*	N/A	• Potential modifications to the regulator structure including raising the weir and interceptor connection relief, relining portions of the Alewife Brook Conduit (ABC) and Alewife Brook Branch Sewer (ABBS) and upstream flow controls have been evaluated but a feasible plan to meet the LTCP goals has not yet been identified. MWRA is coordinating with City of Somerville to investigate whether flood control measures being considered by the City of Somerville may provide CSO reduction benefit.
MYSTIC/CHELSEA CONFLUENCE								
BOS017	6	0.34	1	0.02	0	0.00	• MWRA has developed a concept design to construct modifications to the Sullivan Square siphon structure including adjustable stop logs upstream of each siphon barrel. MWRA is coordinating with BWSC on the feasibility and cost of this alternative.	N/A
FORT POINT CHANNEL								
BOS062	5	1.26	1	0.01	0	0.00	• MWRA is coordinating with BWSC on the feasibility and cost of an alternative to relieve the interceptor connection.	N/A
BOS065	1	0.62	1	0.06	1	0.03	• MWRA is coordinating with BWSC on the feasibility and cost of an alternative to raise the weir at the regulator.	N/A
BOS070/DBC	7	6.14	3	2.19	2	2.06	• MWRA is coordinating with BWSC on the feasibility and cost of an alternative to add a parallel relief pipe downstream of regulator RE070/7-2.	N/A

Table 2-4. Locations of Outfalls Where Site-Specific Investigations (Page 2 of 2)

OUTFALL	Q4-2021 SYSTEM CONDITIONS MODEL		LONG TERM CONTROL PLAN		FUTURE CONDITION		OUTFALLS WITH MODELED CONCEPT DESIGNS PREDICTED TO ATTAIN LTCP GOALS	OUTFALLS PRESENTING SIGNIFICANT CHALLENGES
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)		
CHARLES RIVER								
MWR201 (Cottage Farm)	2	9.10	2	6.30	TBD*	TBD*	N/A	• Evaluated upstream sewer separation and targeted groundwater infiltration removal. • Further alternative development and evaluation with consideration of water quality benefits and cost to be considered beyond December 2021.
CAM005	8	0.74	3	0.84	TBD*	TBD*	N/A	• Further coordination with CSO community to balance level of service needs against evaluated weir raising, cleaning of outfall, and separation of upstream areas. • Further alternative development and evaluation with consideration of water quality benefits and cost to be considered beyond December 2021.
MWR018	2	1.12	0	0.00	TBD*	TBD*	N/A	• Evaluated alternatives including raising weirs, reducing head loss in the BMC, and redirecting upstream BWSC separate storm drains. • Further alternative development and evaluation with consideration of water quality benefits and cost to be considered beyond December 2021.
MWR019	2	0.48	0	0.00	TBD*	TBD*	N/A	
MWR020	2	0.48	0	0.00	TBD*	TBD*	N/A	

Note:
*Insufficient details are available to evaluate impact of alternative on Typical Year activation frequency and volume.

3. Receiving Water Quality Assessments

The goal of a CSO Long Term Control Plan is attainment of water quality standards. In developing its LTCP, MWRA was required to demonstrate that the plan was adequate to meet water quality standards and protect designated uses, unless water quality standards or uses cannot be met as a result of natural background conditions or pollution sources other than CSOs. Additionally, CSO discharges remaining after implementing the planned control program will not preclude attainment of water quality standards or the receiving waters' designated uses or contribute to their impairment (EPA, 2012).

As described in Chapter 1, MWRA's $911 million CSO control program greatly reduced CSO volumes, eliminated combined sewer discharges to beaches and shellfish beds, and provided disinfection of most of the remaining CSO. During the LTCP development process, DEP established the $B_{(CSO)}$ and $SB_{(CSO)}$ water quality classifications for most of the receiving waters where CSOs would remain following implementation of the LTCP. These classifications allowed limited, short-term excursions from the Class B/SB (i.e. "fishable/swimmable") criteria during wet weather, as long as the criteria could be met at least 95% of the time, and the remaining discharges met the levels of control established in the approved LTCP. Modeling and assessments conducted during the planning phases of the project predicted that the 95% percent attainment target for CSO impacts would be met with the levels of control specified in the LTCP. Thus, the LTCP levels of control were consistent with the requirements for attainment of water quality standards for these waters.

Receiving water quality data show that most areas of Boston Harbor meet water quality standards. These results are briefly summarized in Section 3.5 below.

For the Charles River and Alewife Brook/Upper Mystic River, no final determination on water quality classification was made because of the public interest in a higher level of use of these water bodies. Instead, water quality standards variances were implemented to allow more time to study the remaining effects of CSOs and determine what level of CSO control would best achieve water quality goals. Initially, MWRA planned to perform a statistical analysis using the extensive field data collected in these water bodies. However, a subsequent agreement with DEP and EPA was made to update the receiving water quality modeling used in the development of the LTCP. Thus the post-construction monitoring and assessment program includes a water quality assessment that focuses on those areas and specifically includes the development and use of receiving water quality models.

Hydrodynamic and water quality models of the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River (the "CSO variance waters") were updated and calibrated to support the assessment of the performance of the current MWRA system. These models were intended to assess the benefits to water quality, specifically in relation to bacterial counts in these receiving waters resulting from the improvements made by implementing the MWRA CSO Long Term Control Plan over the last 30 years, as well as evaluating the remaining impacts of CSO and non-CSO bacteria sources.

Specifically, these models were intended to:

- Assess the relative impact of remaining CSO on water quality in the Charles River and Alewife Brook/Mystic River;
- Provide information about impacts of stormwater and boundary conditions; and
- Predict resulting *E. coli* and *Enterococcus* counts during 3-month and 1-year storms as well as the Typical Year.

This section presents a summary of the applicable water quality standards and criteria, the assessment of water quality in the variance waters of the Charles River, Alewife Brook and Upper Mystic River based on water quality modeling (a summary of the development and calibration of the water quality models is presented in Chapter 12), and a discussion of the assessment of water quality in the Class $SB_{(CSO)}$ waters of Boston Harbor. This section is organized into the following major subsections:

- 3.1 - Current Water Quality Standards and Criteria. Describes the Massachusetts water quality standards and criteria that were used to assess model results.
- 3.2 - Overview of Water Quality Models. Provides a brief overview of the water quality models. Additional details on the models are presented in Chapter 12.
- 3.3 - Assessment of Compliance with Current Water Quality Criteria. Presents the results of an assessment of compliance with current water quality criteria for 2019 system conditions, as well as sensitivity assessments of changes to CSO or stormwater bacterial concentrations.
- 3.4 - Alternatives Analysis. Presents assessments of various bacterial loading reduction scenarios, including an updated baseline conditions analysis based on Q1-2021 system conditions.
- 3.5 - Non-Variance CSO Receiving Water Quality Assessment. Presents an assessment of water quality conditions in waterbodies not covered by the receiving water quality models, based on sampling data.
- 3.6 - Conclusions. Summarizes the key observations and conclusions from the water quality assessments.

3.1 Current Water Quality Standards and Criteria

Massachusetts Surface Water Quality Standards (314 CMR 4.00) are the regulations that set the minimum water quality applicable to waters of the Commonwealth of Massachusetts. They are adopted by DEP to designate the most sensitive uses (e.g., swimming, aquatic life, public water supply) for which surface waters are to be regulated, prescribe the minimum water quality criteria required to sustain those uses, and outline steps necessary to achieve designated uses and maintain high quality waters. The Clean Water Act (CWA) and federal regulations require DEP to periodically review and update its surface water quality standards, and to adopt any new or updated criteria recommended by EPA.

The Charles River and Alewife Brook/Upper Mystic River are each currently under a variance for CSO Discharges. *A water quality standards variance (WQS variance) is a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflect the highest attainable condition during the term of the WQS variance*[6]. These variances authorize limited CSO discharges from the MWRA and the Cities of Cambridge and Somerville subject to their National Pollutant Discharge Elimination System (NPDES) permits. During wet weather events where the limited CSO discharges are authorized, Class B requirements for bacteria, solids, color and turbidity, and taste and odor may not be met. The variances are a water quality standards revision subject to EPA review and approval. On August 30, 2019, MADEP issued new variances for the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River Basin with a five-year term, running until August 31, 2024. EPA Region 1 approved these variances on May 31, 2020.

For the Water Quality Assessment of the variance waters, attainment with water quality criteria was based on attainment of the Class B criteria for non-bathing beach waters. During the period that MWRA was conducting this CSO performance assessment, DEP was in the process of modifying the Class B criteria for bacteria. The new criteria, however, were not promulgated until November 12, 2021, too late for use in the modeling analysis. The modeling analysis was therefore conducted on the Class B criteria for non-bathing beach waters that were in effect prior to November 12, 2021, as summarized in Table 3-1. It is not anticipated that the change in criteria would affect the conclusions derived from the water quality assessment.

[6] 40 CFR 131.3 (o)

Table 3-1. Class B Criteria during the Study Period

Parameter	Class B Criteria for Non-Bathing Beach Waters (#/100 ml)	
	6-month Geometric Mean	Single Sample Maximum
E. coli	126	235
Enterococcus	33	61

The model results presented are based on attainment using the Class B single sample maximum criteria for non-bathing beach waters shown in Table 3-1. This approach is consistent with the approach taken in the 1997 Combined Sewer Overflow Facilities Plan and Environmental *Impact Report* (FP/EIR) (Metcalf & Eddy, 1997) and the 2003 *Final Variance Report for Alewife Brook/Upper Mystic River* (Metcalf & Eddy, 2003), where compliance was based on a single-sample maximum of 200 #/100mL for fecal coliform. Since the Variance waters are freshwater waterbodies, the summary of the water quality assessment presented here focuses on the *E. coli* criteria. Attainment using the *Enterococcus* criteria was presented in the 2021 *Water Quality Assessment Report* (AECOM, 2021a).

3.2 Overview of Water Quality Models

The water quality models of the Charles River and Alewife Brook/Upper Mystic River computed time-varying and spatially-varying concentrations of *E. coli* and *Enterococcus* in the rivers, taking into account the influence of river flow and geometry, and the impacts of dilution, dispersion, and die-off.

The Charles River model is a horizontally two-dimensional model based on the Delft3D software. The model includes a hydrodynamic part, which calculates water levels and depth-averaged velocities, and a water quality part, which calculates depth-averaged *E. coli* and *Enterococcus* counts. The model extends from the New Charles River Dam and locks to the Watertown Dam (Figure 3-1).

The Alewife Brook/Upper Mystic River model is a one-dimensional model based on the InfoWorks ICM software. The model includes a hydrodynamic part, which calculates water levels and cross-section-averaged velocities, and a water quality part, which calculates cross-section-averaged *E. coli* and *Enterococcus* counts. The model extends from the Amelia Earhart Dam to the Lower Mystic Lake and covers Alewife Brook in its entirety (Figure 3-1).

The various sources of flows and bacteria loads into the receiving waters represented in the models included the following:

- Stormwater;
- Untreated and treated CSO;
- Dry weather base flow (infiltration flow from storm drains or groundwater flow directly to a waterbody; could also include flow from illicit sanitary connections to storm drains); and
- Boundary conditions (flow into the study area from upstream).

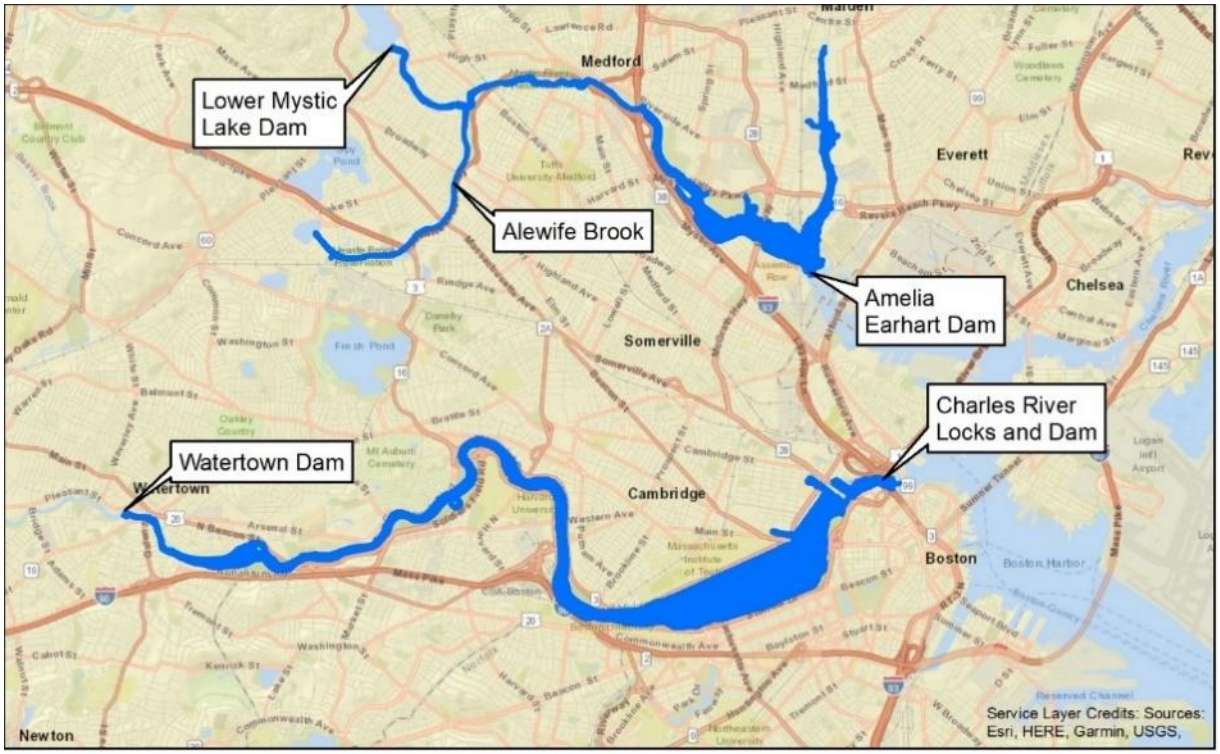


Figure 3-1. Extent of the Charles River and Alewife Brook/Upper Mystic River Models

The models were calibrated by comparing model-predicted *E. coli* and *Enterococcus* counts at specific locations in the receiving waters with concentrations measured at those locations during specific storm events and dry weather periods. Overall there was a good correlation between the modeled and measured concentrations. A summary of the water quality model development and calibration is provided in Chapter 12, and in the *Task 5.2 Receiving Water Quality Model Development and Calibration Report* (AECOM, 2020).

3.3 Baseline Assessment of Compliance with Current Water Quality Criteria

The baseline water quality assessments for the Charles River and Alewife Brook/Upper Mystic River were based on a continuous simulation of the Typical Year rainfall, with MWRA system conditions as represented by the 2019 Conditions version of the MWRA's hydraulic model of its wastewater system (see *Semiannual CSO Discharge Report No. 4*, April 30, 2020, for further details on 2019 system conditions). Output from the baseline assessments included tabulations of the volumes and bacterial loadings from the various sources for the Typical Year, as well as for the 3-month and 1-year storms that are embedded within the Typical Year.

For the Charles River, 2-dimensional isopleth plots of bacterial counts at specific time increments for the 1-year storm were developed, along with 2-dimensional isopleths of hours of exceedance of the existing single-sample maximum criteria for *E. coli* and *Enterococcus*. The hours of exceedance plots were developed for conditions representing all sources, non-CSO sources only, and CSO sources only. The results from the isopleth plots were also summarized in tabular format. Initial sensitivity analyses using varying bacterial counts in the stormwater or CSO were also conducted. Similar information was developed for the Alewife Brook/Upper Mystic River, with the exception that the plots of bacterial counts and hours of exceedance were 1-dimensional along the length of Alewife Brook and the Upper Mystic River. As noted above, the summary presented below focuses on results for *E. coli*. The *Task 5.3 Water Quality Assessment Report* (AECOM, 2021a) also includes the results for *Enterococcus*.

For model calibration and for the initial (baseline) water quality assessment, CSO discharges and sanitary fractions were derived from the MWRA collection system hydraulic/hydrologic model 2019 conditions. Later the modeling team was able to update this input to Q1-2021 conditions, as described in section

3.4.1 below and detailed in *Task 5.4 Water Quality Alternatives Assessment (AECOM, 2021c)*. The update does not substantially change any of the conclusions of the initial assessment based on 2019 system conditions.

3.3.1 Water Quality Assessment - Charles River

3.3.1.1 CSO Activations

CSO discharges to the Charles River in the Typical Year based on 2019 system conditions are summarized in Table 3-2. It should be noted that the 2019 system conditions did not include the partial sewer separation project in Cambridgeport completed by the City of Cambridge in 2020. That project reduced the predicted activation frequency of the treated discharges from the Cottage Farm CSO Facility from 4 to 2 and reduced the volume from 12.36 MG to 8.95 MG. Minor impacts from this partial sewer separation and additional model adjustments based on further system information developed for the Q1-2021 system conditions also resulted in decreasing the total untreated CSO volume to the Charles from 4.06 MG to 3.36 MG. See Section 3.4 for an evaluation of the result of these improvements on modeled water quality.

Table 3-2. Typical Year CSO Discharges to the Charles River, 2019 System Conditions

Outfall	Activation Frequency	Untreated Volume (MG)	Treated Volume (MG)
CAM005	8	0.73	--
CAM007	2	0.39	--
CAM017	0	0	--
MWR010	0	0	--
MWR018	2	1.92	--
MWR019	2	0.56	--
MWR020	2	0.32	--
MWR201 (Cottage Farm Treated Discharge)	4	--	12.36
MWR023	1	0.14	--
Totals	**8 (max.)**	**4.06**	**12.36**

3.3.1.2 Source Volume and Bacterial Loadings

Table 3-3 presents the volumetric loadings and Table 3-4 presents the *E. coli* loadings from the various sources to the Charles River for the 3-month storm, 1-year storm, and the Typical Year. Note that the dry weather and boundary flows for the 3-month storm are slightly higher than those for the 1-year storm because the 3-month storm selected for analysis occurred in March, during high groundwater and upstream river flow, while the only 1-year storm in the Typical year occurred in September, when groundwater and upstream flow were low.

Table 3-4 shows that the *E. coli* loadings from untreated CSOs were small fractions of the loadings due to stormwater and upstream boundary sources. This pattern of relative loading was generally consistent with the findings from the 1997 *CSO FP/EIR* (Metcalf & Eddy, 1997) for the Charles River.

Table 3-3. Source Volumes to the Charles River

Source	Source Volumes					
	3-Month Storm		1-Year Storm		Typical Year	
	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total
Untreated CSOs(1)	0.0	0%	1.4	0.2%	4.7	<0.01%
Treated CSOs(1)	0.0	0%	8.5	1%	12.7	0.01%
Stormwater	264	38%	430	58%	7,016	6%
Dry Weather	64	9%	38	5%	9,238	8%
Boundary	363	53%	259	35%	98,825	86%
Total	**691**	**100%**	**737**	**100%**	**115,096**	**100%**

Notes:
(1) CSO volumes based on MWRA 2019 System Conditions collection system model.

Table 3-4. Bacterial Loadings to the Charles River

Source	*E. coli* Loadings					
	3-Month Storm		1-Year Storm		Typical Year	
	counts ($x 10^{12}$)	Percent of Total	counts ($x 10^{12}$)	Percent of Total	counts ($x 10^{12}$)	Percent of Total
Untreated CSOs(1) Sanitary Component Non-Sanitary Component Total	 0.00 0.00 0.00	0%	 2.27 0.75 3.03	0.8%	 4.16 1.92 6.08	0.1%
Treated CSOs(1)	0.00	0%	0.13	0.03%	0.19	<0.01%
Stormwater	145	80%	228	59%	3,518	61%
Dry Weather	0.32	0.2%	0.19	0.05%	47	0.8%
Boundary	37	20%	158	41%	2,235	38%
Total	**182**	**100%**	**389**	**100%**	**5,806**	**100%**

Notes:
(1) CSO loadings based on volumes from MWRA 2019 System Conditions collection system model.

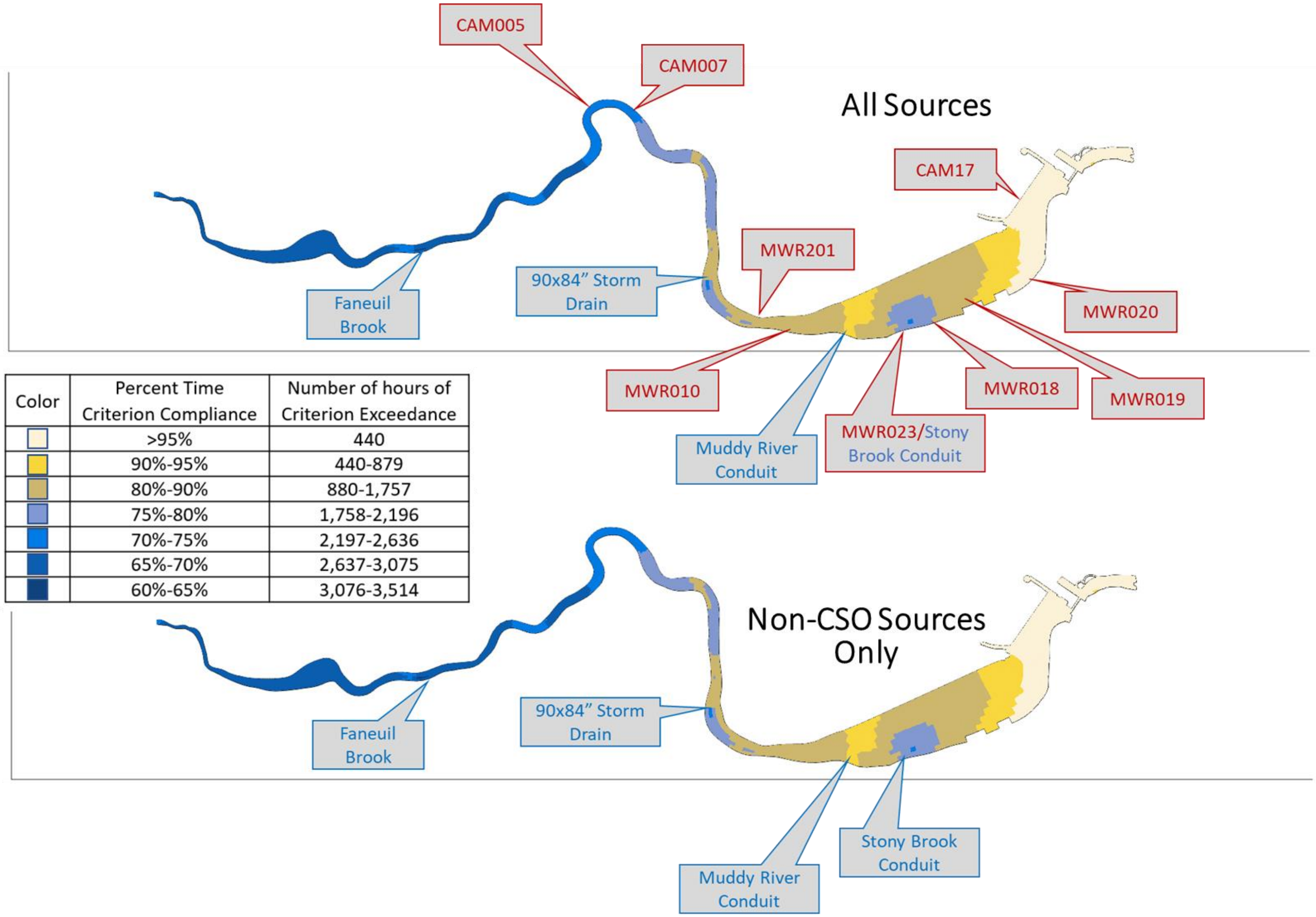
3.3.1.3 Criteria Exceedances

To assess compliance with the water quality criteria for bacteria, the model was used to compute the total duration that the bacteria count in each model cell was predicted to exceed the single-sample maximum criterion for *E. coli* over the course of the Typical Year (plots of changes in *E. coli* counts in the river over time are included in the *Task 5.3 Water Quality Assessment Report* [AECOM, 2021a]). The resulting values for percent annual attainment of the criterion would be generally analogous to the values for annual percent attainment presented in the 1997 FP/EIR. The hours of exceedance and percent annual compliance for *E. coli* are presented in Table 3-5 for six different simulation conditions. The hours shown in Table 3-5 are the number of hours the *E. coli* bacterial counts exceeded the criterion anywhere in the model area. This presents an extremely stringent representation of compliance, as the model cells where exceedances occur shift in time, and the area of exceedance will nearly always be a fraction of the total river area. At any fixed point in the river, the hours of exceedance would be much less than those listed in the table.

Table 3-5. Hours of Exceedance of the Single Sample Maximum Criterion at any Point in the Lower Charles River During the Typical Year (2019 Conditions)

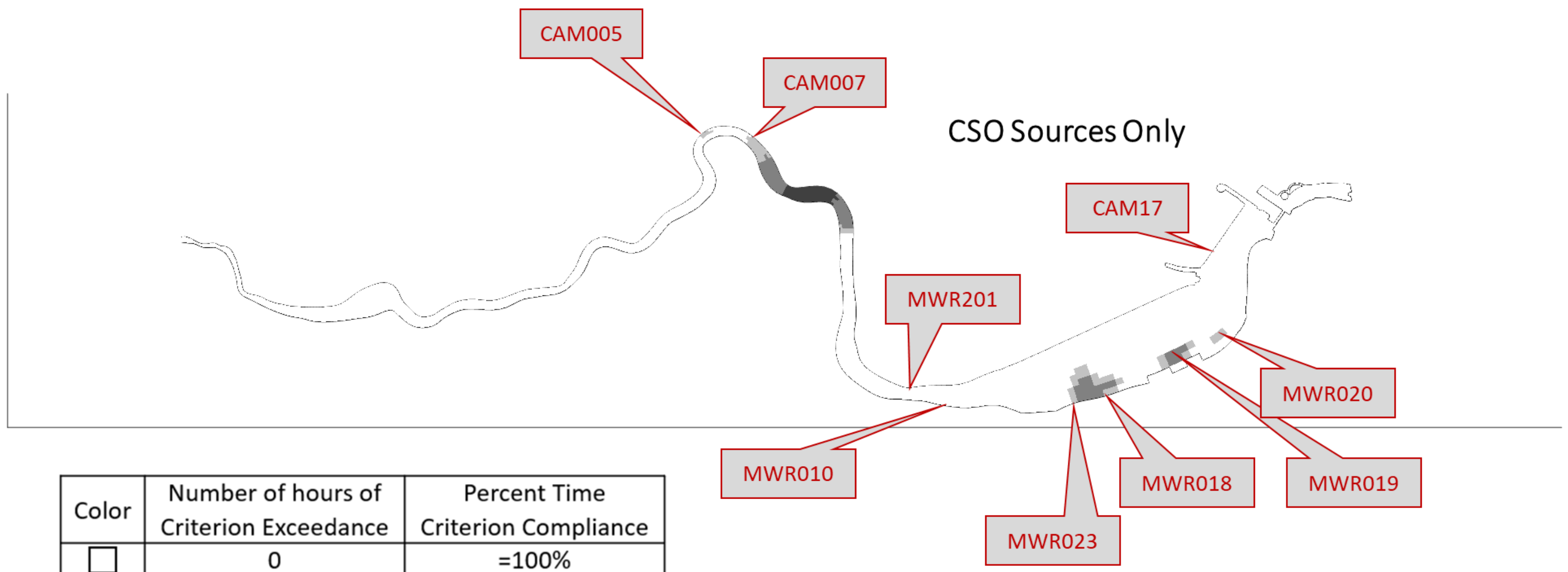
Charles River – 2019 Conditions		
Parameter	*E. coli* Single Sample Maximum Criterion (235 #/100 mL)	
	Hours of Exceedance	Percent Annual Compliance
All Sources	4,570	48%
Non-CSO Sources Only	4,561	48%
Stormwater Only	3,121	64%
Dry Weather sources Only	0	100%
Boundaries Only	3,612	59%
CSOs Only	37	99.6%

Figure 3-2 presents isopleths of the hours of exceedance of the *E. coli* single sample maximum criterion over the Typical Year for “All Sources” and “Non-CSO Sources Only”. Figure 3-3 presents isopleths of the hours of exceedance of the *E. coli* single sample maximum criterion over the Typical Year for “CSO Sources Only”. The scale in Figure 3-3 is very different from the scale in Figure 3-2 with hours of exceedance in Figure 3-3 maximizing at 16 and many areas having 100% criterion compliance over the year. The hours of exceedance displayed in Figure 3-2 and Figure 3-3 are considerably smaller than the numbers listed in Table 3-5 because the figures look at exceedances at fixed points rather than anywhere in the river.



Color	Percent Time Criterion Compliance	Number of hours of Criterion Exceedance
	>95%	440
	90%-95%	440-879
	80%-90%	880-1,757
	75%-80%	1,758-2,196
	70%-75%	2,197-2,636
	65%-70%	2,637-3,075
	60%-65%	3,076-3,514

Figure 3-2. Hours of Exceedance and Percent Compliance with 235#/100mL *E. coli* Single-Sample Max. Criterion for the Typical Year, 2019 Conditions



Color	Number of hours of Criterion Exceedance	Percent Time Criterion Compliance
	0	=100%
	0-4	99.95%-100%
	4-8	99.91%-99.95%
	8-12	99.86%-99.91%
	12-16	99.82%-99.86%

Figure 3-3. Hours of Exceedance and Percent Compliance with 235 #/100mL *E. coli* Single-Sample Max. Criterion for the Typical Year for CSO Sources Only, 2019 Conditions

3.3.1.4 Sensitivity Analysis

An initial set of sensitivity evaluations was conducted to assess how results would change with different assumptions about stormwater and CSO bacterial counts. The initial sensitivity analyses are described in the *Task 5.3 Water Quality Assessment* (AECOM, 2021a) and summarized below and in Table 3-6.

Doubling CSO bacteria counts resulted in only a negligible reduction in the percent annual compliance for the CSO only case: 99.6% to 99.2% for the Charles River.

Reducing stormwater and boundary bacteria counts by half or more (possibly representing stormwater quality improvements), improved compliance by a greater amount, as shown in Table 3-6. The "stormwater only" condition was assessed with stormwater bacterial counts decreased by factors of 2 and 5, and to the 25th percentile value from the sampling data. Boundary values were multiplied by 0.5 and 0.2. Because water quality impacts are dominated by non-CSO sources, the predicted compliance is more sensitive to the bacterial counts in these sources. Scenarios representing possible future improvements in stormwater and boundary water quality are evaluated in Section 3.4 below.

Table 3-6. Single Sample Maximum Sensitivity Analysis – Charles River

Charles River – 2019 System Conditions				
			E. coli Single Sample Maximum Criterion (235 #/100 mL)	
	Source Count Multiplier	***E. coli* Value (#/100 mL)**	**Hours of Exceedance**	**Percent Compliance**
Stormwater Only	1.0	14,000	3,121	64%
	0.5	7,000	2,305	74%
	0.2	2,800	1,491	83%
	25th Percentile	1,110	935	89%
CSO Only	1.0	Time varying Computed by Mass Balance	37	99.6%
	2.0	2x Time varying Computed by Mass Balance	67	99.2%
Boundary Only	1.0	Time varying Computed by Boundary Condition Model	3,612	59%
	0.5	0.5 x Time varying Computed by Boundary Condition Model	2,727	69%
	0.2	0.2 x Time varying Computed by Boundary Condition Model	1,502	83%

3.3.2 Water Quality Assessment – Alewife Brook and Upper Mystic River

3.3.2.1 CSO Activations

CSO discharges to Alewife Brook/Upper Mystic River in the Typical Year based on 2019 system conditions are summarized in Table 3-7. It should be noted that the 2019 system conditions did not include the removal of sediment in the combined sewer downstream of regulator RE401A completed by the City of Cambridge in 2020 as well as other system improvements and model adjustments based on new system information. These efforts have significantly reduced the predicted activation frequency and volume of the discharges from outfall CAM401A, and for Alewife Brook as a whole, reduced the maximum activation frequency from 10 to 8, and the total volume from 9.5 to 6.26 MG. The Q1-2021 system condition in the collection system model reflects these improvements; see Section 3.4 for an evaluation of the result of these improvements on modeled water quality.

Table 3-7. Typical Year CSO Discharges to Alewife Brook/Upper Mystic River, 2019 System Conditions

Outfall	Activation Frequency	Untreated Volume (MG)	Treated Volume (MG)
CAM001	1	0.02	--
CAM002	0	0	--
CAM401A	10	3.59	--
CAM401B	5	0.73	--
SOM001A	6	3.60	--
MWR003	3	1.60	
SOM007A/MWR205A(1)	6	--	4.95
Totals	**10 (max.)**	**9.5**	**4.95**

Notes:

(1) SOM007A/MWR205A is a treated discharge from the Somerville-Marginal CSO Facility into the freshwater reach of the Mystic River upstream of the Amelia Earhart Dam that activates during rain events at high tide.

3.3.2.2 Source Volume and Bacterial Loadings

Table 3-8 presents the volumetric loadings and Table 3-9 presents the *E. coli* loadings from the various sources to Alewife Brook and the Upper Mystic River for the 3-month storm, 1-year storm, and the Typical Year. Note that the dry weather and boundary flows for the 3-month storm are slightly higher than those for the 1-year storm because the 3-month storm selected for analysis occurs in March, during high groundwater and upstream river flow, while the 1-year storm selected for analysis occurs in September, when groundwater and upstream flow are low.

Table 3-9 shows that the *E. coli* loadings from untreated CSOs were small fractions of the loadings due to stormwater and upstream boundary sources. This pattern of relative loading was generally consistent with the findings from the *2003 Final Variance Report for Alewife Brook/Upper Mystic River* (Metcalf & Eddy, 2003).

Table 3-8. Source Volumes to Alewife Brook and Upper Mystic River

Source	Source Volumes – Alewife Brook						Source Volumes – Upper Mystic River					
	3-Month Storm		1-Year Storm		Typical Year		3-Month Storm		1-Year Storm		Typical Year	
	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total
Untreated CSOs(1)	0.003	<0.01%	1.91	5%	8.13	0.5%	N/A	N/A	N/A	N/A	N/A	N/A
Treated CSOs(1)	N/A	N/A	N/A	N/A	N/A	N/A	0.04	0.01%	0.40	0.2%	4.92	0.03%
Stormwater	17	55%	23	62%	383	22%	50	15%	61	31%	1,343	7%
Dry Weather	14	45%	12	32%	1,384	78%	50	15%	44	23%	4,937	27%
Boundary	N/A	N/A	N/A	N/A	N/A	N/A	236	70%	88	45%	12,168	66%
Total	**31**	**100%**	**37**	**100%**	**1,775**	**100%**	**337**	**100%**	**194**	**100%**	**18,453**	**100%**

Notes:

(1) CSO volumes based on MWRA 2019 System Conditions collection system model.

Table 3-9. *E. coli* Loadings to Alewife Brook and Upper Mystic River

Source	*E. coli* Loadings											
	Alewife Brook						Upper Mystic River					
	3-Month Storm		1-Year Storm		Typical Year		3-Month Storm		1-Year Storm		Typical Year	
	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total
Untreated CSOs(1) Sanitary Component Non-Sanitary Component Total	0.003 0.82 0.823	5%	5.48 2.64 8.12	28%	15.8 24.6 40.4	10%	N/A	N/A	N/A	N/A	N/A	N/A
Treated CSOs(1)	N/A	N/A	N/A	N/A	N/A	N/A	0.00003	<0.01%	0.0003	<0.01%	0.0034	<0.01%
Stormwater	16	94%	21	72%	362	88%	48	94%	57	95%	1,270	93%
Dry Weather	0.074	0.4%	0.067	0.2%	7.0	2%	0.25	0.5%	0.22	0.4%	25	2%
Boundary	N/A	N/A	N/A	N/A	N/A	N/A	2.55	5%	3.2	5%	66	5%
Total	**17**	**100%**	**29**	**100%**	**409**	**100%**	**51**	**100%**	**60**	**100%**	**1,361**	**100%**

Notes:

(1) CSO loadings based on volumes from MWRA 2019 System Conditions collection system model.

3.3.2.3 Criteria Exceedances

To assess compliance with the water quality criteria for bacteria, the model was used to compute the total duration that the bacteria count in each segment along the linear model was predicted to exceed the single-sample maximum criterion for *E. coli* over the course of the Typical Year. The resulting values for percent annual attainment of the criteria would be generally analogous to the values for annual percent attainment presented in the *2003 Final Variance Report for Alewife Brook/Upper Mystic River* (Metcalf & Eddy, 2003). The hours of exceedance and percent annual compliance for *E. coli* criteria in Alewife Brook and the Upper Mystic River are presented in Table 3-10 for six different simulation conditions. The hours shown in Table 3-10 are the number of hours the *E. coli* bacterial counts exceed the criterion *anywhere* along the linear model of the Alewife Brook or Mystic River, respectively. As noted for the Charles River, this is an extremely stringent representation of attainment, as the model segments where exceedances occur shift in time, and the area of exceedance is almost always a fraction of the total river area. At any fixed point in the river, the hours of exceedance would be less than those listed in the tables.

Table 3-10. Hours of the *E. coli* Single Sample Maximum Criterion Exceedance at any Point in the Alewife Brook and Upper Mystic River During the Typical Year

	Alewife Brook (2019 Conditions)		Upper Mystic River (2019 Conditions)	
	E. coli Single Sample Maximum Criterion (235 #/100 mL)		*E. coli* Single Sample Maximum Criterion (235 #/100 mL)	
	Hours of Exceedance	Percent Annual Compliance	Hours of Exceedance	Percent Annual Compliance
All Sources	4,818	45%	4,030	54%
All Sources – No CSO	4,818	45%	3,966	55%
Stormwater Only	4,514	48%	3,814	56%
Dry Weather sources Only	0	100%	0	100%
Boundaries Only	0	100%	819	91%
CSOs Only	111	98. 7%	360	95.8%

Plots of hours of *E. coli* criteria exceedances over the Typical Year along Alewife Brook and Upper Mystic River for all sources are presented in Figure 3-4, and for CSO sources only in Figure 3-5. Similar to the Charles River, plots of criteria exceedances over the Typical Year for the condition of all sources except CSO were identical to the “all sources” plots, so the plots are not repeated here. In addition, the scale for Figure 3-5 covers a much lower range of values than the scale for Figure 3-4, as the maximum hours of exceedance for the “CSO Only” case was approximately 40 hours.

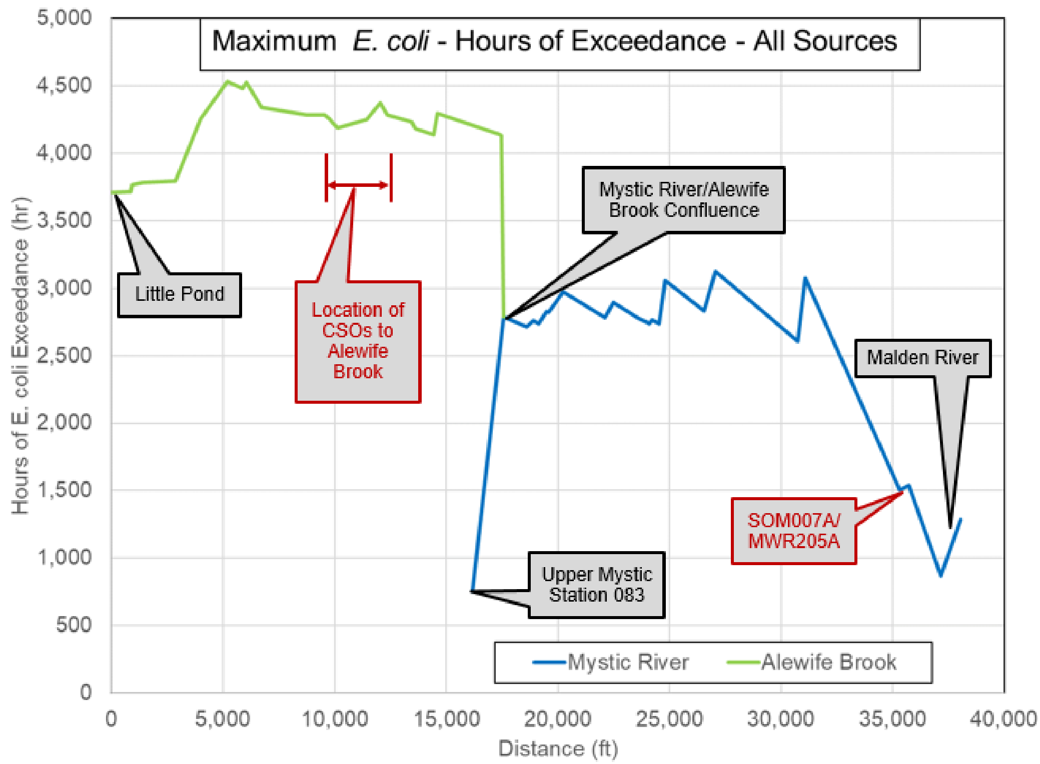


Figure 3-4. Hours of Exceedance of *E. coli* Single Sample Max. Criterion, All Sources, Typical Year, 2019 Conditions

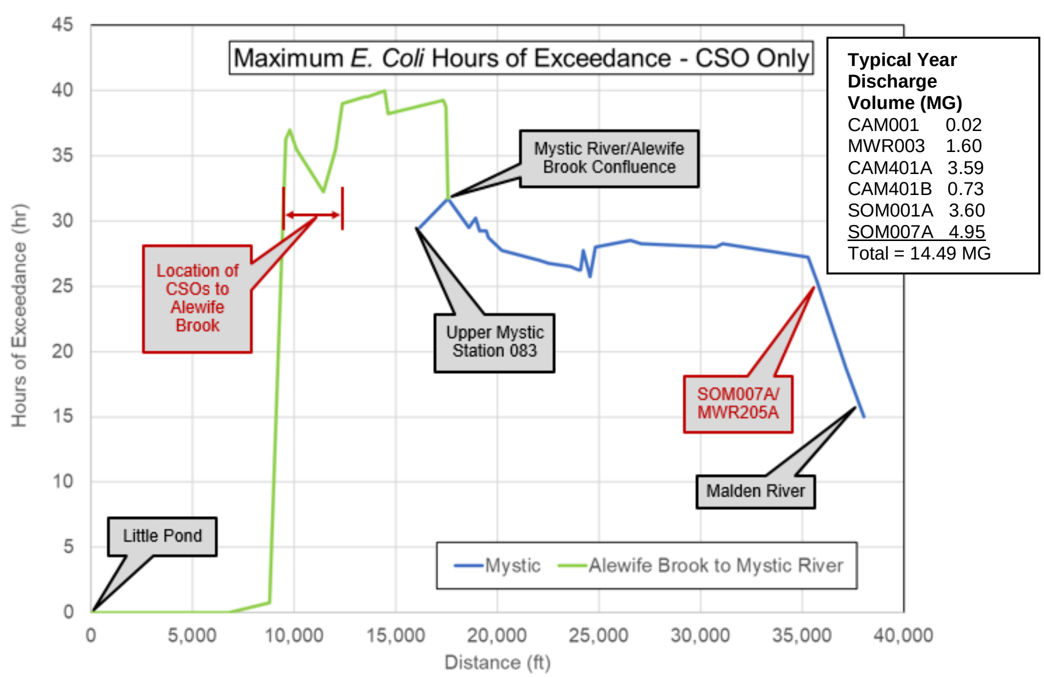


Figure 3-5. Hours of Exceedance of *E. coli* Single Sample Max Criterion, CSOs Only, Typical Year, 2019 Conditions. Note change in scale from "All Sources".

3.3.2.4 Sensitivity Analysis

As was done for the Charles River, hours of exceedance of the *E. coli* criterion were calculated for variations in the bacterial counts in stormwater and CSOs. This initial set of sensitivity evaluations is summarized in Table 3-11, and described more fully in the *Task 5.3 Water Quality Assessment* (AECOM, 2021a).

Doubling CSO bacteria counts resulted in only a negligible reduction in the percent annual compliance for the CSO only case: 96% to 95% for the Alewife/Mystic.

Reducing stormwater bacteria counts by half or more (possibly representing stormwater quality improvements), improved compliance by a greater amount, as shown in Table 3-11. The "stormwater only" condition was assessed with stormwater bacterial counts decreased by factors of 2 and 5, and to the 25th percentile value from the sampling data. Boundary values were multiplied by 0.5 and 0.2. Because water quality impacts are dominated by non-CSO sources, the predicted compliance is even more sensitive to stormwater bacterial counts in the Alewife/Mystic, than in the Charles. Scenarios representing possible future improvements in stormwater and boundary water quality are evaluated in Section 3.4 below.

Table 3-11. Single Sample Maximum Sensitivity Analysis – Alewife Brook/Upper Mystic River

Alewife Brook and Upper Mystic River – 2019 Conditions				
			E. coli **Single Sample Maximum Criterion (235 colonies/100 mL)**	
	Source Count Multiplier	***E. coli*** **Value (#/100 mL)**	**Hours of Exceedance**	**Percent Compliance**
Stormwater Only	1.0	25,000	4,800	44%
	0.5	12,500	4,154	52%
	0.2	5,000	3,379	61%
	25th Percentile	1,110	1,818	79%
CSO Only	1.0	Time varying Computed by Mass Balance	367	96%
	2.0	2x Time varying Computed by Mass Balance	419	95%

3.4 Alternatives Analysis

Following completion of the initial baseline water quality assessment, the next step was to use the water quality models to assess the impacts of various alternatives for reducing the *E. coli* and *Enterococcus* loadings to the Charles River and Alewife Brook/Upper Mystic River. This section describes the establishment of an updated baseline condition, and the subsequent evaluation of various bacterial load reduction scenarios. More details can be found in the *Task 5.4 Water Quality Alternatives Assessment* (AECOM, 2021c).

To evaluate the effect of CSO controls, model runs were performed for two alternatives with modified CSO inputs:

- Q1-2021 system conditions – including reduction of untreated CSO volume to the Charles from 4.06 MG to 3.47 MG and to the Alewife from 9.5 MG to 6.3 MG.
- a "LTCP Goals Attained" alternative in which all CSOs in the study area not yet meeting LTCP activation and volume goals are assumed to be reduced to meet those goals.

To evaluate the effect of aspirational stormwater improvements, model runs were performed with these inputs modified as follows:

- With small storms removed to simulate the effect of possible future stormwater best management practices (BMPs) that capture the first inch of rainfall.
- Stormwater and boundary sources capped at both the water quality criterion and at half the water quality criterion.

The results of these evaluations are summarized below.

3.4.1 Updated Collection System Condition

The first step in the alternatives evaluation was to establish an updated collection system condition based on more recent (Q1-2021) system conditions. The Q1-2021 collection system conditions incorporated a number of CSO reduction projects completed since 2019 as well as model updates based on new system investigations and information developed since 2019. System improvements and model updates implemented from 2019 to Q1-2021 are described “Alternative 1” in *Task 5.4 Water Quality Alternatives Assessment* (AECOM, 2021c). These improvements include reduction of untreated CSO volume to the Charles from 4.06 MG to 3.47 MG and to the Alewife from 9.5 MG to 6.3 MG. The main collection system improvements and model updates implemented from 2019 to Q1-2021 were:

For the Charles River:

- The City of Cambridge completed the Cambridgeport partial sewer separation project, and the associated changes were incorporated into the model. This project reduced treated discharge activation frequency at Cottage Farm from four to two, and reduced the volume from 12.6 MG to 8.95 MG.
- The model configuration of outfalls MWR018, MWR019, and MWR020 was updated based on field investigations. These updates reduced the total CSO volume at these outfalls by 0.58 MG, with no change to activation frequency.
- Overall, the changes reduced the total untreated CSO volume in the Typical Year from 4.1 MG to 3.5 MG.

For Alewife Brook/Upper Mystic River:

- The City of Cambridge completed a project to remove sediment in the combined sewers downstream of the CAM401A regulator. This project reduced the activation frequency at CAM401A from ten to five, and reduced the volume from 3.59 MG to 0.66 MG.
- Model refinements and calibration adjustments at SOM001A resulted in an increase in the activation frequency from six to eight, and an increase in volume from 3.60 to 4.47 MG.
- MWRA implemented a revised operating procedure at Alewife Brook Pump Station. This change was incorporated into the model but did not substantially affect CSO volumes or activations.
- Overall, the changes reduced the total untreated CSO volume in the Typical Year from 9.5 MG to 6.3 MG.

Table 3-12 presents a comparison of the percent annual compliance with the *E. coli* single-sample maximum criterion for the 2019 Conditions and Q1-2021 Conditions water quality runs for the Charles River, Alewife Brook and Upper Mystic River. Results are presented for the same range of source loading conditions as presented above in Table 3-5 and Table 3-10. The following observations can be made:

- For the Charles River, the percent annual compliance remained unchanged relative to 2019 conditions for all of the loading conditions except for the CSO-Only case, where the percent compliance increased from 99.6% to 99.9%.
- For the Alewife Brook, the percent annual compliance remained unchanged relative to 2019 conditions for all of the loading conditions except for the CSO-Only case, where compliance increased from 98.7% to 99.6%.
- For the Upper Mystic River, the percent annual compliance remained unchanged relative to 2019 conditions for all of the loading conditions except for the CSO-Only case, where the percent compliance increased from 96.9% to 97.9%.

Table 3-12. Compliance Statistics for 2019 and Q1-2021 Conditions

	Percent Annual Compliance with *E. coli* Single-Sample Maximum Criterion (235#/100mL)					
Condition	**All Sources**	**Non-CSO Sources Only**	**Stormwater Only**	**Dry Weather Sources Only**	**Boundaries Only**	**CSOs Only**
Charles River						
2019	48%	48%	64%	100%	59%	99.6%
Q1-2021	48%	48%	64%	100%	59%	99.9%
Alewife Brook						
2019	45%	45%	47%	100%	100%	98.7%
Q1-2021	45%	45%	47%	100%	100%	99.6%
Upper Mystic River						
2019	55%	55%	57%	100%	100%	96.9%
Q1-2021	55%	55%	57%	100%	100%	97.9%

In summary, the system improvements and model updates implemented between the 2019 and Q1-2021 system conditions versions of the model further reduced the impacts of CSOs on attainment of the single-sample maximum criterion when considering CSO loads only. The impacts of other individual sources on attainment of the criterion did not change, nor did the level of attainment change when considering all sources together. In comparing the All Sources and Non-CSO Sources Only columns, it is clear that further reduction in CSOs would not affect the overall percent attainment with the single-sample maximum criterion when non-CSO sources are considered.

3.4.2 "LTCP Goals Attained": Q1-2021 Conditions but with All Outfalls Meeting the LTCP Goals for Activation Frequency and Volume

Description/Intent. As of the Q1-2021 collection system conditions, several CSO outfalls still exceeded the numerical LTCP goals in terms of activation frequency and/or volume. This alternative was intended to assess the improvement in attainment with water quality criteria that would be achieved if all outfalls were brought into attainment with the LTCP goals for CSO activation frequency and volume.

Modeling Approach. This alternative was modeled by removing CSO activations at outfalls where the Q1-2021 conditions activation frequency exceeded the number specified in the LTCP and, when needed, prorating the CSO flows down to meet the LTCP annual volume goal. Outfalls with fewer activations or lower volumes than the LTCP goals were left unchanged. Specifics about adjustments made can be found in *Task 5.4 Water Quality Alternatives Assessment* (AECOM, 2021c) (Alternative 4). All other sources were held at their original levels.

Results. The percent compliance for this alternative compared to the base case of Q1-2021 conditions is presented for the Charles River, Alewife Brook, and Upper Mystic River in Table 3-13 (this table also presents the results for the other alternatives described further below). For the Charles River, the compliance statistics are identical to those of the base case of Q1-2021 conditions. For both the Alewife Brook and Upper Mystic River, the statistics are identical to those of the base case, except for the CSOs Only conditions where a slight improvement is noted.

Feasibility. The relatively marginal improvement in attainment with the water quality criteria demonstrated by the “LTCP Goals Attained” alternative compared to Q1-2021 Conditions will need to be considered when evaluating the costs and potential implementation challenges of alternatives needed to meet the numerical LTCP goals for the outfalls assessed.

Table 3-13. Compliance Statistics for Stormwater and Boundary Load Reduction Scenarios, Compared to Q1-2021 Baseline Conditions (Page 1 of 2)

Alternative	Percent Annual Compliance with *E. coli* Single Sample Maximum Criterion (235#/100mL)					
	All Sources	Non-CSO Sources Only	Stormwater Only	Dry Weather Sources Only	Boundaries Only	CSOs Only
Charles River						
Q1-2021 Conditions	48%	48%	64%	100%	59%	99.9%
Q1-2021 Conditions, “LTCP Goals Attained” Conditions	48%	48%	64%	100%	59%	99.9%
Q1-2021 Conditions, BMPs to Control First Inch of Rain in Stormwater Areas	50%	50%	71%	100%	59%	99.9%
Q1-2021 Conditions, Non-CSO Sources Capped at 100% of WQ Criterion	98%	100%	100%	100%	100%	99.9%
Q1-2021 Conditions, Non-CSO Sources Capped at 50% of WQ Criterion	99.8%	100%	100%	100%	100%	99.9%
Alewife Brook						
Q1-2021 Conditions	45%	45%	48%	100%	100%	99.6%
Q1-2021 Conditions, “LTCP Goals Attained” Conditions	45%	45%	48%	100%	100%	99.8%
Q1-2021 Conditions, BMPs to Control First Inch of Rain in Stormwater Areas	82%	82%	82%	100%	100%	99.6%
Q1-2021 Conditions, Non-CSO Sources Capped at 100% of WQ Criterion	99.2%	100%	100%	100%	100%	99.6%
Q1-2021 Conditions, Non-CSO Sources Capped at 50% of WQ Criterion	99.2%	100%	100%	100%	100%	99.6%

Table 3-13. Compliance Statistics for Stormwater and Boundary Load Reduction Scenarios, Compared to Q1-2021 Baseline Conditions (Page 2 of 2)

Alternative	Percent Annual Compliance with *E. coli* Single Sample Maximum Criterion (235#/100mL)					
	All Sources	Non-CSO Sources Only	Stormwater Only	Dry Weather Sources Only	Boundaries Only	CSOs Only
Upper Mystic River						
Q1-2021 Conditions	54%	55%	56%	100%	91%	97.9%
Q1-2021 Conditions, "LTCP Goals Attained" Conditions	54%	55%	56%	100%	91%	99.0%
Q1-2021 Conditions, BMPs to Control First Inch of Rain in Stormwater Areas	76%	80%	80%	100%	91%	97.9%
Q1-2021 Conditions, Non-CSO Sources Capped at 100% of WQ Criterion	97.1%	100%	100%	100%	100%	97.9%
Q1-2021 Conditions, Non-CSO Sources Capped at 50% of WQ Criterion	97.8%	100%	100%	100%	100%	97.9%

3.4.3 Stormwater and Boundary Load Reduction Scenarios

The water quality models were used to assess the impact of a range of bacterial load reduction scenarios on attainment with the water quality criteria. These scenarios included the following:

- Stormwater capture scenario: This model run approximated the impact of implementing stormwater management projects that would control the first one inch of rainfall throughout the separate stormwater areas tributary to the Charles River, Alewife Brook and Upper Mystic River.
- Non-CSO sources capped at 100% of water quality criterion: For this run, the bacterial counts for the non-CSO sources were set to the value of the single-sample maximum criterion, unless the values of the counts currently used in the modeling were less than the single-sample maximum criterion, in which case the current values were used.
- Non-CSO sources capped at 50% of the water quality criterion: For this run, the bacterial counts for the non-CSO sources were set to one half of the value of the single-sample maximum criterion, unless the values of the counts currently used in the modeling were less than half of the single-sample maximum criterion, in which case the current values were used.

3.4.3.1 BMPs to Control First Inch of Rain in Stormwater Areas

Description/Intent. One of the stormwater Best Management Practices (BMPs) targeted for use in meeting Total Maximum Daily Load (TMDL) goals for stormwater involves infiltrating stormwater runoff, with a typical target being to infiltrate the runoff from the first inch of rain. This approach would decrease the runoff flows but increase the dry weather flows resulting from groundwater infiltration. The alternative described in this section was aimed at assessing the potential benefits of applying this BMP over the entire separate stormwater area tributary to the Charles River and Alewife Book/Upper Mystic River included in the model.

Modeling Approach. An accurate simulation of the infiltration BMP would require extensive modification to the hydrological models used to estimate stormwater runoff and dry weather discharges to the streams. To provide a general indication of the benefits of this approach, separate stormwater runoff from storms of less than 1 inch was removed, but runoff from larger storms as well as dry weather discharges were unchanged – so the effects of increased dry weather flows from higher groundwater infiltration were not modeled. This approach somewhat underestimates the benefit of the BMP, as runoff from larger storms would in reality be reduced by some fraction. In addition, there could be a disproportionate reduction of bacteria by capturing any “first flush”, although the stormwater data collected to support the water quality model development did not show consistent evidence of a “first flush”. This approach would, however, represent the benefits achieved during the more common smaller storms. As a sensitivity analysis, this approach was considered to be acceptable.

The number of storms in the Typical Year applied to the separate stormwater areas was reduced from 42 to 15 and the total rainfall depth from 43.9 inches to 28.0 inches. Thus, the number of storms was reduced by 60%, but the total rainfall depth was only reduced by 36%. This difference reflects the fact that the storms that were removed were smaller storms.

Results. For the Charles River, the percent compliance for All Sources (50%) is not much different than for the baseline condition (48%). This is because the boundary sources were unchanged assuming, in effect, that the BMPs were applied only downstream of the Watertown Dam. For Stormwater Only conditions, the percent compliance increased from 64% to 71%.

For Alewife Brook and Upper Mystic River, the percent compliance increased substantially for All Sources, Non-CSO Sources Only, and Stormwater Only. The CSOs Only statistics were unchanged, as expected.

These results suggest that the smaller rain events have a relatively larger impact on compliance in the Alewife Brook/Upper Mystic River than in the Charles River.

Feasibility. This alternative is a hypothetical condition which is not likely to be achievable over the entire tributary area, but it nevertheless provides an indication of the potential benefits.

3.4.3.2 Non-CSO Sources Capped at 100% of Water Quality Criterion

Description/Intent. This alternative was intended to reflect an ideal condition where the concentration of *E. coli* in stormwater discharges and other non-CSO sources were capped at the single-sample maximum criterion of 235#/100mL through implementation of Best Management Practices and other measures designed to improve stormwater quality. With non-CSO sources capped at the *E. coli* single-sample maximum criterion, this alternative would be expected to perform similar to the CSOs Only case for the baseline alternative.

Modeling Approach. The starting point for this alternative was the Q1-2021 conditions model. For this alternative, the CSO loads remained as they were in the Q1-2021 conditions model, but where the *E. coli* counts in the other, non-CSO inputs were above 235#/100mL, they were set to a constant value of 235#/100mL. Stormwater discharges all had *E. coli* counts larger than 235#/100mL, so they were all set to 235#/100mL. Boundary sources had variable counts with values greater than 235#/100mL during wet weather. The wet weather counts were adjusted to 235#/100mL but the dry weather counts that were below 235#/100mL were not changed.

Results. The percent compliance for this alternative compared to the baseline case of Q1-2021 Conditions are presented for the Charles River, Alewife Brook, and Upper Mystic River in Table 3-13 above.

For this alternative, the Non-CSO Sources Only, Stormwater Only, Dry Weather Sources and Boundaries Only compliance is 100% as these discharges are capped at the *E. coli* criterion of 235 #/100 mL and have no CSO inputs. For both the Charles River and the Alewife Brook/Upper Mystic River the percent compliance for All Sources is slightly less than the CSOs Only percentage. For the All-Sources case, the CSOs still discharge into ambient waters that contain *E. coli* from other sources, even though the counts from those sources was capped at 235 #/100mL. For the CSOs Only case, the discharge is into theoretically pristine waters with no other *E. coli* sources. Therefore, for this alternative, the *E. coli* counts due to CSOs decline to below the criterion more slowly in the All-Sources case than in the CSOs Only case.

Feasibility. This alternative represents an aspirational target for controlling *E. coli* counts in stormwater and other sources, but the level of stormwater controls needed to achieve these *E. coli* levels in stormwater discharges is not realistically implementable in the foreseeable future.

3.4.3.3 Non-CSO Sources Capped at 50% of Water Quality Criterion

Description/Intent. This alternative assessed the benefits of achieving Non-CSO (stormwater, dry weather and boundary sources) *E. coli* counts that would be capped at a value of half of the current single sample maximum criterion of 235 #/100mL. Alternative 2, which had the Non-CSO *E. coli* counts capped at the criterion, showed that for All Sources, the compliance was less than for the CSOs Only case. Therefore, a lower *E. coli* count was simulated in the Non-CSO discharges to see if the compliance would be improved for the All Sources case.

Modeling Approach. This alternative was simulated in a manner similar to the alternative with non-CSO sources capped at 100% of the water quality criterion described above, but with the non-CSO sources *E. coli* counts capped at 117 #/100mL.

Results. The percent compliance for this alternative compared to the baseline case of Q1-2021 Conditions is presented for the Charles River, Alewife Brook, and Upper Mystic River in Table 3-13 above. For both the Charles River and the Alewife Brook/Upper Mystic River, the percent compliance for All Sources is very slightly below the compliance for CSO Sources Only.

Feasibility. As for the alternative with non-CSO sources capped at 100% of the water quality criterion, this alternative is a hypothetical alternative aimed at assessing the benefits of an extreme level of stormwater quality improvements.

3.5 Water Quality Assessment for non-Variance Waters

Although the variance waters are the primary focus of this section, for completeness this section provides a summary of receiving water quality in areas of Boston Harbor with remaining CSOs. Boston Harbor is part of MWRA's long-term CSO Receiving Water Monitoring program, from which MWRA has been collecting and analyzing samples since 1989.

As described below, water quality models developed for this assessment evaluate compliance with state indicator bacteria standards in regions with CSO variances, the Charles River and Alewife Brook/Upper Mystic River. MWRA also conducts routine monitoring where CSO discharges remain to Class $SB_{(CSO)}$ designated waters, including the Mystic River mouth, Chelsea Creek, Inner Harbor, Reserved Channel, and Fort Point Channel. In order to present water quality in those regions, MWRA has adopted methodology used to develop annual report cards for Boston Harbor's tributary watersheds. Originally developed by Mystic River Watershed Association in 2014, the report cards summarize compliance with state bacteria standards by subregion.[7] Beginning in 2020, EPA publicized report cards for the Mystic, Charles, and Neponset River watersheds using this methodology.

The grades are calculated from an average compliance rate with primary and secondary contact standards, weighted based on antecedent rainfall, and calculated on a three year rolling basis. As noted above, DEP issued revised water quality criteria in November 2021, too late to be incorporated into the performance assessment. The Class SB criteria for marine waters in effect prior to November 2021 included a single sample maximum standard of 104 *Enterococcus* #/100mL, often referred to as a swimming standard. Class SC marine waters, designated to support secondary contact recreation like boating, fishing and sailing had a criterion of 350 *Enterococcus* #/100mL, often referred to as a boating standard. The weighting of wet and dry weather is designed to approximate the fact that roughly 75% of the year falls into dry weather. This is supported by the fact that the Typical Year for the LTCP has about 90 storms in 365 days. Wet weather is defined as >0.25" of rain at Logan Airport in the two days preceding sampling and the day of sampling. Calculating the grades on a three year rolling basis balances year-to-year variability for a more accurate depiction of long term trends.

The three year compliance rate for a given station with *n* number of samples is calculated as follows and converted to a letter grade based on EPA report card publications.[8]

$$Swimming\ Compliance = 0.75 * \left(\frac{Dry\ Samples \leq 104}{Total\ Dry\ Samples}\right) + 0.25 * \left(\frac{Wet\ Samples\ \leq 104}{Total\ Wet\ Samples}\right)$$

$$Boating\ Compliance = 0.75 * \left(\frac{Dry\ Samples \leq 350}{Total\ Dry\ Samples}\right) + 0.25 * \left(\frac{Wet\ Samples\ \leq 350}{Total\ Wet\ Samples}\right)$$

$$Report\ Card\ Compliance\ (\%) = 100 * \left(\frac{Swimming\ Compliance + Boating\ Compliance}{2}\right)$$

Table 3-14 below shows grades for MWRA monitoring stations in non-variance regions that still receive CSO discharges in the Typical Year. Data from 2010-2020 was used to calculate grades for 2012-2020.

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[7] "Water Quality Grade: EPA." Mystic River Watershed Association. Accessed October 8, 2021. https://mysticriver.org/epa-grade

[8] "2020 Mystic River Watershed Report Card Frequently Asked Questions". Environmental Protection Agency. Accessed October 8, 2021. https://www.epa.gov/mysticriver/2020-mystic-river-watershed-report-card-frequently-asked-questions

Table 3-14. Report Card Grades for MWRA Monitoring Stations in Non-variance Regions, 2012-2020.

		Assigned Grades by Year[1]								
Station	**Description**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
075	Fort Point (Head)	F	D-	D+	C+	C+	C	C-	D-	D-
018	Fort Point (Mid)	B-	B	B+	A-	A	A-	A-	B+	B
178	Fort Point (Mouth)	B+	B+	A-	A-	A	A	A	A-	B+
019	Fort Point (Inner Harbor)	A+	A	A	A	A+	A+	A+	A+	A
022	Reserved Channel	A+	A	A	A-	A	A	A+	A+	A
024	Inner Harbor (Airport)	A+	A+	A+	A+	A+	A+	A+	A+	A+
138	Inner Harbor (Aquarium)	A+	A+	A+	A+	A+	A+	A+	A+	A+
014	Inner Harbor (Charles mouth)	A+	A+	A+	A+	A+	A+	A+	A+	A+
015	Inner Harbor (Tobin Br)	A	A	A	A	A	A	A+	A+	A
052	Mystic mouth (@MWR205)	A-	B+	A-	A-	A-	A-	A-	B	B
069	Mystic mouth (@BOS017)	A	A-	A	A-	A	A	A-	A-	B+
137	Mystic mouth (mid-channel)	A+	A+	A+	A+	A+	A+	A+	A+	A+
027	Chelsea Creek	A+	A	A	A	A+	A+	A+	A+	A+

Notes: (1) Color shading follows existing EPA report card publications.

As indicated in Table 3-14, of the 117 grades calculated in 2012 to 2020 period (13 locations x 9 years), 79 were A+ or A; 24 were A- or B+; and only 14 were B or less. The only location with grades lower than B- was at the head of Fort Point Channel. CSO discharge to the Fort Point Channel in the Typical Year is 34.71 MG (Q4-2021 system conditions), less than half of the LTCP goal of 73.89 MG. Although some discharges are slightly over the LTCP goal (BOS062, BOS065 and BOS070/DBC), CSO activation frequency and volumes at all Fort Point Channel outfalls have been reduced or eliminated from 1992 conditions as a result of the projects implemented under the LTCP. Overall, CSO discharge to Fort Point Channel has been reduced 88% from 298.81 MG in 1992 to 34.71 MG (Q4-2021 system conditions). Currently the most frequent CSO is the treated discharge from the Union Park Facility (MWR215) at 10 times within a typical year, followed by BOS070/DBC at 7 activations. The grading system does not distinguish the sources of non-attainment, and in the head end of Fort Point Channel, non-CSO factors such as stormwater and minimal tidal flushing/dilution contribute to the relatively low grade at that location. With the exception of that one location, the consistently high grades throughout the stations in the Class $SB_{(CSO)}$ waters over the nine-year period demonstrate the success of the efforts by MWRA and the CSO communities in improving water quality in Boston Harbor. Figure 3-6 below is a map of the monitoring stations with the 2020 grades shown as colored symbols.

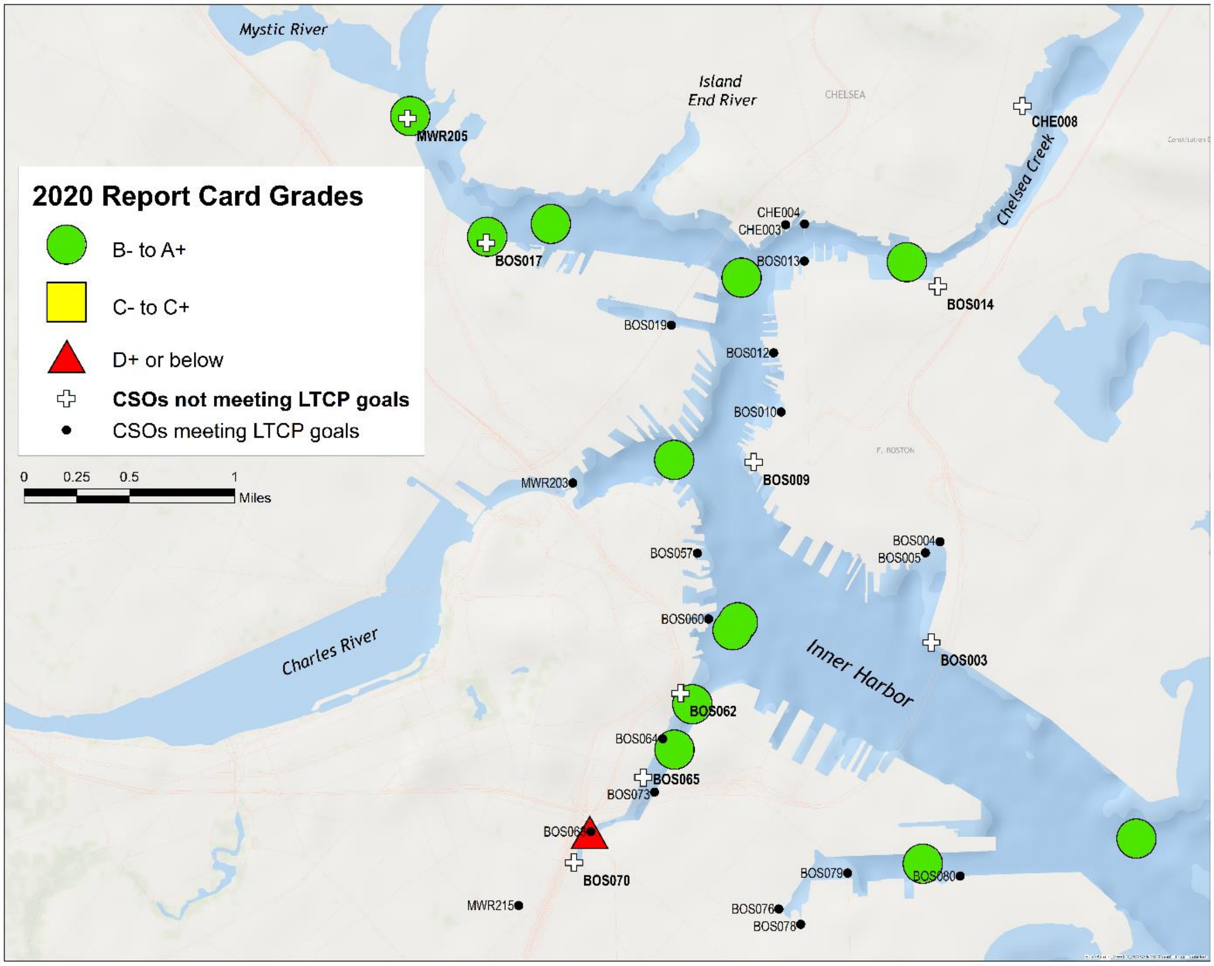


Figure 3-6. MWRA Monitoring Stations in Non-Variance Regions, with Colored Symbols Showing Associated "Report Card" Grades for 2020.

3.6 Conclusions

The following observations and conclusions were drawn from the assessment of water quality in the Charles River and Alewife Brook/Upper Mystic River:

- In both the Charles River and Alewife Brook/Upper Mystic River, the predominant source of bacteria loading was non-CSO sources.
    - For the Charles River, approximately 99% of the bacteria load was from non-CSO sources, split approximately 40% from upstream sources and 60% from stormwater for the 1-year storm and for the Typical Year.
    - For Alewife Brook, stormwater was the predominant source, but CSO accounted for approximately 28% of the bacteria load in the 1-year storm, and 10% for the Typical Year.
- In the Charles River and Alewife Brook/Upper Mystic River, the annual percent attainment with *E. coli* criteria was driven by the non-CSO loads.
- Further reduction of CSOs to a level such that all CSOs to the Charles River and Alewife Brook/Upper Mystic River met the numerical targets for activation frequency and volume per the LTCP would not substantively change the percent attainment.

- Under Q1-2021 conditions, CSOs alone would contribute to annual non-attainment of the *E. coli* criterion less than 1% percent of the time for the Charles River, and approximately 2% of the time in the Alewife Brook/Upper Mystic River, consistent with the targets established in previous CSO planning efforts.

- Reductions in *E. coli* loading from stormwater would improve the annual percent attainment, but even with an order-of-magnitude reduction in *E. coli* counts in stormwater, non-CSO sources would still be the primary driver of non-attainment of the *E. coli* criteria.

- In SB_{cso} areas, including the Mystic River mouth, Chelsea Creek, Inner Harbor, Reserved Channel, and Fort Point Channel, MWRA adopted the methodology used by EPA to publish grades presented in annual "report cards" for Boston Harbor's tributary watersheds. The receiving water quality has consistently achieved a report grade of B- or better and in many instances as high as A+ (The only location with grades lower than B- was at the head of Fort Point Channel).

4. Recommendations and Continuing Work for Outfalls Currently Forecast not to Attain LTCP Activation and Volume Goals

As described in Chapter 2 above, of the 46 CSO outfalls in the MWRA's system that remain active (i.e. are not physically closed or associated with the North Dorchester Bay CSO Storage Tunnel), 30 meet the LTCP goals as of Q4-2021 conditions. Of the remaining 16 outfalls, six are projected to meet the LTCP goals after December 2021, and ten outfalls continue to be investigated. For the 16 remaining outfalls not expected to achieve the LTCP volume and/or activation goals by the current milestone deadline of December, 2021, significant progress by the MWRA and CSO communities has been made on advancing the designs or construction for six of the outfalls to improve CSO performance and make progress towards meeting LTCP goals. With improvements these outfalls are expected to attain LTCP volume and activation goals by December, 2024. With respect to the remaining 10 CSO outfalls currently not meeting LTCP goals, preliminary projects have been identified for four of the outfalls; but the final six outfalls present significant challenges, potentially requiring substantial and costly system modifications to achieve LTCP goals. This chapter presents a summary of the ongoing work and site-specific investigations that have been and will continue to be conducted by MWRA and the CSO communities. The discussion of the remaining outfalls presented below is organized by the following groupings as presented in Table 4-1 and Table 4-2:

Table 4-1. CSO Outfalls Predicted to Attain LTCP Goals by December 2024

Receiving Water	Outfall	Anticipated System Improvements
Inner Harbor Mystic/Chelsea Confluence (East Boston)	BOS003 BOS009 BOS014	BWSC sewer separation Contract 3 and other CSO improvements; MWRA Board approved $2.1 million in funding under a Financial Assistance Agreement with BWSC
Chelsea Creek	CHE008	Providing a new interceptor connection to replace the existing 30-inch connection with a 48-inch pipe
Mystic/Chelsea Confluence and Upper Mystic River	MWR205 MWR205A	Adding a second interceptor connection

Table 4-2. CSO Outfalls Where Site-Specific Investigations Continue

Receiving Water	Outfalls with Modeled Concept Designs Predicted to Attain LTCP Goals	Outfalls Presenting Significant Challenges
Alewife		SOM001A
Mystic/Chelsea Confluence	BOS017	
Fort Point Channel	BOS062 BOS065 BOS070/DBC	
Charles River		MWR201 (Cottage Farm) MWR018 MWR019 MWR020 CAM005

4.1 Outfalls projected to meet LTCP goals after December 2021

4.1.1 East Boston Outfalls (Upper/Lower Inner Harbor, Mystic/Chelsea Confluence)

Eight CSO outfalls (BOS003, BOS004, BOS005, BOS009, BOS010, BOS012, BOS013, and BOS014) are included in the East Boston sub-system and discharge to either the Inner Harbor or Mystic/Chelsea Confluence. The dry weather flows from the regulators associated with these CSO outfalls discharge to either the Condor Street Interceptor or the East Boston Branch Sewer, which carry flows to the Caruso Pump Station. When the hydraulic grade line (HGL) exceeds the elevation of the overflow points in the regulators along the Condor St. Interceptor and East Boston Branch Sewer, excess flow is discharged to the Inner Harbor and/or the Mystic/Chelsea Confluence. A schematic of the East Boston sub-system is shown in Figure 4-1.

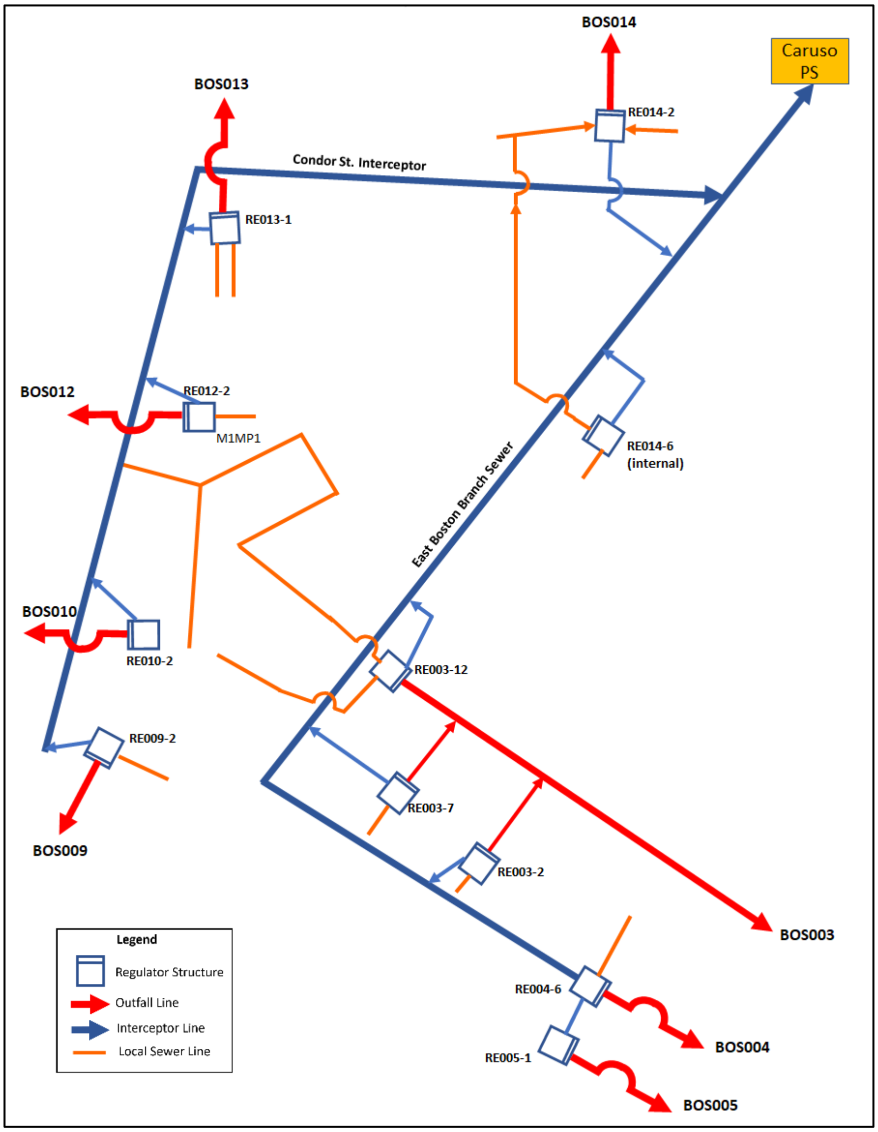


Figure 4-1. East Boston System Schematic

Table 4-3 presents the Q4-2021 Typical Year model results compared to a “Future Conditions” scenario that includes completion of on-going and planned projects in East Boston by the BWSC, and the LTCP goals for East Boston. Substantial CSO reductions have resulted from the construction of the East Boston Branch Relief Sewer project by MWRA and ongoing sewer separation work by BWSC, reducing

East Boston CSO discharge from 1992 conditions of 69.5 MG and as many as 48 activations to 8.44 MG and 10 activations for the Q4-2021 conditions. Despite this progress, five of the eight outfalls in East Boston fall short of the LTCP goals for either activation frequency, volume, or both for the Q4-2021 conditions.

Table 4-3. East Boston Existing and Future Conditions for Proposed Modifications Compared to the LTCP Goals

Outfall	Regulator	Q4-2021 System Conditions (1)		Future Conditions		Long Term Control Plan	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
BOS013	RE013-1	8	0.27	8	0.27	4	0.54
BOS014	RE014-2	8	1.44	0	0.00	0	0
BOS009	RE009-2	10	0.73	5	0.15	5	0.59
BOS010	RE010-2	1	0.07	1	0.06	4	0.72
BOS012	RE012-2	0	0.00	0	0.00	5	0.72
BOS003	RE003-2	1	0.01	0	0.00	4 (2)	2.87 (2)
	RE003-7	8	1.65	0	0.00		
	RE003-12	9	4.27	4	0.89		
BOS004	RE004-6	0	0.00	2	0.09	5	1.84
BOS005	RE005-1	0	0.00	0	0.00	1	0.01
Total (3)		**10 (max)**	**8.44**	**8 (max)**	**1.46**	**5 (max)**	**7.29**

(1) Grey shading indicates model prediction is greater than LTCP value.

(2) For the LTCP goals for outfall BOS003, activation frequency shown is the maximum among its three regulators. Volume is the sum of the regulator volumes.

(3) Activation frequency shown is the maximum among East Boston regulators. Volume is the total summed volume.

BWSC has been implementing a multi-phased sewer separation project in East Boston (Figure 4-2) as well as other system modifications in an effort to make further progress towards meeting LTCP goals. BWSC completed sewer separation Contract 1 in 2020, and completed Contract 2 in the fall of 2021. This work was included in the Q4-2021 conditions model. This work mostly affected flows at regulator RE0012-2 (outfall BOS012), and regulator RE-010-2, which now meet LTCP levels of control in the Typical Year.

The Future Conditions model run includes sewer separation Contract 3. This contract will separate certain areas tributary to outfalls BOS012, BOS009, and BOS003. The construction contract was awarded in late spring of 2021, with an estimated completion date of 2023. The following improvements are also included with Contract 3:

- Upgrading the restricted interceptor connection at Regulator RE003-12;
- Reconstructing regulators RE003-2 and RE003-7 to provide relief only in extreme events; following completion of sewer separation these regulators will not activate in the Typical Year; and

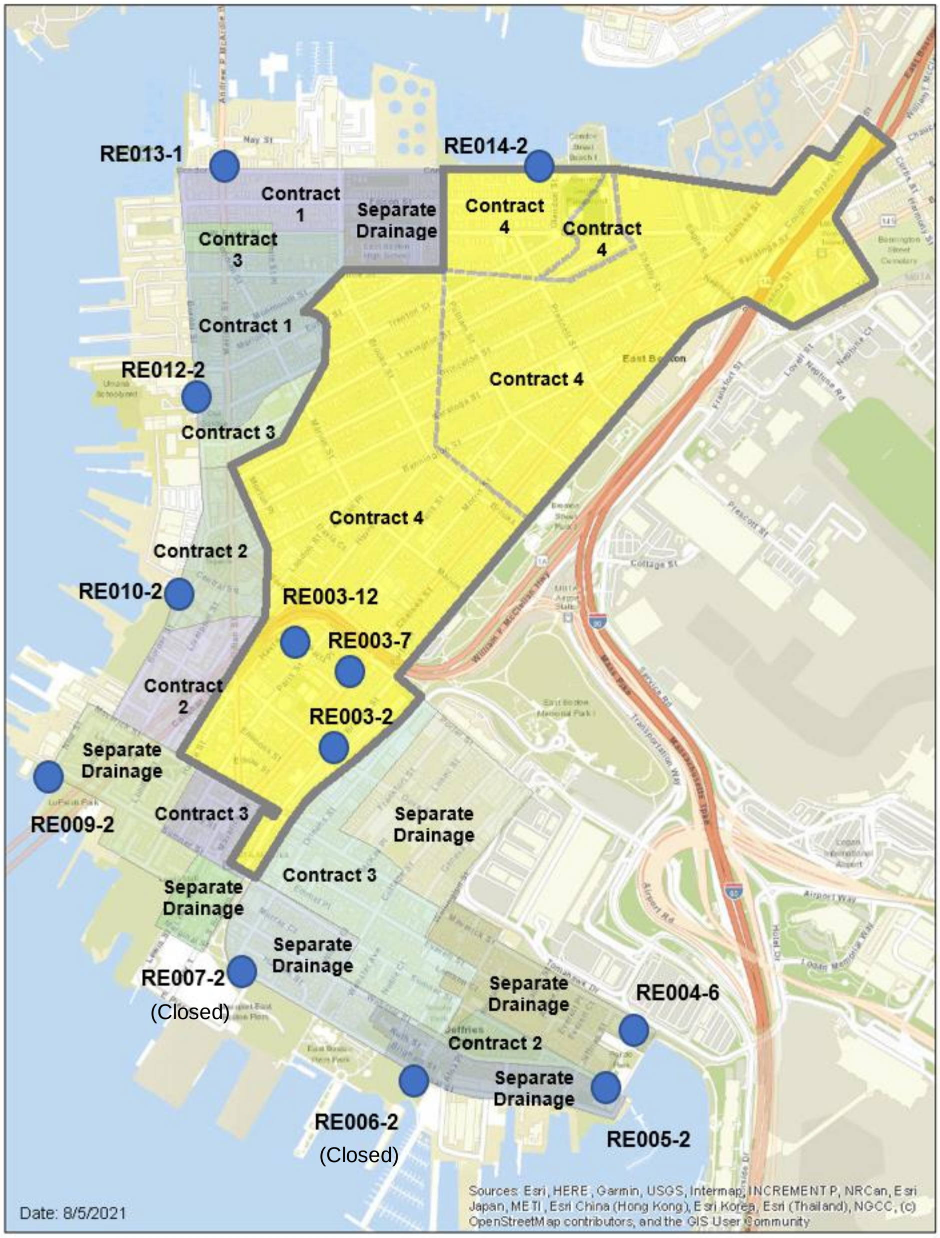


Figure 4-2. East Boston Sewer Separation

- Constructing a new dry weather flow connection between the combined sewer tributary to regulator RE014-2 from Eagle Square and an existing manhole on the Condor Street Interceptor along East Eagle Street.

A more detailed description of these improvements as well as previous work in East Boston is provided in Semiannual Report No. 6.

The completion of BWSC's three sewer separation contracts in East Boston and constructing modifications to regulators RE003-2, RE003-7, RE003-12, and RE0014-2 are predicted to significantly reduce CSO activations and volumes at the CSO outfalls within the sewer separation project areas. As indicated in Table 4-3, under Future Conditions all outfalls are predicted to meet LTCP levels of control for activation frequency and volume with the exception of the activation frequency at BOS013. As also indicated in Table 4-3 the activation frequency at BOS013 is eight compared to the LTCP goal of four.

However, the volume discharged at outfall BOS013 is 0.27 MG in a Typical Year which is less than the LTCP goal of 0.54 MG. Furthermore, the consideration is given to the small activation volumes (<0.05MG) that make up four of the eight activations predicted in a typical year. The performance at this location has improved dramatically since 1992 to a level believed to achieve anticipated water quality improvements. The difference between the Q4-2021 performance and the LTCP goal for BOS013 is relatively nominal, and the inability to precisely meet the activation goal at this location is considered immaterial. BWSC is continuing sewer separation and system improvements within East Boston including Contract 4 as shown in Figure 4-2.

4.1.2 Outfall CHE008 (Mystic/Chelsea Confluence)

Figure 4-3 shows a schematic of the outfall CHE008 system. Regulator RE-081 receives flow from an upstream flow diversion on Crescent Avenue. During dry weather, flow in the Crescent Avenue combined sewer is routed via an 18-inch sewer through meter CH8 to the Revere Extension Sewer. During wet weather, a weir set at the crown of the 18-inch Crescent Avenue combined sewer diverts flow to the 61 x 72 inch combined sewer tributary to regulator RE-081. During dry weather and small storms, flows entering regulator RE-081 are routed through meter CH7 to Structure C via a 30-inch sewer. Structure C is located at the confluence of the Revere Extension Sewer, the Chelsea Branch Sewer and the Chelsea Branch Sewer Relief. From Structure C the flow is routed through the MWRA interceptor system towards the Chelsea Screen House and ultimately to the Caruso Pump Station. During larger storms, the flow can overtop the weir in regulator RE-081 and flow to outfall CHE008. A temporary flow meter (M1MP1) was installed on the influent line to regulator RE-081 from April 2018 through June 2020. The City of Chelsea also maintains a CSO overflow meter on this outfall.

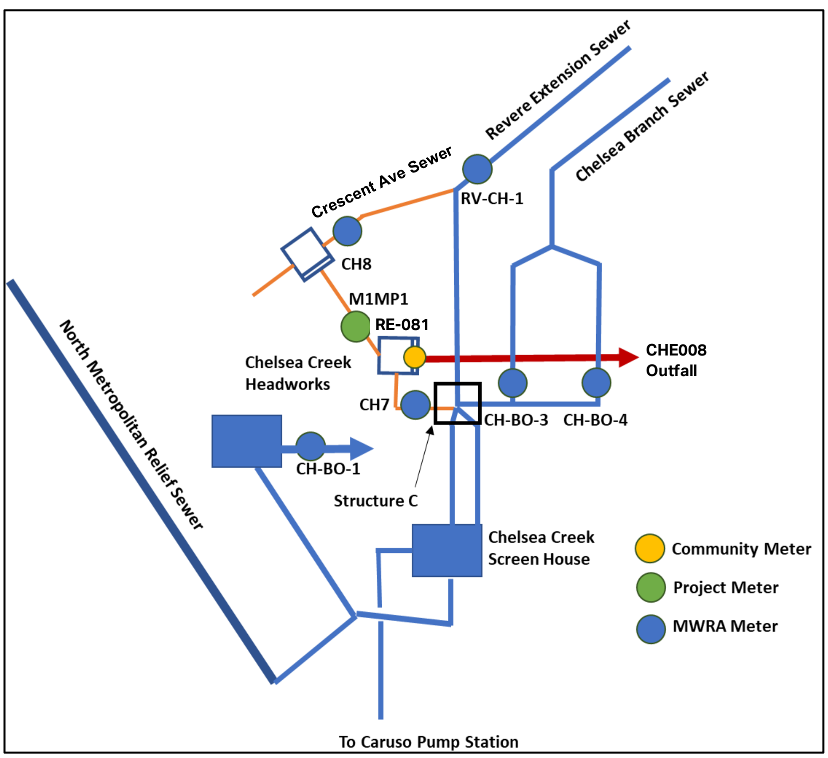


Figure 4-3. System Schematic for CHE008

In Semiannual Report No. 5, it was reported that outfall CHE008 was predicted to activate 11 times in the Typical Year under Mid-2020 conditions, with an annual overflow volume of 3.81 MG. This level of performance exceeded the LTCP goals for outfall CHE008 of zero activations and volume in the Typical

Year. Based on this difference, MWRA initiated an investigation as to why the actual performance differed from the expected performance at this location. The results of an initial desktop analysis were reported in Semiannual Report No. 5. Also as reported in Semiannual Report No. 5, on October 1, 2020 MWRA performed field work to cut away a portion of a protrusion of the 30-inch dry weather flow connection pipe into the CHE008 regulator structure, with the expected benefit of reducing head loss and increasing flow to the interceptor. MWRA and the City of Chelsea continued to collect flow meter data to assess the benefit of the removal of the protrusion and to support recalibration of the model in the vicinity of outfall CHE008.

Semiannual Report No. 6 included a detailed description of the process of updating the calibration to reflect updated information on the configuration of regulator RE-081, and the evaluation of alternatives to increase the capacity of the dry weather flow (DWF)connection.

The following configuration was recommended:

- Replace the existing 30-inch connection between regulator RE-081 and Structure C with a 48-inch connection along the same route;
- Provide an orifice plate at the downstream end of the 48-inch connection, with a 36-inch diameter orifice set with the invert of the orifice at the downstream invert of the 48-inch connection;
- Eliminate the existing interior weir within Structure C; and
- Lower the weir in MH22 on the Chelsea Branch Sewer from elevation 106 to elevation 105.

Figure 4-4 and Figure 4-5 provide conceptual sketches for the elements of the recommended project as described above.

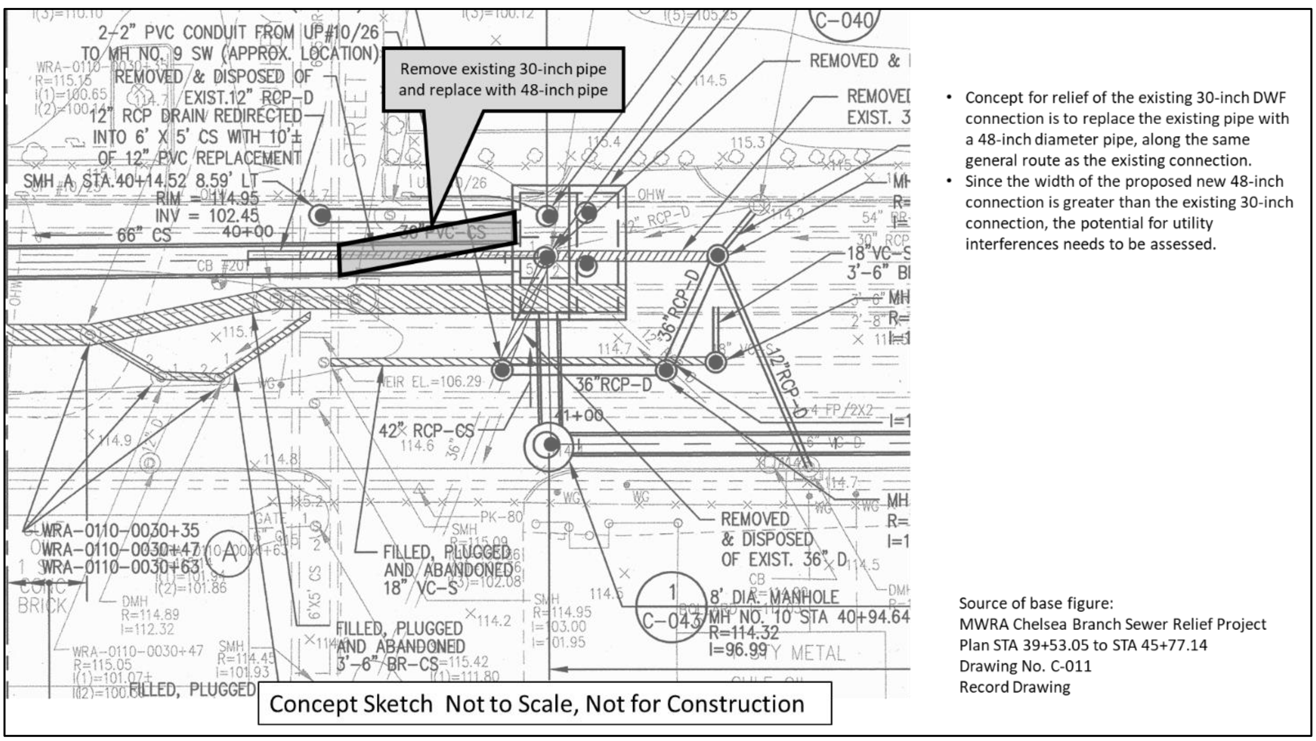


Figure 4-4. Concept Sketch Plan View of CHE008 Proposed DWF Connection

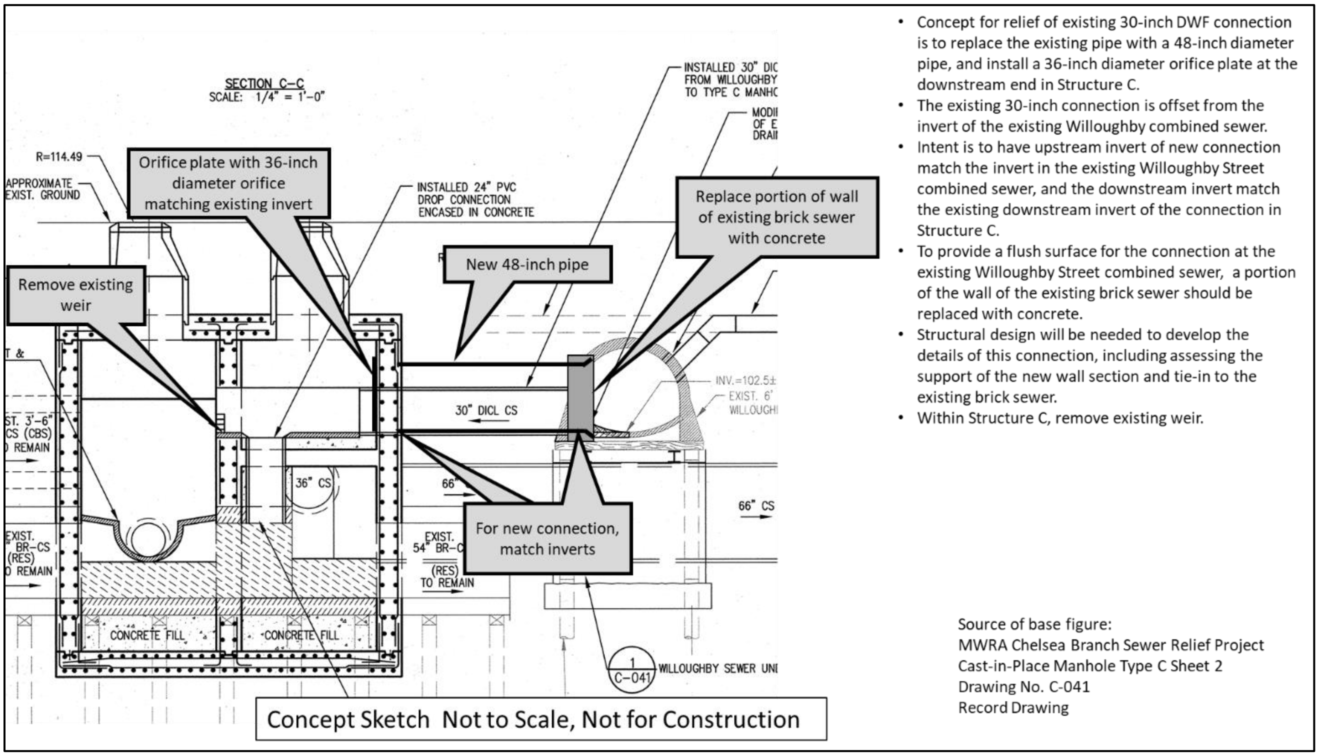


Figure 4-5. Sketch Section View of CHE008 Proposed DWF Connection

Modeling showed that the 48-inch dry weather flow connection with 36-inch diameter orifice would provide the highest level of CSO control in the Typical Year without creating adverse HGL impacts during the 5-year storm. This project would bring outfall CHE008 to within one 0.07 MG activation of meeting its LTCP goals. The difference between this projected performance and the LTCP goal is considered to be immaterial, making this location consistent with LTCP goals once this project is implemented.

As of December 2021, MWRA had nearly completed the final design of this project. The project schedule anticipates commencement of construction in spring of 2022, and completion of construction in the summer of 2022.

4.1.3 Somerville-Marginal CSO Facility Discharges (Upper Mystic River, Mystic/Chelsea Confluence)

Outfall MWR205 is located in tidal waters of the Mystic River immediately downstream of the Amelia Earhart Dam, and discharges treated CSO from the Somerville-Marginal Facility, along with separate stormwater that enters the Somerville-Marginal Conduit downstream of the CSO facility. Outfall SOM007A/MWR205A is a relief outfall off of the Somerville Marginal Conduit that discharges to the freshwater reach of the Mystic River upstream of the Amelia Earhart Dam when the Somerville-Marginal CSO Facility activates during high tide (see Figure 4-6).

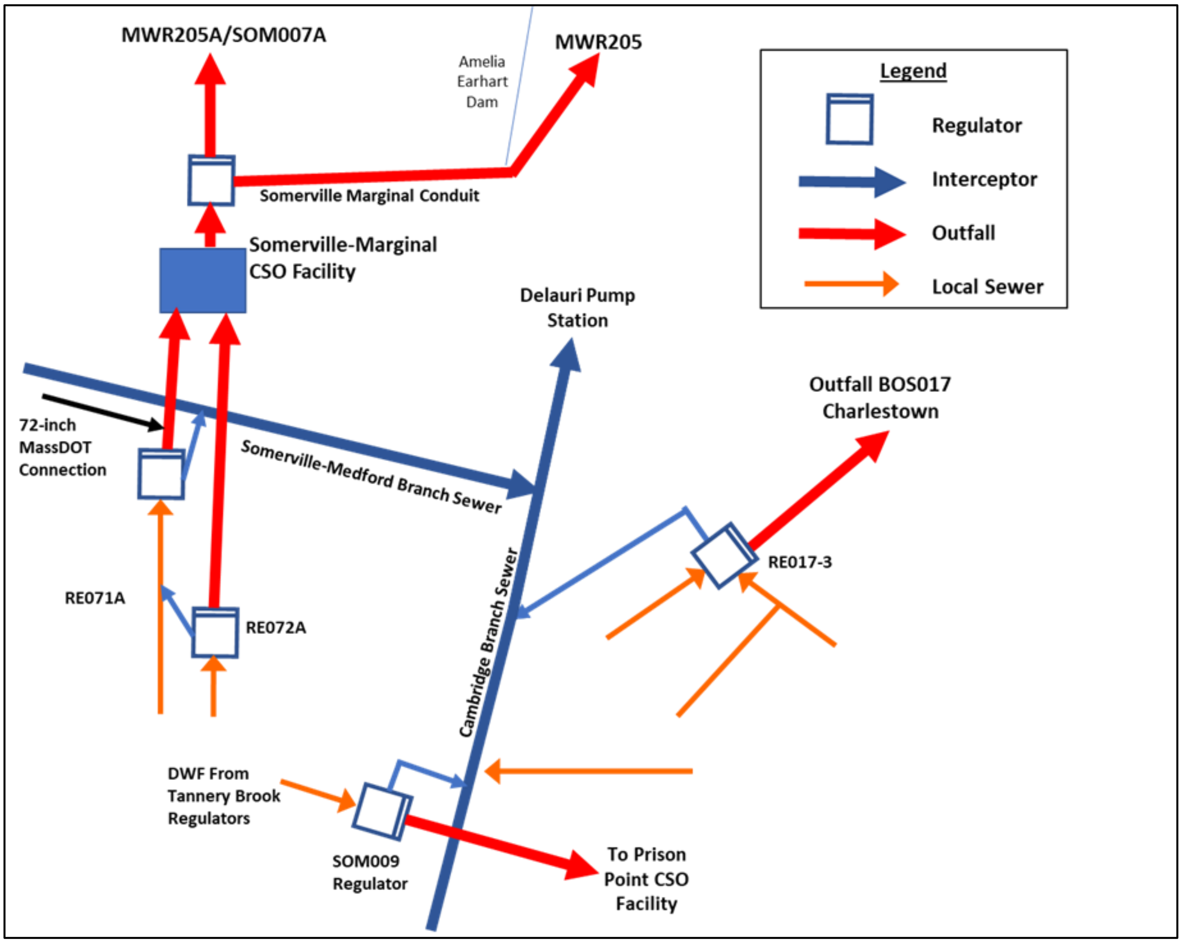


Figure 4-6. Schematic of Somerville-Marginal CSO Facility, MWR205A/SOM007A and MWR205

As indicated in Chapter 2, under Q4-2021 conditions, the Somerville-Marginal CSO Facility activation frequency was consistent with the LTCP level of control, but the treated discharge volume (99.7 MG) exceeded the LTCP target (60.6 MG). Meter data collected in 2018 and 2019 indicated that stormwater flows entering the combined sewer system upstream of the facility were higher than those simulated with prior models. In accordance with a condition in the Alewife Brook/Upper Mystic River CSO Variance, MWRA commenced evaluations of specific projects that could potentially reduce overflows to the Somerville-Marginal CSO Facility and discharges from outfalls MWR205 and MWR205A/SOM007A. The details of the evaluation of alternatives and the results of the alternative selection are presented in a Technical Memorandum dated December 2021: *The Charles River and Alewife Brook/Upper Mystic River CSO Variances Task 8.4: Preliminary Design Report MWR205/205A Somerville Marginal CSO Reduction Project.* The results of the investigation led to two options ultimately selecting what is referred to as Option 2 which includes construction of a gated connection between an existing 42-inch storm drain that ties into the 85 x 90-inch influent combined sewer to the Somerville Marginal Facility and a manhole on the 42-inch Somerville-Medford Branch Sewer (Figure 4-7).

Table 4-4 presents the CSO discharge activation frequency and volume for the Typical Year for the baseline condition (Q1-2021 Conditions), Option 2, and the LTCP goals. As indicated in Table 4-4, Option 2 would result in a significant reduction in activation frequency and volume at the Somerville-Marginal CSO Facility. Discharge volume at the Prison Point CSO Facility would increase, but the net discharge from the sewer system would decrease. Option 2 would reduce the activation frequency at Somerville Marginal by about 40 percent, well below the LTCP target, and bring the activation volume to within 3 to 5 percent of the LTCP target. The difference in treated volume between the predicted performance of these options and the LTCP goals for outfalls MWR205 and MWR205A/SOM007A is considered to be immaterial, and the options are considered to meet the LTCP goals.

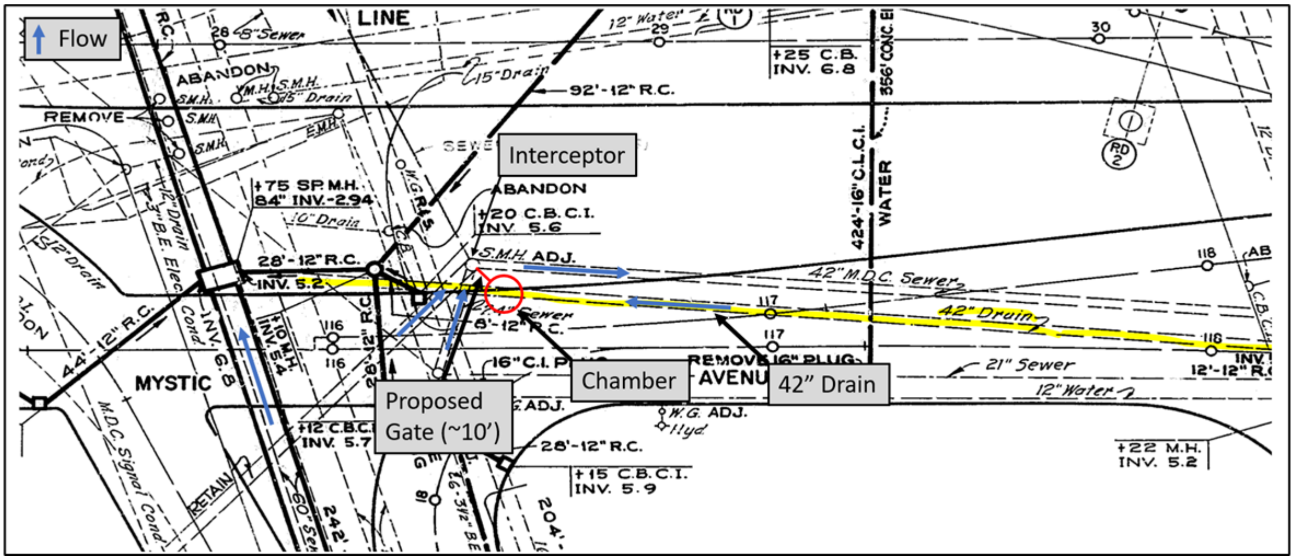


Figure 4-7. Proposed Option 2 Configuration for Somerville Marginal

Table 4-4. Preliminary Results for Alternatives at Somerville Marginal CSO Facility

Outfall	Regulator ID	Baseline(1) (Q1-2021 Conditions)		Option 2: 36-inch gate(1)		Typical-Year Rainfall w/ Long Term CSO Control Plan	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
SOM007A/MWR205A		5	4.50	3	3.59	3	3.48
MWR205 (Somerville Marginal Facility)		30	100.5	17	63.34	39	60.58
BOS017(2)	RE017-2	6	0.34	4	0.45	1	0.02
MWR203 (Prison Point)		17	254	17	263	17	243
Total of Above Outfalls			359		330		307
Net Change From Baseline					-29		

(1) Grey shading indicates model prediction is greater than LTCP value.

(2) MWRA has developed a concept design that is predicted to meet the LTCP goal at this location. Additional detail is provided below.

MWRA is moving forward with Option 2 and will prepare a detailed design for construction of the new connection and control gate.

4.2 Outfalls for which Investigations Continue

This section is organized into subsections for outfalls with concept designs predicted to attain LTCP goals and outfalls presenting significant challenges which require further investigation.

4.2.1 Outfalls with Concept Designs Predicted to Attain LTCP Goals

4.2.1.1 Outfall BOS017 (Mystic/Chelsea Confluence)

A schematic of the pipe network upstream of outfall BOS017 is presented in Figure 4-8. As indicated in Chapter 2, outfall BOS017 was not predicted to meet the LTCP goal of 1 activation and 0.02 MG of CSO discharge in the Typical Year under Q4-2021 conditions. As described in Semiannual Report No. 6, MWRA updated and recalibrated its model to incorporate the results of recent BWSC inspections in the Charlestown/BOS017 area. MWRA also conducted system inspections to attempt to locate sources of tidal inflow. Through the inspections and a review of meter data, MWRA identified a leaky tide gate that was allowing tidal inflow to enter regulator RE017-3. In addition, a separate stormwater area was found to be connected to the combined sewer at Rutherford Ave. near Middlesex St. upstream of outfall BOS017. BWSC replaced the leaky tide gate and relocated the stormwater area to an adjacent separate storm drain. These changes were incorporated into the Q4-2021 conditions model.

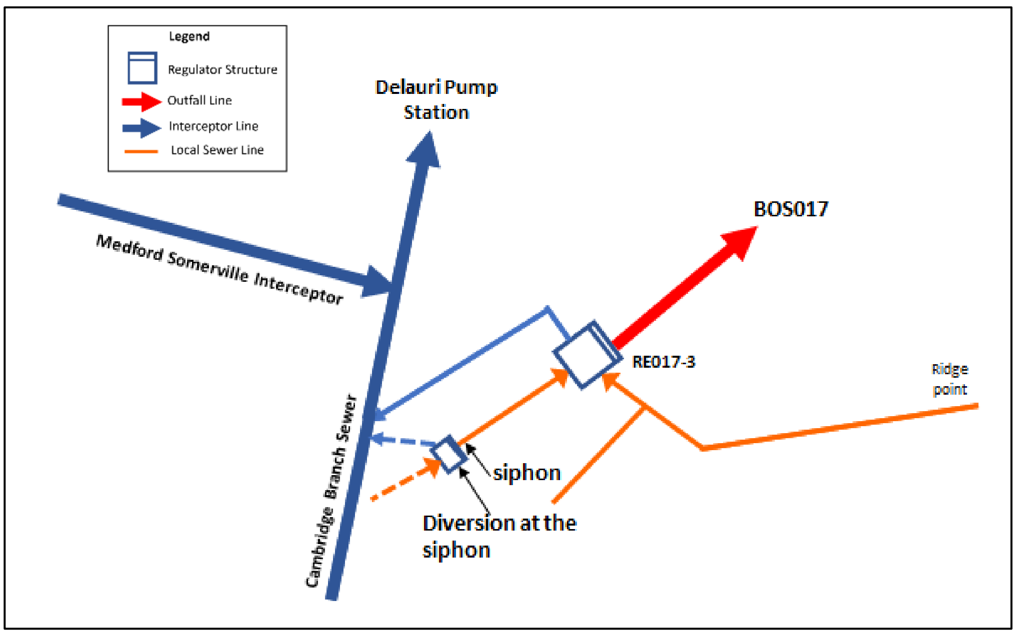


Figure 4-8. Schematic of BOS017 System

Subsequent evaluations focused on optimizing the Sullivan Square siphon chamber upstream of regulator RE017-3. Hydraulic modeling indicated that closing the siphon would achieve the LTCP goals at outfall BOS017 for the Typical Year. However, initial modeling indicated this configuration would cause adverse upstream HGL impacts from closing the siphon in the 5-year storm. The model was used to evaluate the elevation of the weirs upstream of the siphon barrels needed to eliminate overflows in the Typical Year but not adversely affect the HGLs in the surrounding areas in the 5-year storm. This configuration would allow water to flow over the weirs without creating a restriction in the openings to the siphon barrels, thus providing a reduction in headloss during larger storm events compared to the current configuration. The proposed modifications to the siphon structure are presented in Figure 4-9 and Figure 4-10 on the following page.

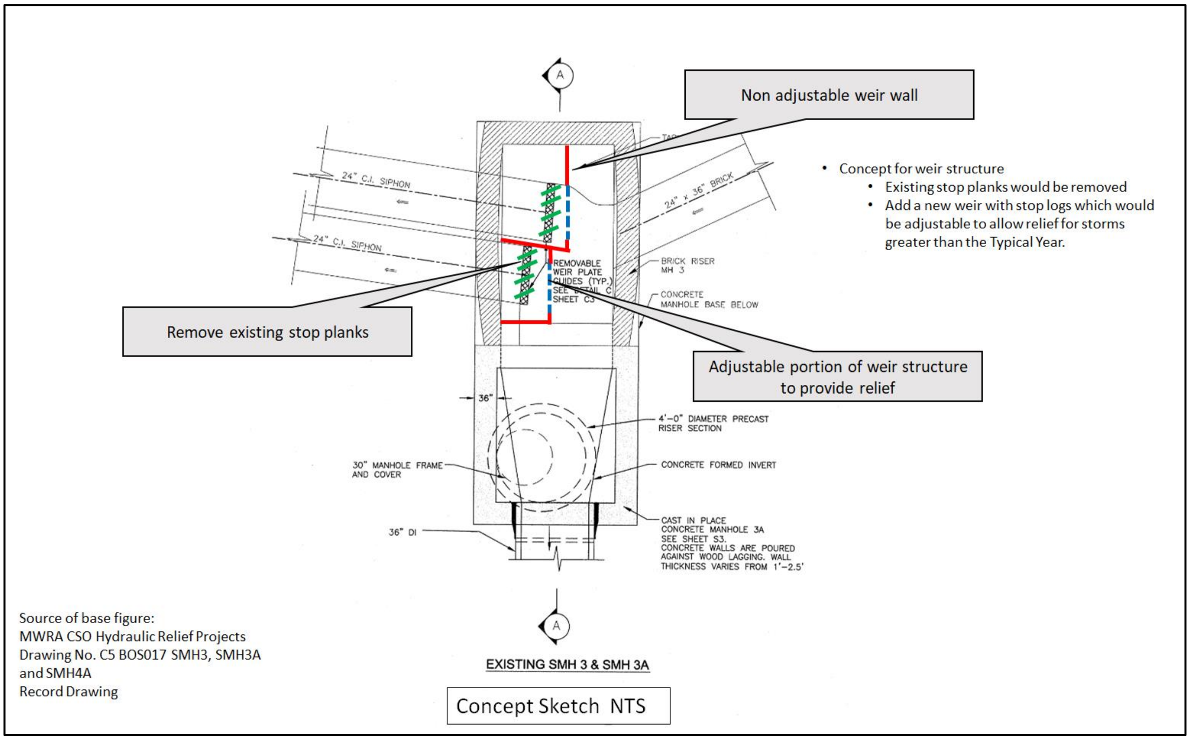


Figure 4-9. BOS017 – Concept Sketch of Sullivan Square Siphon Structure Modifications – Plan View

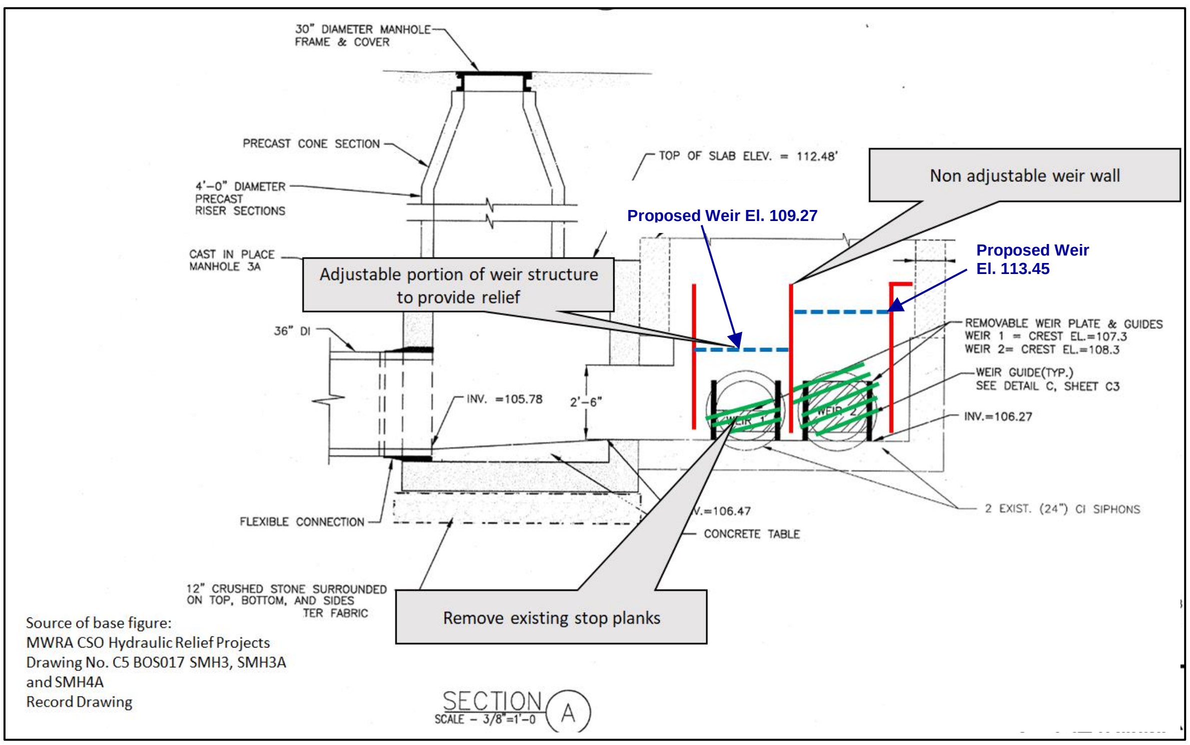


Figure 4-10. BOS017 – Concept Sketch of Sullivan Square Siphon Structure Modifications – Section View

4.2.1.2 Outfall BOS070 (Fort Point Channel)

Figure 4-11 presents a schematic of the South Boston interceptor system which includes the BOS070 regulators and outfall. As presented in Semiannual Report No. 6, BWSC completed a program to remove sediment in South Boston sewers and removed a temporary weir. These improvements, however, were not sufficient to meet the LTCP goals for the BOS070/DBC regulators. MWRA then evaluated the CSO benefits of BWSC's planned multi-phased "South Boston Sewer Separation Project" that involves the removal of stormwater from combined sewers serving approximately 400 acres of area tributary to the BOS070 system. The South Boston Sewer Separation Project (Figure 4-12) includes five construction contracts that BWSC plans to phase over a 20-year period. BWSC completed the design and awarded the construction contract for Contract 1 in May 2021. Contract 1 is scheduled to be completed in May 2023. The design of Contract 2 is progressing and BWSC expects construction to begin in 2022 and be completed in 2024. BWSC had not commenced design of the remaining three contracts as of fall 2021.

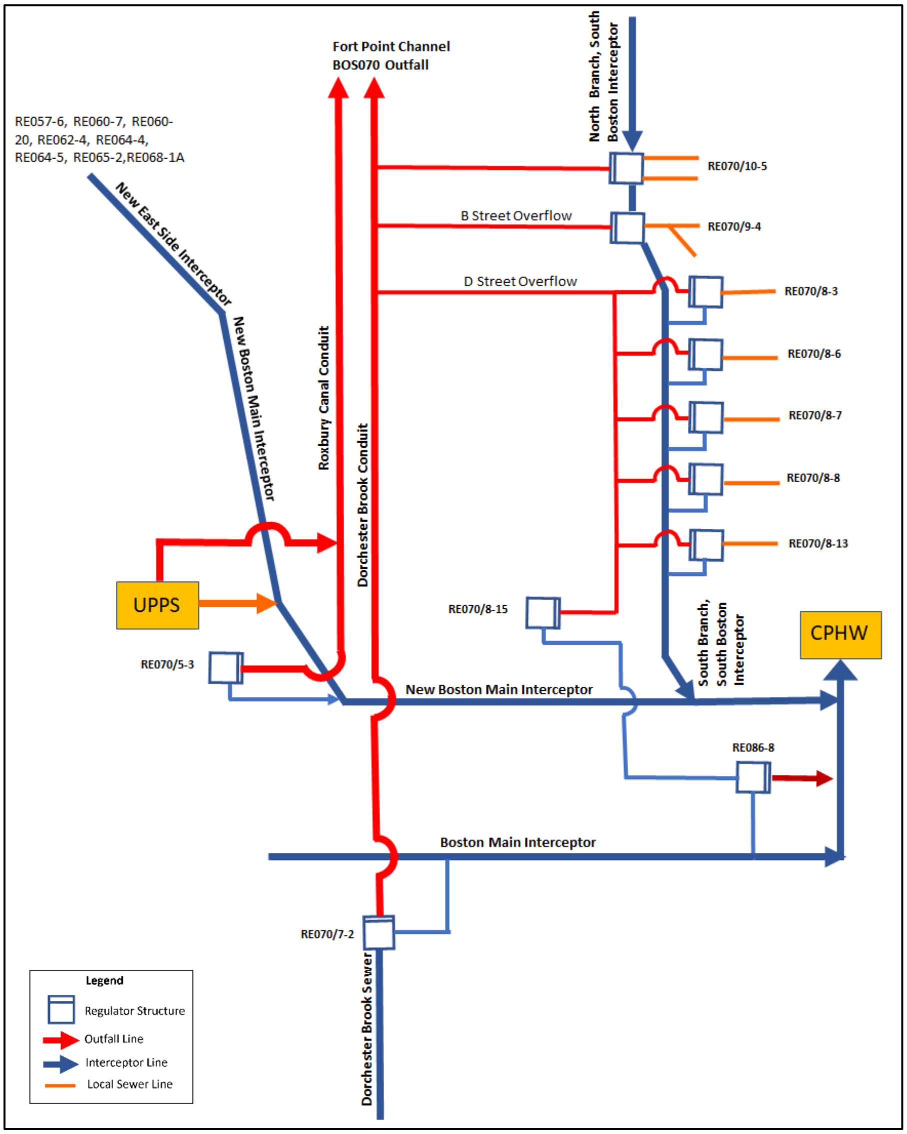


Figure 4-11. Schematic of the South Boston Interceptor System

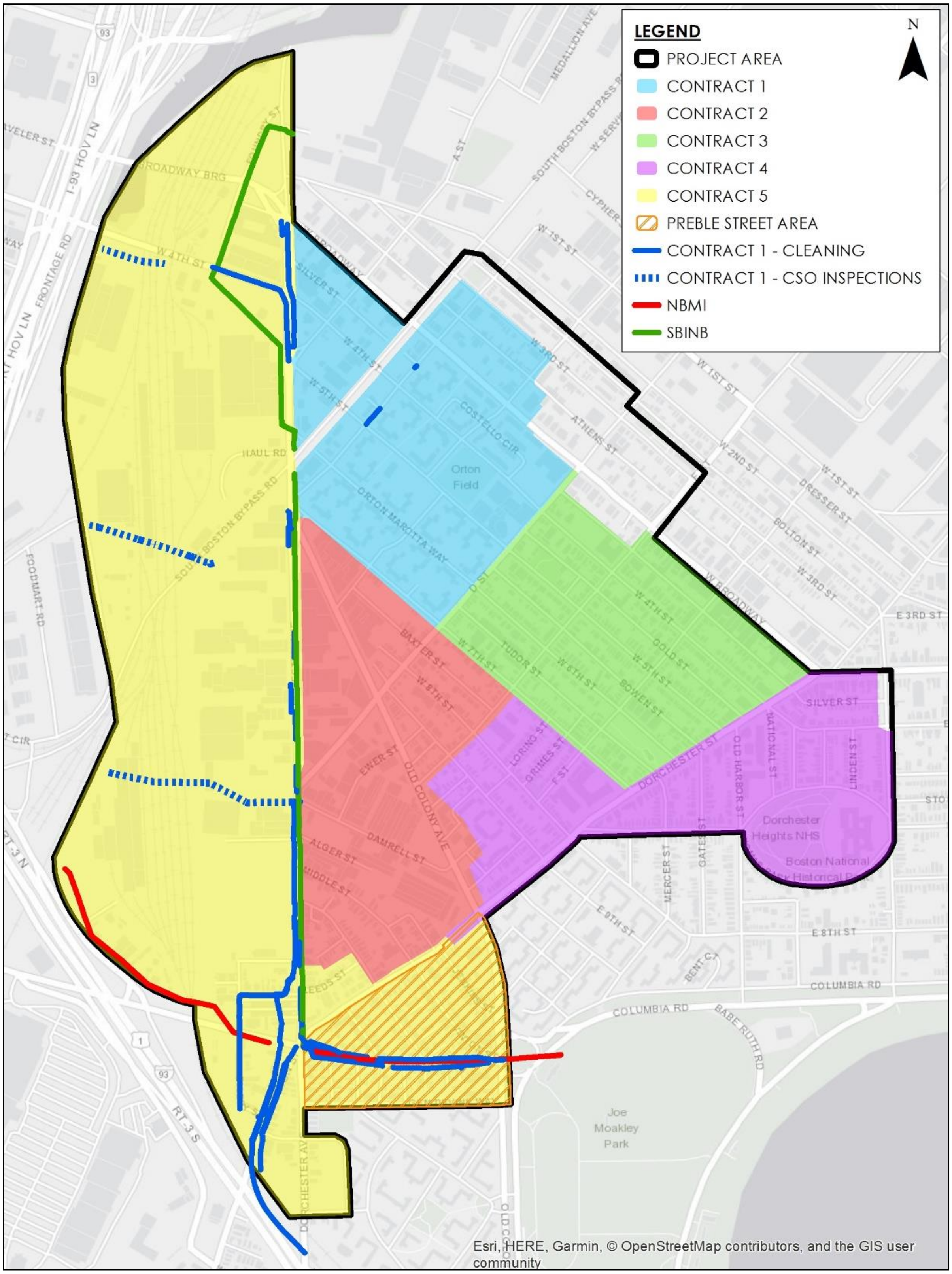


Figure 4-12. South Boston Sewer Separation Contracts

MWRA evaluated the potential CSO control benefits of Contracts 1 and 2 using its hydraulic model. The Typical Year model results are presented in Table 4-5 for each of the BOS070/DBC regulators, and the BOS070/DBC regulator volumes are totaled for comparison with the LTCP activation and volume goals. As shown in Table 4-5, the LTCP activation and volume goals at all of the BOS070/DBC regulators are predicted to be attained with sewer separation Contracts 1 and 2 except for the volume at regulator RE070/7-2.

Table 4-5. Typical Year Model Simulations of South Boston Sewer Separation Contracts 1 & 2

Outfall	Regulator	Interim Q3Q4-2020 System Conditions(1)		Interim Q3Q4-2020 System Conditions w/Contract 1 (Completion 2023)(1)		Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024)(1)		Long Term CSO Control Plan	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Fort Point Channel									
BOS070/ DBC	RE070/8-3	7	1.31	6	0.79	1	0.02	3	2.19
	RE070/8-6	0	0.00	0	0.00	0	0.00		
	RE070/8-7	2	0.05	2	0.05	0	0.00		
	RE070/8-8	0	0.00	0	0.00	0	0.00		
	RE070/8-13	0	0.00	0	0.00	0	0.00		
	RE070/8-15	0	0.00	0	0.00	0	0.00		
	RE070/9-4	6	1.93	3	0.40	1	0.05		
	RE070/10-5	1	0.04	0	0.00	0	0.00		
	RE070/7-2	2	2.77	2	2.66	2	2.41		
SUM BOS070/DBC		**7 Max**	**6.10**	**6 Max**	**3.90**	**2 Max**	**2.48**	**3 Max**	**2.19**

(1) Grey shading indicates model prediction is greater than LTCP value.

As indicated in Table 4-5, regulator RE070/7-2 met the LTCP goal for activation frequency as of Q4-2020 conditions, however, by itself it would still exceed the total discharge volume goal for BOS070/DBC even with completion of sewer separation Contracts 1 and 2. MWRA evaluated a range of alternatives to further reduce the volume at regulator RE070/7-2. In coordination with BWSC, MWRA identified that providing relief of approximately 540 linear feet of a 60-inch diameter section of the Boston Main Interceptor (BMI) downstream of regulator RE070/7-2 would reduce the CSO discharge volume at regulator RE070/7-2 to 2.06 MG, which would bring the total BOS070/DBC CSO discharge volume within the LTCP goals. The proposed relief pipe would extend approximately 540 linear feet along Massachusetts Avenue between the regulator RE070/7-2 connection to the BMI and Enterprise Street as shown schematically in Figure 4-13. A comparison of the Typical Year model results for the Interim Q3Q4-2020 model conditions with sewer separation contracts 1 and 2 with and without the proposed relief of that section of the BMI is presented in Table 4-6.

MWRA and BWSC intend to further evaluate the constructability and benefit of this alternative, given the anticipated significant cost, community impacts and marginal reduction CSO performance before advancing the alternative into design.

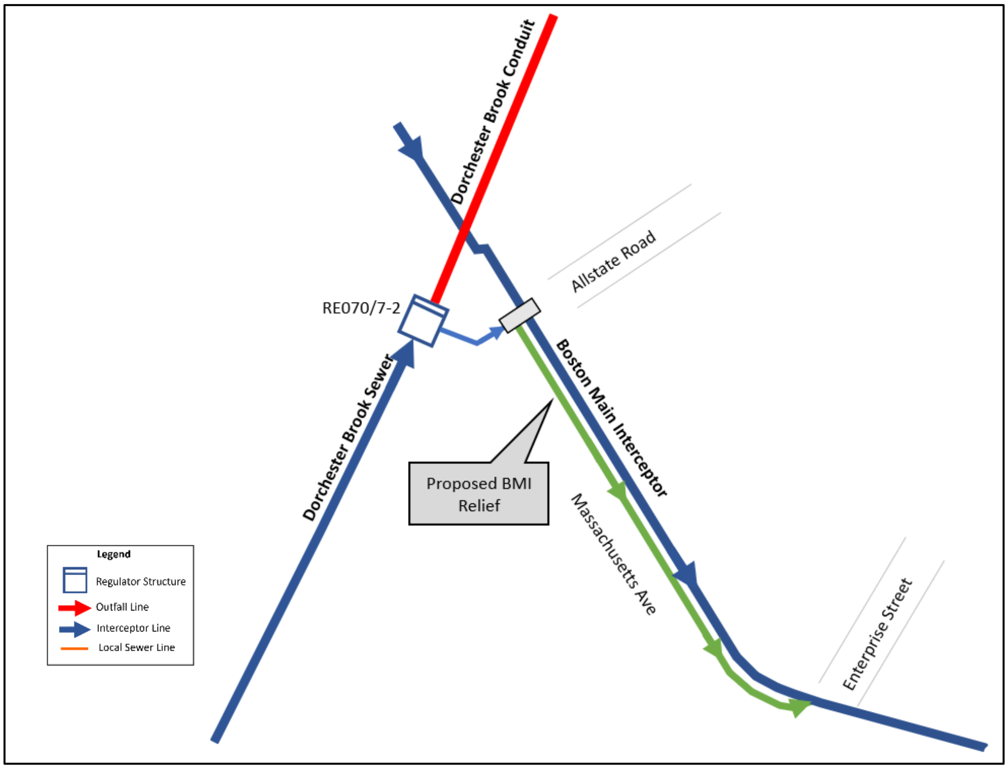


Figure 4-13. Schematic of Proposed BMI Relief Pipe along Massachusetts Avenue

Table 4-6. Comparison of Typical Year Model Simulations of South Boston Sewer Separation Contracts 1 & 2 with and without Relief of the BMI

Outfall	Regulator	Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024)(1)		Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024) and Relief of BMI(1)		Long Term CSO Control Plan	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
BOS070/ DBC	RE070/8-3	1	0.02	2	0.05	3	2.19
	RE070/8-6	0	0.00	0	0.00		
	RE070/8-7	0	0.00	0	0.00		
	RE070/8-8	0	0.00	0	0.00		
	RE070/8-13	0	0.00	0	0.00		
	RE070/8-15	0	0.00	0	0.00		
	RE070/9-4	1	0.05	1	0.06		
	RE070/10-5	0	0.00	0	0.00		
	RE070/7-2	2	2.41	2	2.06		
SUM BOS070/DBC		**2 Max**	**2.48**	**2 Max**	**2.17**	**3 Max**	**2.19**

(1) Grey shading indicates model prediction is greater than LTCP value.

4.2.1.3 Outfalls BOS062 and BOS065 (Fort Point Channel)

Figure 4-14 presents a schematic of the upstream end of the New East Side Interceptor (NESI) system. Semiannual Report No. 6 presented a description of minor adjustments made to the physical configuration of the regulators tributary to outfalls BOS060, BOS062, BOS064, and BOS065. MWRA used the updated model to identify and evaluate system modifications that could further lower CSO discharges toward attainment of the LTCP activation and volume goals at outfalls BOS062 and BOS065.

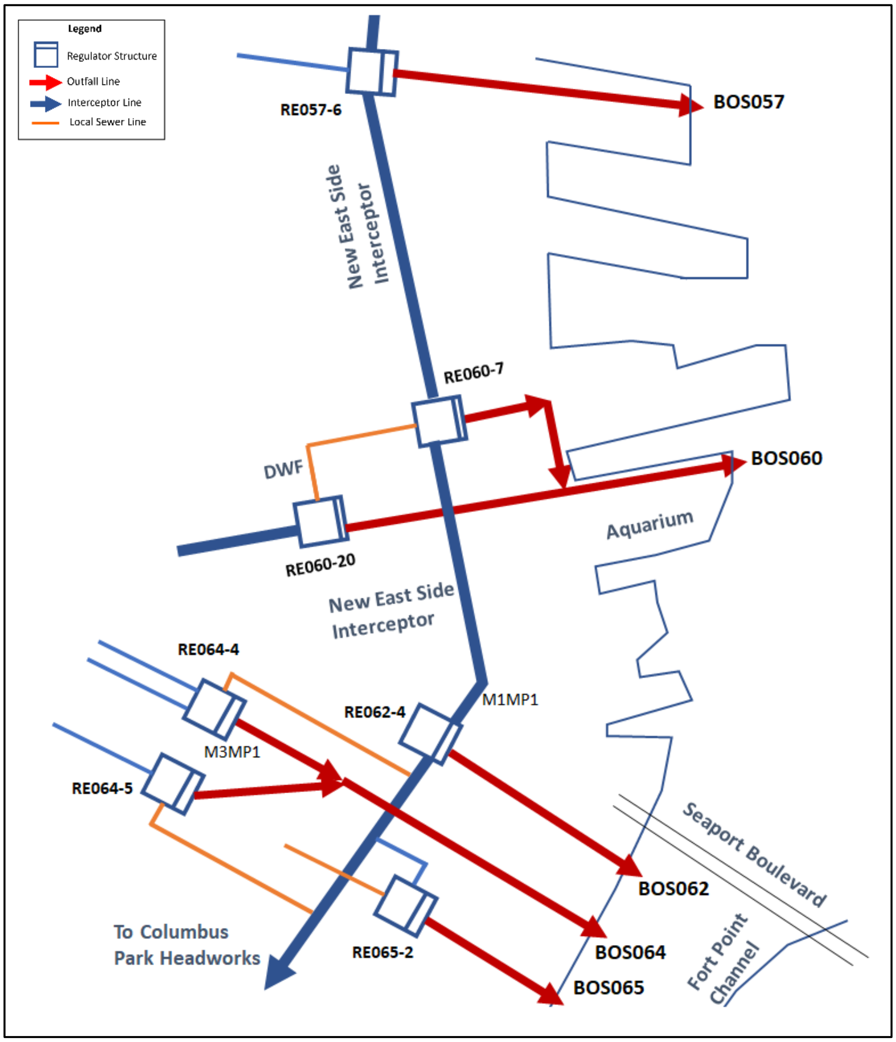


Figure 4-14. Schematic of New East Side Interceptor System

These system modifications included raising the overflow weirs and upgrading interceptor connection capacities at the BOS62 and BOS65 regulators, and the results of these evaluations were presented in Semiannual Report No. 6.

Following that report MWRA updated the model to include Contracts 1 and 2 of the South Boston Sewer Separation project as described above and continued evaluating alternatives. Table 4-7 presents the Interim Q3Q4-2020 results as presented in Semiannual Report No. 6, Interim Q3Q4-2020 Conditions with South Boston sewer separation Contracts 1 and 2, and the LTCP goals for outfalls BOS062 to BOS068. As indicated in Table 4-7, sewer separation Contracts 1 and 2 were predicted to provide a nominal benefit on Typical Year CSO volume at Fort Point Channel regulators along the NESI due to a reduction in the downstream HGL.

Table 4-7 Typical Year Model Simulations of Proposed Regulator Modifications at BOS062 and BOS065

Outfall	Regulator	Current Weir Elevation	Interim Q3Q4-2020(1)		Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024)		Long-Term Control Plan	
			Activations	Volume (MG)	Activations	Volume (MG)	Activations	Volume (MG)
BOS062	RE062-4	106.69	5	1.25	5	1.23	1	0.01
BOS065	RE065-2	102.83	1	0.60	1	0.40	1	0.06
BOS064	RE064-4	107.73	0	0.00	0	0.00	0	0.00
	RE064-5	104.32	1	0.01	0	0.00		
BOS068	RE068-1A	105.97	0	0.00	0	0.00	0	0.00

(1) Grey shading indicates model prediction is greater than LTCP value.

With the updated model, MWRA, in coordination with BWSC, continued to analyze the alternatives to bring regulators RE062-4 and RE065-2 into attainment with LTCP goals. The evaluations identified an alternative referred to as the "BOS062/BOS065 Alternative" with the following components:

- Constructing a second interceptor connection at regulator RE062-4
- Raising the weir at regulator RE064-5 by 3 inches from El. 104.32 to El.104.57
- Raising the weir at regulator RE065-2 by 2.8 feet from El. 102.83 to El.105.60

Table 4-8 presents a comparison of the Typical Year model results for the Interim Q3Q4-2020 conditions, Interim Q3Q4-2020 conditions with sewer separation contracts 1 and 2, Interim Q3Q4-2020 conditions with sewer separation contracts 1 and 2 plus the "BOS062/BOS065 Alternative", and the LTCP goals.

Table 4-8 Typical Year Model Simulations of Regulator Modifications at BOS062 and BOS065

Outfall	Regulator	Current Weir Elevation	Interim Q3Q4-2020		Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024)(1)		Interim Q3Q4-2020 System Conditions w/Contracts 1 & 2 (Completion 2024) BOS062/BOS065 Alternative		Long-Term Control Plan	
			Activations	Volume (MG)	Activations	Volume (MG)	Activations	Volume (MG)	Activations	Volume (MG)
BOS062	RE062-4	106.69	5	1.25	5	1.23	0	0.00	1	0.01
BOS065	RE065-2	102.83	1	0.60	1	0.40	1	0.03	1	0.06
BOS064	RE064-4	107.73	0	0.00	0	0.00	0	0.00	0	0.00
	RE064-5	104.32	1	0.01	0	0.00	1	0.03		
BOS068	RE068-1A	105.97	0	0.00	0	0.00	0	0.00	0	0.00

(1) Grey shading indicates model prediction is greater than LTCP value.

The model results show that adding a second interceptor connection at RE062-4 would bring CSO discharges at BOS062 into attainment with the LTCP goals and result in no activation in the Typical Year. The increased flow to the NESI required that the weir at RE065-2 be raised as described above. The model results showed, however, that allowing more flow to enter the NESI at RE062-4 would not affect overflows at other hydraulically related regulators except at regulator RE064-5, where one very small-volume activation is predicted to reappear. While this one activation would theoretically put outfall BOS064 slightly over the LTCP goal, the one predicted small-volume activation is still considered to be immaterial.

MWRA and BWSC are evaluating this group of alternatives for constructability and cost.

4.2.2 Outfalls Presenting Significant Challenges

4.2.2.1 SOM001A (Alewife Brook)

A schematic of the Alewife Brook system is shown in Figure 4-15. As indicated in Chapter 2, outfalls CAM001, CAM002, MWR003, CAM401A and CAM401B met the LTCP goals for activation frequency and discharge volume under Q4-2021 conditions, while outfall SOM001A was the only outfall not meeting the LTCP goals. Investigations into alternatives that could reduce the activation frequency and volume at outfall SOM001A have included:

- raising the weir in the SOM001A regulator;
- increasing the capacity of flow conveyance between the SOM001A regulator and the interceptor system;
- diverting upstream flows away from the Tannery Brook Drain, towards regulator SOM009 and the Prison Point system; and
- utilizing in-system storage within the Tannery Brook Drain to attenuate peak flows to the regulator.

After evaluating many different variations of the alternatives listed above, an alternative was identified which was predicted to meet the LTCP goals in the Typical Year. This alternative included:

- raising the weir in the SOM001A regulator 3 inches;
- increasing the size of the orifice connection to the Alewife Brook Conduit (ABC) from 32x32-inch to 56x32-inch; and
- relining the ABC and Alewife Brook Branch Sewer (ABBS) from approximately the location of SOM001A to the Alewife Brook Pump Station to slightly increase the conveyance capacity.

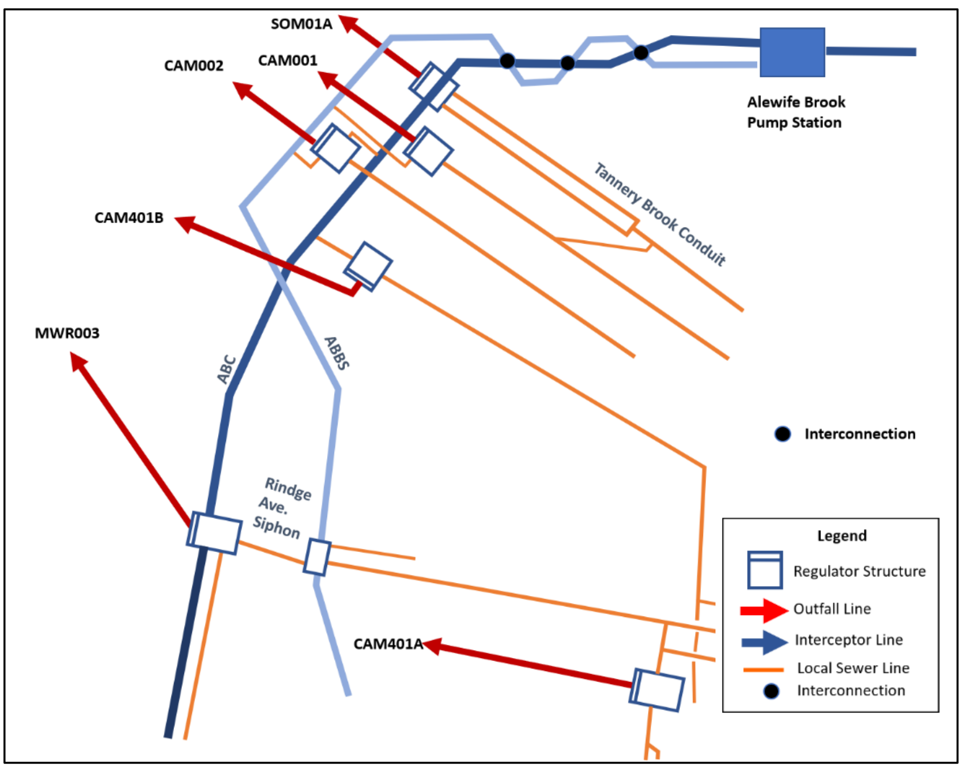


Figure 4-15. Schematic of Alewife Sub-System

The model predicted that in the Typical Year this alternative would reduce the CSO activation frequency and CSO discharge volume at outfall SOM001A to 3 activations and 1.23 MG, meeting the LTCP goal of 3 activations and 1.67 MG. However, the volume at outfall MWR003 was predicted to increase from 0.61

MG to 1.09 MG (activation frequency stayed at 3). The LTCP goal for MWR003 is 5 activations and 0.98 MG. The discharge volume also increased at the other Alewife regulators but not above the LTCP goals for those regulators. This alternative did not cause adverse impacts to the HGL during the Typical Year. However, during a 5-year storm the alternative was predicted to create adverse impacts at a critical location just downstream of the SOM001A regulator. Several additional model runs were conducted with modifications to operations at MWR003 as well as making small reductions to the dry weather flow connection to attempt to mitigate the HGL impacts, but the adverse impacts remained.

MWRA is currently working with the City of Somerville to see if flood mitigation efforts that the city is currently investigating will reduce and/or attenuate the stormwater tributary to SOM001A and mitigate the adverse impacts noted for the alternative described above in the 5-year storm. The City of Somerville is also working to assess if these potential flood mitigation efforts may have an overall benefit on CSO control. MWRA and the City of Somerville continue to work together to identify and investigate alternatives as well as the appropriate combination of flood mitigation and system modifications for CSO control that will meet the dual objectives, considering overall cost, constructability, and overall receiving water benefits.

4.2.2.2 Cottage Farm CSO Facility Discharges (Charles River)

Figure 4-16 below presents a schematic of the interceptors tributary to the Cottage Farm facility. Under Q4-2021 system conditions, the Cottage Farm CSO facility met the LTCP goal for activation frequency with two activations predicted in the Typical Year. However, the CSO discharge volume was predicted to be 9.06 MG and the LTCP goal is 6.30 MG. The Q4-2021 system conditions include the benefit realized from the partial sewer separation effort in the Cambridgeport area which was completed by the City of Cambridge in August 2020.

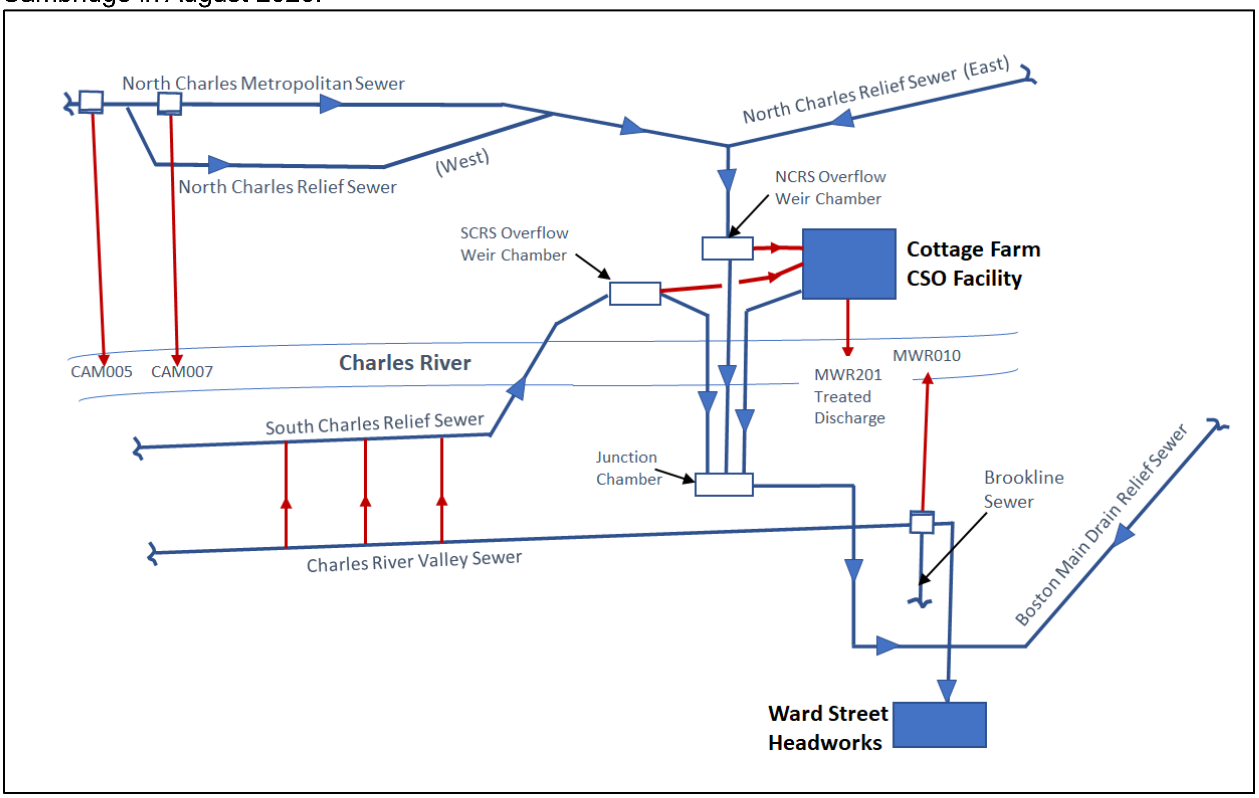


Figure 4-16. Cottage Farm CSO Facility Area Schematic

A number of alternatives were evaluated to decrease the volume discharged from the facility during the Typical Year including:

- facility operation changes;

- groundwater infiltration removal from catchments tributary to Cottage Farm; and
- sewer separation upstream of CAM011.

Adjustments to facility activation and deactivation procedures or other operational changes at Cottage Farm were not found to provide additional benefit in reducing the CSO discharge volume. A combination of the removal of 25% of the seasonal infiltration caused by high groundwater conditions and sewer separation of approximately 300 acres upstream of CAM011 was predicted to reduce the CSO discharge volume to the level needed to meet the LTCP goal. However, the groundwater volume to be removed and the areas to be separated would be significant, and the feasibility of implementing projects to achieve the needed groundwater removal and sewer separation has not yet been established. This alternative is still being evaluated based on constructability, cost, and benefits considering the limited water quality improvements to the Charles River that would be achieved by the incremental reduction in treated discharge needed to achieve LTCP goals. In addition, the water quality impacts of the additional stormwater loadings due to sewer separation have not yet been evaluated. The MWRA and its member CSO communities continue to work to identify and investigate other alternatives to meet the LTCP goal.

4.2.2.3 Outfalls MWR018, MWR019, and MWR020 (Charles River)

Outfalls MWR018, MWR019 and MWR020 are located along the Boston Marginal Conduit (BMC) upstream of the Prison Point CSO Facility (Figure 4-17). These outfalls overflow to the Charles River when the HGL in the BMC exceeds the controlling weir elevations at each structure.

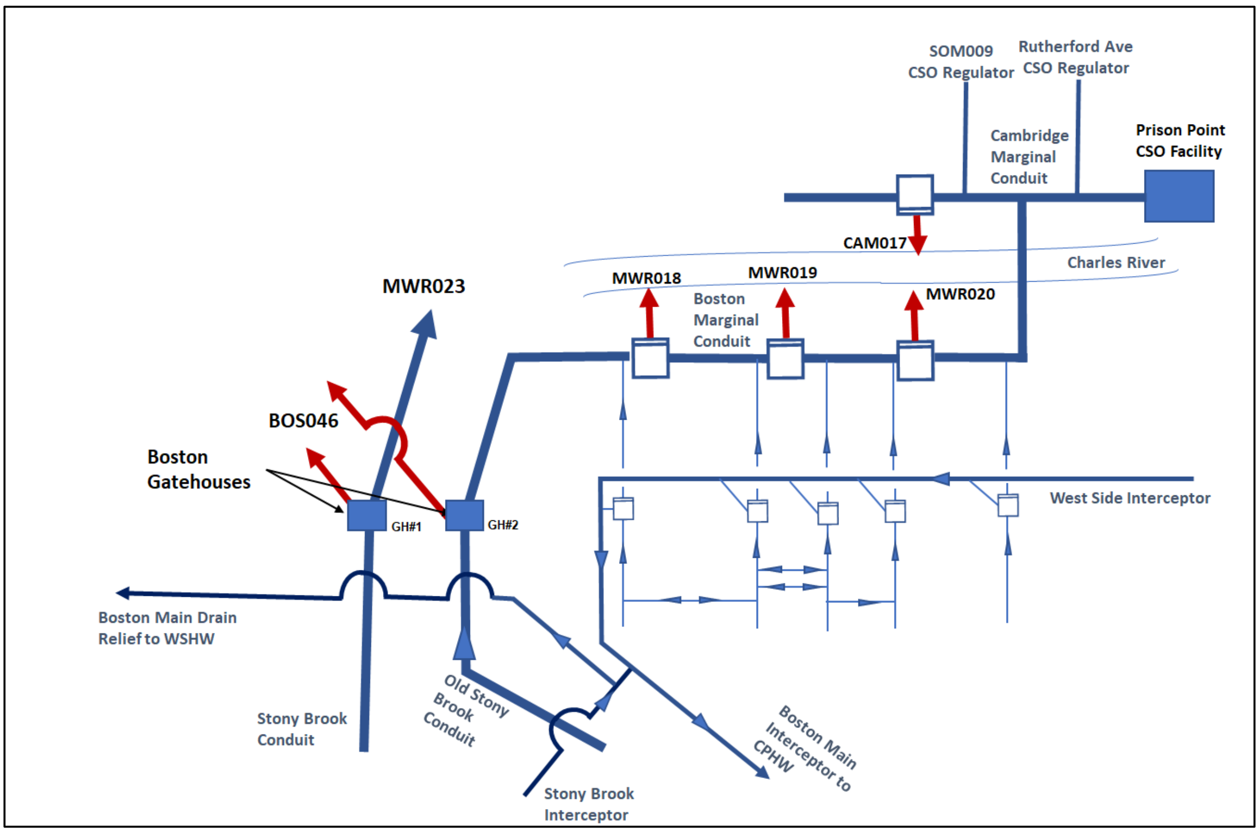


Figure 4-17. MWR018, MWR019, MWR020 System Schematic

The LTCP goal for these outfalls is no discharges in the Typical Year. Table 4-9 presents the Typical Year activation frequency and volumes for all the outfalls to the Lower Charles River as well as for Prison Point for Q4-2021 system conditions compared to the LTCP goals. As indicated in Table 4-9, the LTCP goals for activation frequency and volume were projected to be exceeded for the Q4-2021 conditions at outfalls MWR018, MWR019 and MWR020.

Table 4-9. Comparison of Q4-2021 System Conditions to LTCP – Lower Charles River

Outfall	Q4-2021 System Conditions(1)		Long Term Control Plan	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Lower Charles River				
CAM017	0	0	1	0.45
MWR010	0	0	0	0
MWR018	2	1.11	0	0
MWR019	2	0.47	0	0
MWR020	2	0.46	0	0
MWR201 (Cottage Farm CSO Facility)	2	9.09	2	6.3
MWR023	1	0.04	2	0.13
BOS046 – Boston GH1(3)	1	0.10	2	5.38
BOS046 – Boston GH2(4)	0	0.00		
Total (2)	**2 (Max.)**	**11.26**	**2 (Max.)**	**6.88**
Upper Inner Harbor				
MWR203 (Prison Point CSO Facility)*	17	248.33	17	243.0

*Model predicted activation and volume for Q4-2021 System Conditions has decreased since 1992 levels to a level believed to achieve anticipated water quality improvements. The inability to precisely meet activation and/or volume goals at these locations is considered immaterial.

(1) Grey shading indicates model prediction is greater than LTCP value.

(2) Activation frequency shown is the maximum among Lower Charles regulators. Volume is the total summed volume.

(3) BOS046 (Gatehouse 1) is primarily a stormwater discharge but may contain CSO if the upstream regulators overflow. The upstream regulators are monitored directly. Gatehouse 1 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 MWR023 are based on 25% of the CSO volume upstream and BOS046 are based on 75% of the predicted CSO volume upstream.

(4) BOS046 (Gatehouse 2) contains a gate which may also be overtopped in very wet weather; this gate was added to the model after the Q1-2021 system conditions model run per new field information.

A number of alternatives were evaluated in an effort to bring outfalls MWR018, MWR019 and MWR020 into attainment with LTCP goals. These alternatives focused on ways to reduce the HGL in the BMC and are summarized below:

1. Shifting flow from the BMC to Union Park CSO Facility: The intent of this alternative was to reduce flows into the BMC from the Westside Interceptor system by lowering the HGL in the BMC downstream of the connection from the Westside Interceptor. However, modeling indicated that this alternative had no impact on overflows at outfalls MWR018, MWR019, or MWR020.

2. Operating Prison Point more aggressively: This alternative evaluated opening the influent gate to Prison Point earlier in the storm event compared to the current operating protocol. This alternative did reduce the HGL in the BMC slightly, with nominal reductions in the discharge volume at outfalls MWR018, MWR019, and MWR020, but increased the volume discharged at Prison Point by about 18 MG.

3. Installing gates on outfalls MWR018/019/020 that would only open in storms larger than the Typical Year: The intent of this alternative was to use gates to eliminate the discharges in the Typical Year, but allow the gates to open to provide relief in storms larger than the Typical Year storms. However, this alternative created adverse HGL impacts in the BMC during the Typical Year.

4. Removing stormwater tributary to the Old Stony Brook Conduit: The intent of this alternative was to see how much separate stormwater tributary to the Old Stony Brook Conduit would need to be relocated to the Stony Brook Conduit (SBC) in order to mitigate the adverse HGL impacts in the Typical Year associated with Alternative 3 above. Preliminary modeling indicated that approximately 140 acres of separate stormwater would need to be relocated, and the feasibility of relocating that stormwater has not been established. Therefore, the alternative which includes installing gates and relocating stormwater is still being evaluated for constructability and cost. Further consideration would also need to be given to the additional hydraulic load placed on the SBC as well as additional pollutant load tributary to the Charles River resulting from additional stormwater flows.

5. Increasing the size of the connection from the Old Stony Brook Conduit to the Boston Main Drain Relief Sewer ("Boston Main Drain") in addition to relocating the stormwater as described above: The intent of this alternative was to reduce the HGL in the BMC by shifting flows from the Old Stony Brook Conduit towards Ward Street Headworks (WSHW) via the Boston Main Drain. Initial modeling of this alternative showed some beneficial results in terms of reducing the peak HGL in the BMC in conjunction with relocating upstream stormwater. However, the alternative would increase the activation frequency at Cottage Farm by 2 activations and would increase the discharge volume by 4.3 MG. Additional field investigations are needed to check that the model properly reflects existing conditions before this alternative can be further investigated.

MWRA and its member CSO communities continue to work to identify and investigate options for reducing the CSO activations and volumes at outfalls MWR018, MWR019 and MWR020.

4.2.2.4 Outfall CAM005 (Charles River)

As indicated in Chapter 2, the annual volume at CAM005 was predicted to meet the LTCP level of control under Q4-2021 conditions (0.75 MG vs. 0.84 MG), but the annual activation frequency still exceeded the target by five activations. Initial evaluations included raising the weir at the CAM005 regulator by 6 inches and 12 inches and cleaning the outfall pipe. While these alternatives (summarized in Semiannual Report No. 6) were predicted to further reduce activations and volume, they did not result in attainment of the LTCP goal for activation frequency at CAM005. In addition, the City of Cambridge raised concerns about the potential impacts of raising the weir on historic upstream flooding . Further investigations then included the following:

- Incorporating sewer separation planned by the City of Cambridge in the Willard Street area, covering an approximately 28-acre area tributary to the MWRA interceptor downstream of CAM005;
- Evaluating different combinations of weir raising at CAM005 with sewer separation upstream of CAM005. For this sensitivity assessment, model runs were conducted to incrementally increase the area of sewer separation, starting from the areas closest to the Charles River and then moving further upstream.

The combined sewer areas tributary to CAM005 that were evaluated are presented in Figure 4-18.

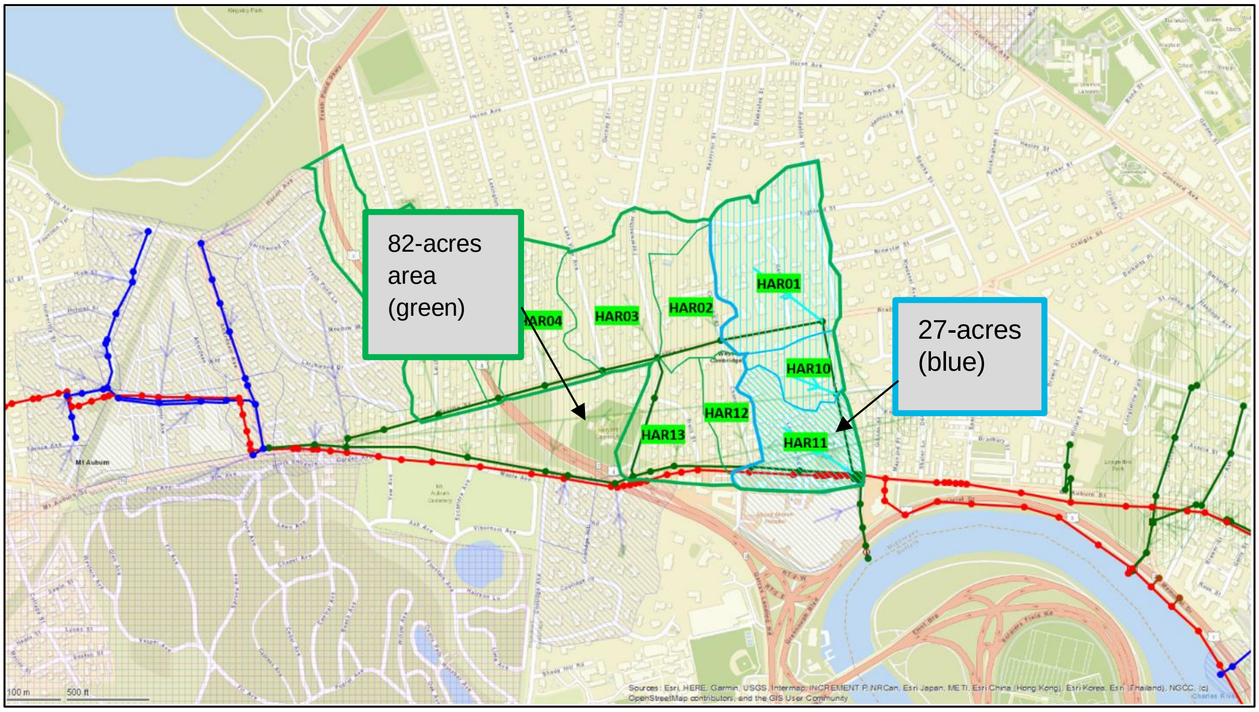


Figure 4-18. Combined Area Tributary to CAM005

For the second bullet on the previous page, various combinations of acreage of tributary area to be separated were run for the Typical Year with and without the CAM005 outfall cleaned and the weir raised 6 inches and 12 inches. For this evaluation it was assumed that the areas would be 75% separated. The evaluations were conducted based on the Q1-2021 conditions model, updated to include the proposed Willard Street separation work. Table 4-10 presents the results of the evaluations for the Typical Year for alternatives that included raising the weir 6 inches and 12 inches and cleaning the outfall at CAM005; 12 acres of separation with the outfall cleaned and the weir raised 12 inches; 27 acres of separation with the outfall cleaned and the weir raised 12 inches; and then 82 acres separated with no changes to the outfall or weir.

As indicated in Table 4-10, separating the 12 acres (areas HAR10 and HAR11 in Figure 4-18) with raising the weir 12 inches and cleaning the outfall reduced the activation frequency to within one low-volume activation of the LTCP. Separating 27 acres (areas HAR10, HAR11 and HAR01 in Figure 4-18) with raising the weir 12 inches and cleaning the outfall reduce the activation frequency to 2 which is less than the LTCP goal. To meet the LTCP goal for activations without cleaning the outfall and raising the weir would require separating a total of 82 acres (all 10 areas highlighted in green in Figure 4-18). The sewer separation evaluations focused on the reduction of CSO activation frequency and volume. The water quality impacts of increasing the stormwater loads as a result of sewer separation have not been evaluated.

MWRA is continuing to coordinate with the City of Cambridge regarding the feasibility and hydraulic impacts of alternatives for outfall CAM005. The City of Cambridge planned to have the CAM005 outfall cleaned by the end of 2021. Improvements to CSO control must be balanced against the need for improved level of service to address flooding experienced in this tributary system during large storm events as well as the potential for increase pollutant load that can result from additional stormwater discharges to the Charles River resulting from sewer separation.

Table 4-10. Preliminary Model Results of Sensitivity Analyses at CAM005

Outfall	Regulator ID	Q1-2021Updated Willard St Areas 90% Separation (New Baseline)(1)		New Baseline with Weir Raised 6 inches and Outfall Cleaned		New Baseline with Weir Raised 12 inches and Outfall Cleaned		New Baseline with 12 acres of Separation (HAR011/HAR10) Weir Raised12 inches/Outfall Cleaned		New Baseline with 27 acres of Separation (HAR011/HAR10/ HAR01)/Weir Raised 12 inches/Outfall Cleaned		New Baseline with 82 acres of Separation (HAR01 to HAR06 and HAR010 to HAR13)		Long Term CSO Control Plan	
		Act Freq	Volume (MG)	Volume (MG)	Volume (MG)	Act Freq	Volume (MG)	Act Freq	Volume (MG)	Act Freq	Volume (MG)	Act Freq	Volume (MG)	Act Freq	Volume (MG)
CAM005	**RE-051**	7	0.64	5	0.66	5	0.52	4	0.40	2	0.33	3	0.30	3	0.84
CAM007	**RE-071**	2	0.43	2	0.29	2	0.35	2	0.34	2	0.31	1	0.18	1	0.03
MWR201	**Cottage Farm**	2	8.92	2	8.91	2	8.93	2	8.90	2	8.84	2	8.52	2	6.3

Notes: (1) Grey shading indicates model prediction is greater than LTCP value.

5. Summary and Conclusions from Key Findings

This report presents the results of field investigations and modeling assessments undertaken to assess the level of performance achieved by the MWRA's LTCP program and describes recent work that has been and will continue to be undertaken to further improve attainment with the LTCP goals. Overall the implementation of the LTCP has been very successful, as demonstrated by the key findings from the Post Construction Monitoring Program and Performance Assessment summarized below.

Attainment of LTCP Targets for CSO Control

From 1987 through 2015, MWRA addressed 182 CSO-related court schedule milestones, including completing the construction of the 35 wastewater system projects that comprised the LTCP by December 2015. As a result of the projects implemented under the LTCP and the continued work by MWRA and its CSO partners, both treated and untreated CSO discharges have been reduced significantly as shown both in Figure 5-1 and Table 5-1. Figure 5-1 presents a a comparison of the treated discharge, untreated discharge and total discharge volume for 1988 conditions, 1992 conditions, present (Q4-2021) conditions, and the LTCP goal. The overall CSO discharge volume has decreased by 87% from 1988 levels, close to the LTCP goal of 88%.

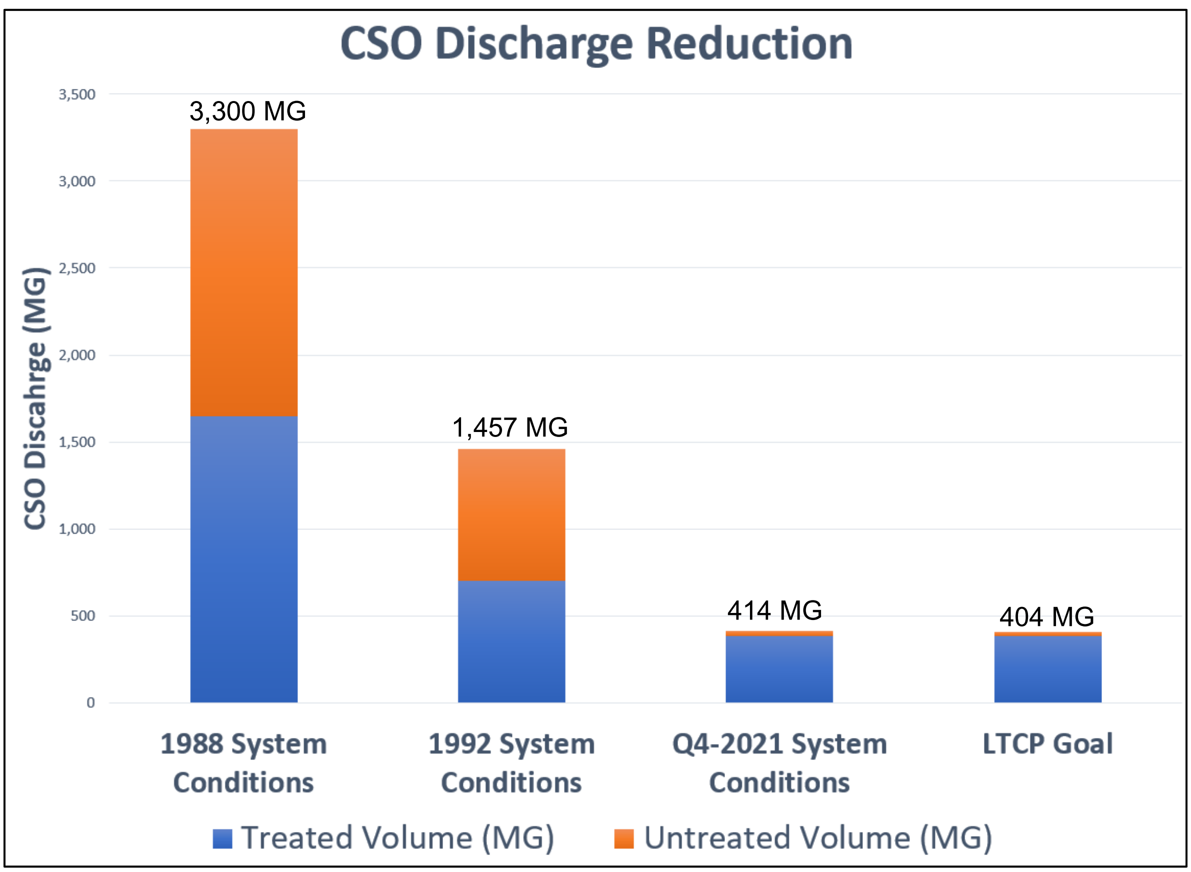


Figure 5-1. CSO Discharge Reduction from 1988 to Present Conditions Compared to LTCP Goals

Table 5-1. CSO Discharge Reduction from 1988 to Present Conditions Compared to LTCP Goals

	1988 System Conditions	1992 System Conditions	Q4-2021 System Conditions	LTCP Goal
Treated Volume (MG)	1,650	698	384	381
Untreated Volume (MG)	1,650	759	30	23
Grand Total (MG)	3,300	1,457	414	404

- As of the end of 2021, the LTCP goals for average annual CSO activation and volume were achieved, or materially achieved at 70 of the 86 outfalls for which performance targets were defined in the Second Stipulation.
- Since 1988, the average annual CSO volume systemwide has been reduced by over 2.8 billion gallons, a reduction of 87%. This is very close to the overall LTCP goal of 88% reduction.
- All of the 25 outfalls designated as “closed” or “to be closed” under the Second Stipulation were confirmed to be closed, along with 10 additional outfalls that were closed through additional work by MWRA and the CSO communities.
- Of the 16 remaining outfalls that did not meet the LTCP goals for activation frequency and/or volume by the end of 2021, plans were developed at 6 outfalls to meet LTCP goals after 2021. The outfalls projected to meet LTCP goals after December 2021 include:
  - BOS003, BOS009 (Lower/Upper Inner Harbor)
  - BOS014, CHE008, Somerville Marginal CSO Facility-MWR205 (Mystic/Chelsea Confluence)
  - Somerville Marginal CSO Facility – SOM007A/MWR205A (Upper Mystic River)
- For the remaining 10 outfalls not projected to meet the LTCP goals after 2021, MWRA has identified through hydraulic modeling potentially feasible alternatives that are predicted to achieve LTCP volume and activation goals at four outfalls:
  - BOS017 (Mystic/Chelsea Confluence)
  - BOS062, BOS065, BOS070 (Fort Point Channel)
- Athough MWRA continues to evaluate and investigate alternatives and work with its CSO community partners to identify system changes that will improve CSO perfomance, the following six CSO outfalls remain particulary challenging:
  - SOM001A (Alewife Brook)
    - Significant progress has been made at this outfall through implementation of the LTCP and subsequent activities by the CSO communities, reducing the CSO discharge volume from 11.93 MG in 1992 to 4.47 MG in Q4-2021 conditions, a 63% reduction in volume that brings this outfall to within 2.8 MG of the LTCP goal.
  - CAM005 (Charles River)
    - At this outfall the discharge volume has been reduced from 41.56 MG in 1992 to 0.75 MG in Q4-2021 system conditions. This volume is less than the LTCP goal, but the activation frequency still exceeds the LTCP goal by five relatively low-volume activations.

- Cottage Farm CSO Facility-MWR201 (Charles River)
  - Through implementation of the LTCP and other system improvements implemented by MWRA and the CSO communities, the treated discharge from the Cottage Farm Facility has been reduced from 214.1 MG in 1992 to 9.09 MG, a reduction of 96%.
- MWR018, MWR019, MWR020 (Charles River)
  - The total CSO discharge volume at outfalls MWR018, MWR019 and MWR020 has been decreased from 5.14 MG in 1992 to 2.04 MG, a reduction of 60%, while the activation frequency has stayed consistent at two in the Typical Year. The LTCP goal at these locations is no discharges in the Typical Year.

Attainment of Water Quality Standards – Variance Waters

- In both the Charles River and Alewife Brook/Upper Mystic River, the predominant source of bacteria loading was demonstrated to be non-CSO sources.
  - For the Charles River, approximately 99% of the bacteria load was from non-CSO sources, split approximately 40% from upstream sources and 60% from stormwater for the 1-year storm and for the Typical Year.
  - For Alewife Brook, stormwater was the predominant source, but CSO accounted for approximately 28% of the bacteria load in the 1-year storm, and 10% for the Typical Year.
  - For the Upper Mystic River, over 99% of the bacteria load was from non-CSO sources, with 93% or greater coming from stormwater for the 1-year storm and for the Typical Year.
- In the Charles River, both the annual percent attainment with *E. coli* criteria and the maximum *E. coli* counts were driven by the non-CSO loads. In the Alewife Brook/Upper Mystic River, the annual percent attainment was driven by the non-CSO loads. However, CSOs cause the *E. coli* counts to reach high levels for short periods of time.
- Further reduction of CSOs to a level such that all CSOs to the Charles River and Alewife Brook/Upper Mystic River met the numerical targets for activation frequency and volume per the LTCP was not predicted to substantively change the percent of time allowable *E. coli* counts are exceeded in either waterbody.
- Under current conditions, CSOs alone would contribute to annual non-attainment of the *E. coli* criterion less than 1% percent of the time for the Charles River, and approximately 2% of the time in the Alewife Brook/Upper Mystic River, consistent with the targets established in previous CSO planning efforts. This is because the remaining CSO discharge is predominantly treated.
- Reductions in *E. coli* loading from stormwater would improve the annual percent attainment, but even with an order-of-magnitude reduction in *E. coli* counts in stormwater, non-CSO sources would still be the primary driver of non-attainment of the *E. coli* criteria.

Attainment of Water Quality Standards – Non-variance Waters

- For the Class B waters of the Neponset River and the Class SB waters of North Dorchester Bay, South Dorchester Bay and Constitution Beach, CSO discharges were confirmed to be eliminated (or no discharges in up to a 25-year storm for North Dorchester Bay). Thus, CSOs do not contribute to any non-attainment of water quality standards in these waters. As a result of these CSO closures, beach closings due to high bacteria are relatively infrequent, allowing for swimming on most summer days at all beaches.
- MWRA conducts routine monitoring where CSO discharges remain to Class SB_{CSO} designated waters, including the Mystic River mouth, Chelsea Creek, Inner Harbor, Reserved Channel, and Fort Point Channel. In order to present water quality in those regions, MWRA adopted the methodology

used by EPA to publish grades presented in annual “report cards” for Boston Harbor’s tributary watersheds. The grades were calculated from an average attainment rate with primary and secondary contact standards, weighted based on antecedent rainfall, and calculated on a three-year rolling basis.

- MWRA calculated grades for MWRA’s 13 monitoring stations located in the Class SB_{CSO} waters that still receive CSO discharges in the Typical Year. Data from 2010-2020 was used to calculate grades for the nine-year period covering 2012-2020. Of the 117 grades calculated in that period (13 locations x 9 years), 79 were A+ or A; 24 were A- or B+; and only 14 were B or less. The only location with grades lower than B- was at the head of Fort Point Channel. CSO discharge to the Fort Point Channel in the Typical Year is 34.71 MG (Q4-2021 system conditions), which is less than half of the LTCP goal of 73.89 MG . Although some individual outfalls do not currently meet the LTCP goals (BOS062, BOS065 and BOS070/DBC), CSO activation frequency and volumes at all Fort Point Channel outfalls have been reduced or eliminated from 1992 conditions as a result of the projects implemented under the LTCP. Overall, CSO discharge to Fort Point Channel has been reduced by 88% from 298.81 MG in 1992 to 34.71 MG (Q4-2021 system conditions), of which 77% of remaining CSO is treated at the Union Park CSO facility. Currently the most frequent CSO is the treated discharge from Union Park (MWR215) at 10 activations within a typical year, followed by BOS070/DBC at 7 activations.

  The grading system does not distinguish the sources of non-attainment, and in the head end of Fort Point Channel, non-CSO factors such as stormwater and minimal tidal flushing/dilution contribute to the relatively low attainment at that location. With the exception of that one location, the consistently high grades throughout the stations in the Class SB_{CSO} waters over the nine-year period demonstrate the success of the efforts by MWRA and the CSO communities in improving water quality in Boston Harbor.

With the completion of the Post Construction Monitoring Program and Performance Assessment, MWRA has demonstrated that in Q4-2021 conditions at 70 of the 86 outfalls listed in Exhibit B of the Second Stipulation have achieved or materially achieved LTCP goals. The next phase of this project will be to focus on the 16 additional outfalls not yet forecasted to meet LTCP goals. As described above, six of the 16 outfalls are projected to meet LTCP goals after December 2021. For the remaining 10 outfalls, using hydraulic modeling MWRA has identified potentially feasible alternatives that could enable four of the outfalls to achieve LTCP volume and activation goals. MWRA will continue to evaluate these four outfalls as well as the remaining six that have been particularly challenging to resolve.

Part II Summary of Supporting Activities

6. Summary of CSO Inspection Program

6.1 Chapter Synopsis

One of the early activities in the Post Construction Compliance Monitoring Program was to inspect each of the regulators tributary to outfalls listed in Exhibit B to the Second Stipulation (see Table 1-2 in Chapter 1). The intent of these inspections was to assess whether outfalls listed as "closed" or "to be closed" in the Second Stipulation were in fact closed, and to obtain relevant information to support installation of flow metering equipment at the regulators associated with outfalls that remained open.

Key findings presented in this chapter are as follows:

- MWRA and the CSO communities eliminated CSO discharges at all 25 outfalls that were required to be closed in the Second Stipulation, plus an additional 8 outfalls that were not required to be closed by the Second Stipulation. In addition, two outfalls (SOM002 and SOM006) that were not listed in the Second Stipulation were closed. Thus, the MWRA and the CSO communities have closed a total of 35 outfalls. The total of 10 additional outfalls that were closed beyond the 25 listed in the Second Stipulation were the following:
    - SOM002 on Alewife Brook and SOM006 on the Upper Mystic River, closed by the City of Somerville in the 1980s and 1990s;
    - CHE002 on the Mystic/Chelsea Creek Confluence, closed by the City of Chelsea in 2014;
    - BOS006 and BOS007 in East Boston, closed by BWSC in 2008;
    - BOS072 on Fort Point Channel, closed by BWSC in 2014;
    - BOS083 and BOS087 on the South Boston beaches, closed by MWRA in 2011 with construction of the South Boston CSO storage tunnel; and
    - CAM009 and CAM011 on the Charles River, which were closed by the City of Cambridge in 2007 on an interim basis. The City of Cambridge maintains CAM009 and CAM011 in a closed condition while it continues to evaluate hydraulic conditions in the local sewer system before making a decision to close them permanently.
- Among the multiple regulators tributary to outfall MWR023, the following differences were found:
    - Regulator RE046-54 was originally believed to be closed, but was found to be open;
    - Regulators RE046-80 and RE046-110 were originally believed to be open, but were found to be closed;
- At two outfalls, two regulators were found to be tributary to the outfall, where the LTCP had only one regulator:
    - Regulator BOS078 was revised to include two regulators, RE078-1 and RE078-2;
    - Regulator RE101 at outfall MWR010 was revised to include two regulators, RE037 and RE036-9.

6.2 Introduction

As noted above, each of the regulators tributary to outfalls listed in Exhibit B to the Second Stipulation (see Table 1-2 in Chapter 1) were inspected. These inspections were conducted with the purpose of confirming that outfalls listed as "closed" or "to be closed" in the Second Stipulation were in fact closed. Surface inspections utilizing drop-down cameras were conducted on regulators that were initially identified as closed in the MWRA system. Regulators that were identified as open received internal inspections. Figure 6-1 presents examples of a blocked high outlet overflow and a former CSO outfall.

Brick and mortar bulkhead of high outlet overflow

Former CSO Outfall CHE002 now discharges only stormwater

Figure 6-1. Closed High Outlet Overflow (left) and Former CSO Outfall CHE002 (right)

In total 57 regulators received internal inspections. Metering plans were prepared for open regulators that discharged directly to permitted outfalls. Metering plans were not developed for upstream regulators where the overflow was re-regulated downstream.

A map showing the locations of regulators that were inspected is presented in Figure 6-2. Regulators shown in Figure 6-2 as receiving only surface inspections are shown in green and locations that received internal inspections are shown in blue. The following sections describe the inspections of closed and open CSO regulators in more detail. Current inspection information was available for CAM009 and CAM0011 so they were not inspected as part of this program and therefore are not shown on the map.

Figure 6-2. Map of CSO Inspection Locations

6.3 Closed CSO Inspections

The initial list of regulators identified as closed in the MWRA and CSO community systems was generated from the list of regulators provided in the 1992 sampling program conducted in support of MWRA's LTCP (Metcalf and Eddy, 1993). This list was compared to a list of open regulators provided by MWRA prior to the start of the inspections. Regulators listed in the 1992 sampling program that were not identified as open in the list provided by MWRA were initially assumed to be closed and were targeted for surface inspections. An example of an inspection form for a closed regulator location is presented in Figure 6-3.

Regulators that were identified as being open from the surface inspections received internal inspections as described below. Regulators that were identified as closed but in need of repair were referred to MWRA so repairs could be made.

Table 6-1 presents a summary of the regulator inspections and whether the open/closed status changed from the LTCP based on the inspection work. The main differences between the LTCP and the inspection findings as indicated in Table 6-1 were as follows:

- One regulator originally believed to be closed was found to be open (RE046-54);
- Two regulators originally believed to be open were found to be closed (RE046-80, RE046-110);
- At two outfalls, two regulators were found to be tributary to the outfall, where the LTCP had only one regulator:
    - Regulator BOS078 was revised to include two regulators, RE078-1 and RE078-2, and
    - Regulator RE101 at MWR010 was revised to include two regulators, RE037 and RE036-9).

Massachusetts Water Resource Authority

Inspection Date: 1/30/2018

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

Regulator Insepction Log

Location:	Boylston St at Amory St	Feature ID:

Regulator Namer 046-63

CSO: BOS046

Video File Name: RE_046_63_VID_1

Regulated CSO: Yes

Regulator Features

Open or Closed: Closed

Downstream

Upstream

Weir

Comments

Regulator located on the field between the church and the T-station.

Inspector: **Benjamin Silberman**

SDE, Inc. RE_046_63_INSP_1

Figure 6-3. Example Closed Regulator Surface Inspection Form

Table 6-1. Summary of Regulator Inspections (Page 1 of 3)

Outfall	Regulator ID	Status per LTCP	Status per Inspection	Comment/Resolution
Alewife Brook				
CAM001	RE-011	Open	Open	No change from LTCP
CAM002	RE-021	Open	Open	No change from LTCP
MWR003	RE-031	Open	Open	No change from LTCP
CAM004		Closed	Closed	No change from LTCP
CAM400		Closed	Closed	No change from LTCP
CAM401A	RE-401	Open	Open	No change from LTCP
CAM401B	RE-401B	Open	Open	No change from LTCP
SOM001A	RE-01A	Open	Open	No change from LTCP
SOM001		Closed	Closed	No change from LTCP
SOM002A		Closed	Closed	No change from LTCP
SOM003		Closed	Closed	No change from LTCP
SOM004		Closed	Closed	No change from LTCP
Upper Mystic River				
SOM007A/MWR205A		Open	Open	No change from LTCP
SOM007		Closed	Closed	No change from LTCP
Mystic/Chelsea Confluence				
MWR205 (Somerville Marginal CSO Facility)		Open	Open	No change from LTCP
BOS013	RE013-1	Open	Open	No change from LTCP
BOS014	RE014-2	Open	Open	No change from LTCP
BOS015		Closed	Closed	No change from LTCP
BOS017	RE017-3	Open	Open	No change from LTCP
CHE002		Open	Closed	LTCP did not require outfall to be closed(1)
CHE003	RE-031	Open	Open	No change from LTCP
CHE004	RE-041	Open	Open	No change from LTCP
CHE008	RE-081	Open	Open	No change from LTCP
Upper Inner Harbor				
BOS009	RE009-2	Open	Open	No change from LTCP
BOS010	RE010-2	Open	Open	No change from LTCP
BOS012	RE012-2	Open	Open	No change from LTCP
BOS019	RE019-2	Open	Open	No change from LTCP
BOS050		Closed	Closed	No change from LTCP
BOS052		Closed	Closed	No change from LTCP
BOS057	RE057-6	Open	Open	No change from LTCP
BOS058		Closed	Closed	No change from LTCP
BOS060	RE060-7	Open	Open	No change from LTCP
	RE060-20	Open	Open	No change from LTCP
MWR203 (Prison Point CSO Facility)		Open	Open	No change from LTCP
Lower Inner Harbor				
BOS003	RE003-2	Open	Open	No change from LTCP
	RE003-7	Open	Open	No change from LTCP
	RE003-12	Open	Open	No change from LTCP
BOS004	RE004-6	Open	Open	No change from LTCP
BOS005	RE005-1	Open	Open	No change from LTCP
BOS006		Open	Closed	LTCP did not require outfall to be closed (1)
BOS007		Open	Closed	LTCP did not require outfall to be closed(1)
Constitution Beach				
MWR207 (Constitution Beach CSO Facility)		Closed	Closed	No change from LTCP
Fort Point Channel				
BOS062	RE062-4	Open	Open	No change from LTCP
BOS064	RE064-4	Open	Open	No change from LTCP
	RE064-5	Open	Open	No change from LTCP
BOS065	RE065-2	Open	Open	No change from LTCP
BOS068	RE068-1A	Open	Open	No change from LTCP

Table 6-2. Summary of Regulator Inspections (Page 2 of 3)

Outfall	Regulator ID	Status per LTCP	Status per Inspection	Comment/Resolution
BOS070/DBC	RE070/8-3	Open	Open	No change from LTCP
	RE070/8-6	Open	Open	No change from LTCP
	RE070/8-7	Open	Open	No change from LTCP
	RE070/8-8	Open	Open	No change from LTCP
	RE070/8-13	Open	Open	No change from LTCP
	RE070/8-15	Open	Open	No change from LTCP
	RE070/9-4	Open	Open	No change from LTCP
	RE070/10-5	Open	Open	No change from LTCP
	RE070/11-2	Closed	Closed	No change from LTCP
	RE070/7-2	Open	Open	No change from LTCP
MWR215 (Union Park CSO Facility)		Open	Open	No change from LTCP
BOS070/RCC	RE070/5-3	Open	Open	No change from LTCP
	RE070/6-1	Closed	Closed	No change from LTCP
BOS072		Open	Closed	LTCP did not require outfall to be closed(1)
BOS073	RE073-4	Open	Open	No change from LTCP
Reserved Channel				
BOS076	RE076/2-3	Open	Open	No change from LTCP
	RE076/4-3	Open	Open	No change from LTCP
BOS078	RE078-1 RE078-2	Open	Open	Single regulator in LTCP revised to two regulators per inspection.
BOS079	RE079-3	Open	Open	No change from LTCP
BOS080	RE080-2B	Open	Open	No change from LTCP
North Dorchester Bay				
BOS081	RE081-2	Open(2)	Open(2)	No change from LTCP(2)
BOS082	RE082-2	Open(2)	Open(2)	No change from LTCP(2)
BOS083		Open(2)	Closed	LTCP did not require outfall to be closed (1)
BOS084	RE084-3	Open(2)	Open(2)	No change from LTCP(2)
BOS085	RE085-5	Open(2)	Open(2)	No change from LTCP(2)
BOS086	RE086-1	Open(2)	Open(2)	No change from LTCP(2)
BOS087		Open(2)	Closed	LTCP did not require outfall to be closed(1)
South Dorchester Bay				
BOS088/BOS089 (Fox Point CSO Facility)		Closed	Closed	No change from LTCP
BOS090 (Commercial Point CSO Facility)		Closed	Closed	No change from LTCP
Upper Charles				
BOS032		Closed	Closed	No change from LTCP
BOS033		Closed	Closed	No change from LTCP
CAM005	RE-051	Open	Open	No change from LTCP
CAM007	RE-071	Open	Open	No change from LTCP
CAM009		Open	Closed(3)	LTCP did not require outfall to be closed(1)
CAM011		Open	Closed(3)	LTCP did not require outfall to be closed (1)
Lower Charles				
BOS028		Closed	Closed	No change from LTCP
BOS042		Closed	Closed	No change from LTCP
BOS049		Closed	Closed	No change from LTCP
CAM017	CAM017	Open	Open	No change from LTCP
MWR010	RE37	N/A	Open	LTCP had single regulator RE101 at MWR010; revised to include two regulators, RE037 and RE036-9 per inspection.
	RE036-9	N/A	Open	
MWR018		Open	Open	No change from LTCP
MWR019		Open	Open	No change from LTCP
MWR020		Open	Open	No change from LTCP
MWR021		Closed	Closed	No change from LTCP
MWR022		Closed	Closed	No change from LTCP
MWR201 (Cottage Farm CSO Facility)		Open	Open	No change from LTCP

Table 6-3. Summary of Regulator Inspections (Page 3 of 3)

Outfall	Regulator ID	Status per LTCP	Status per Inspection	Comment/Resolution
MWR023	RE046-19	Open	Open	No change from LTCP
	RE046-30	Open	Open	No change from LTCP
	RE046-50	Open	Open	No change from LTCP
	RE046-54	N/A	Open	Regulator was not identified as open in the LTCP; Inspection found regulator to be open.
	RE046-55	Open	Open	No change from LTCP
	RE046-62A	Open	Open	No change from LTCP
	RE046-63	Closed	Closed	No change from LTCP
	RE046-80	Open	Closed	Inspection indicated regulator was closed.
	RE046-90	Open	Open	No change from LTCP
	RE046-100	Open	Open	No change from LTCP
	RE046-105	Open	Open	No change from LTCP
	RE046-110	Open	Closed	Inspection indicated regulator was closed.
	RE046-381	Open	Open	No change from LTCP
	RE046-192	Open	Open	No change from LTCP
SOM010		Closed	Closed	No change from LTCP
Neponset River				
BOS093		Closed	Closed	No change from LTCP
BOS095		Closed	Closed	No change from LTCP
Back Bay Fens				
BOS046	Boston Gatehouses #1 and #2	Open	Open	No change from LTCP

(1) Outfall is one of the eight closed outfalls that was not required to be closed by the Second Stipulation.

(2) Overflow from regulator captured by North Dorchester Bay Tunnel in up to 25-year storm.

(3) Outfall maintained in a closed condition while the City of Cambridge continues to evaluate hydraulic conditions in the local sewer system before making a decision to close them permanently.

6.4 Open CSO Inspections

Regulators that were identified as open received internal inspections. In total 57 regulators were inspected. Information recorded as part of the inspections included:

- Location information:
    - Location of the outfall site;
    - Location of the CSO regulator with photo documentation; and
    - Location of proposed meters (if applicable).
- Condition information:
    - Sewer manhole and rim structure;
    - Pipe and regulator structure; and
    - Tide gate conditions.
- Measurements:
    - Connecting pipe dimensions and elevations (rim to invert measurements);
    - Tide gate size;
    - Weir elevation (rim to top of weir); and
    - Silt measurement.
- Other observations:
    - Hydraulic conditions;
    - Unusual influences on hydraulics (such as slope change, drop connections, etc.);
    - Roadway or traffic concerns; and
- Permit requirements.

The information collected during the inspections was recorded on site sheets. For locations where a meter was installed, multiple pages of information were provided for each site including a location plan, a paragraph summarizing the operation of the regulator and the metering plan, and the meter site sheets. Figure 6-4 shows examples of the information that was collected during the inspection for regulator RE003-2, which had meters installed.

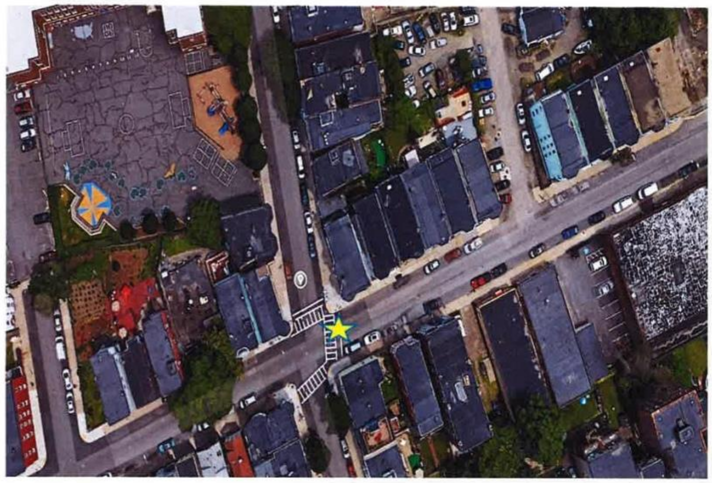
Each open regulator was evaluated for meter placement. Ideal conditions for installation of flow monitors would include:

- The flow surface is fairly smooth (<.50” waves);
- Velocity is sufficient to scour the bottom of the pipe (> 1.5 fps);
- The pipe does not surcharge or is not affected by tides or river intrusion;
- The pipe is free of debris; and
- No intermittent acceleration of the flow occurs due to upstream or downstream pump stations.

When the conditions were not ideal, additional tools were deployed to mitigate the concern such as adding additional sensors to measure surcharge, river or tidal flows, or increasing the sample rate to account for rapidly changing flows. Details on the metering approach for each regulator are described in Chapter 7.

RE003-2 Cottage St at Maverick St

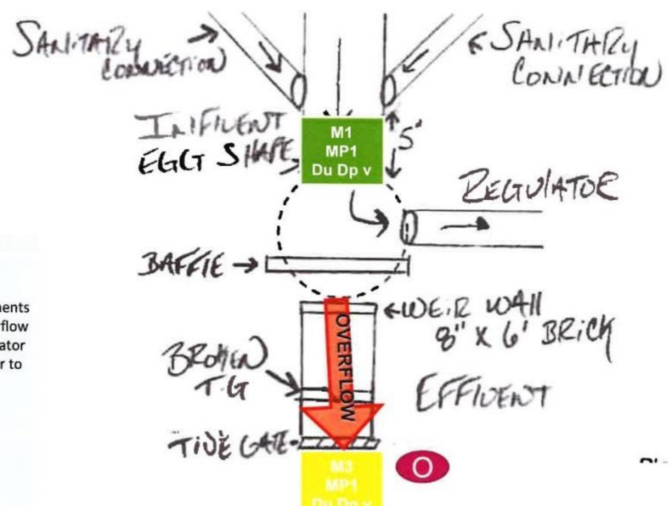
Regulator RE003-2 is located at Cottage St at Maverick St. The regulator has three influent lines and overflow line that discharges to Lower Inner Harbor. Modeling at this location indicates the possibility of overflow. Flow monitors were placed in the influent pipe downstream of the two additional influent pipes. There is a tide gate near the regulator structure that has an inclinometer and area velocity sensor installed for overflow measurement. During inspection no unusual observations were noted. The inspection data, meter schematic, and site sheets for this regulator follows this page



AECOM

RE003-2 Cottage St at Maverick St

Meter Name	Method	Notes
RE003-2_M1	Incoming Combined Sewers (CS) Flow Q=VA; used for model validation and providing total flow into Regulator structure.	Depth measurements will indicate overflow over weir. Regulator submerged prior to overflow
RE003-2_M3	CSO Outfall measured flow Q=VA; used for overflow calculation. Inclinometer on tide gate.	
CSOFLOWRE003-2	M3 Q=VA when Inclinometer > 5 and M1 depth > weir wall	Final data will use be processed through the ADS QA/QC program and posted to FlowView monthly



AECOM

Figure 6-4 Example of Information Collected at Monitored Flow Regulators Shown for Regulator RE003-2 (Page 1 of 4)

MWRA	ADS ENVIRONMENTAL SERVICES	Site I.D.
Flow Monitoring Site Installation Report		**RE003-2_M1**

		Monitor Series	Location Type
Site Address / Location:	Cottage St. @ Maverick St.	TRITON+	Temporary
		Pipe Size (H x W)	Pipe Shape
Site Access:	Drive- Detailed needeed (Area A)	42.25 x 29	Standard Egg

Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light

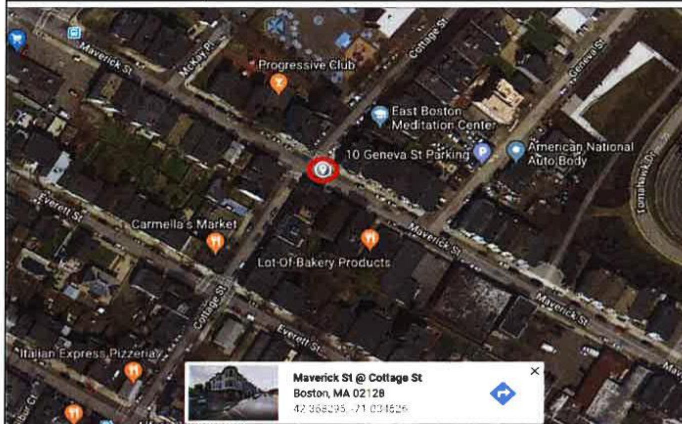
Installation Information	
Installation Date:	Installation Type:
Friday, March 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Downstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
12:54:00 PM	42.25 x 29
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
2	40.25
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0.9	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Slow	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
9	Common Trench
Manhole Material:	Manhole Condition:
Concrete	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Concealed	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete
Additional Site Info. / Comments:	
S/N: 20532 I/P: 107.80.26.16	

ADS Project Name:	MWRA
ADS Project Number:	32547.22.325

Figure 6-4. Example of Information Collected at Monitored Flow Regulators Shown for Regulator RE003-2 (Page 2 of 4)

MWRA	ADS ENVIRONMENTAL SERVICES	Site I.D.
Flow Monitoring Site Installation Report		RE003-2_M3

		Monitor Series	Location Type
Site Address / Location:	Cottage St. @ Maverick St.	TRITON+	Temporary
		Pipe Size (H x W)	Pipe Shape
Site Access:	Drive- Detailed Needede (Area A)	42.25 x 29	Rectangular



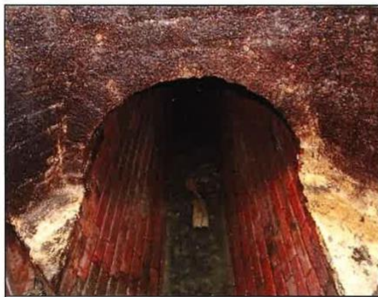
Manhole #	System Characteristics
N/A	Residential
Access	Traffic
Drive	Light

Installation Information	
Installation Date:	Installation Type:
Friday, March 23, 2018	Doppler Special Installation
Monitoring Location (Sensors):	Monitor Location:
Downstream 0-5 FT	Manhole
Sensors / Devices:	Pressure Sensor Range (psi)
Peak Combo (CS4)	0 -5 psi
Installation Confirmation:	
Confirmation Time:	Pipe Size (HxW)
11:18:00 AM	59.5 x 55
Depth of Flow (Wet DOF) (in)	Range (Air DOF) (in)
0	59.5
Downlooker Physical Offset (in)	Measurement Confidence (in)
N/A	0.25"
Peak Velocity (fps)	Velocity Sensor Offset (in)
0	N/A
Silt (in)	Silt Type
0	N/A
Hydraulic Comments:	
Tidal, Dry at Install	
Manhole / Pipe Information:	
Manhole Depth (Approx. FT):	Manhole Configuration
9	CSO Flow Divider
Manhole Material:	Manhole Condition:
Brick	Good
Manhole Opening Diameter (in)	Manhole Diameter (Approx.):
N/A	N/A
Manhole Cover	Manhole Frame
Concealed	Normal
Active Drop Connections	Air Quality:
No	Good
Pipe Material	Pipe Condition:
Brick	Good
Communication Information:	
Communication Type	Antenna Location
Wireless	Drilled Pavement / Concrete
Additional Site Info. / Comments:	
S/N: 20208 I/P: 107.80.26.39	

ADS Project Name:	MWRA
ADS Project Number:	32547.22.325

Figure 6-4. Example of Information Collected at Monitored Flow Regulators Shown for Regulator RE003-2 (Page 3 of 4)

Additional Photos



Overflow

Location

Location

Elevations (in.)

Rim to invert M1 MP1	118.25
Rim to invert M1 MP2	n/a
Rim to invert M2 MP1	n/a
Rim to invert outfall	
Rim to baffle top	n/a
Rim to baffle bottom	n/a
Invert to weir	
Weir measurement	96x72
Length	n/a
Width	n/a
Overflow	n/a
Regulator	n/a

Location

Figure 6-4. Example of Information Collected at Monitored Flow Regulators Shown for Regulator RE003-2 (Page 4 of 4)

7. Summary of CSO Metering Program

7.1 Chapter Synopsis

The performance assessment metering program included the installation of meters (including multiple instruments) at 64 regulator locations. In addition to the performance assessment meters, data collected included existing MWRA and community flow meter data, and MWRA facility operational data.

This section provides an overview of the meter installation approach at the regulator locations, locations where the meters were installed, the types of metering equipment used, and a brief description of MWRA's CSO Notification Program.

Meter data were collected from April 15, 2018 through June 2020. Meters were removed at 21 of the 64 meter locations in March of 2019 after sufficient meter data had been collected for model calibration. The remaining project meters were in place until June 2020 when 34 were removed and 9 were converted to permanent meters as part of the MWRA's CSO Notification Program. MWRA uses existing meters as well as these project meters converted to permanent meters to support this program.

Overall the metering program provided extensive data to assess CSO activations and for model calibration.

7.2 CSO Flow Metering Background

Flow meters can be installed in sewer systems to help understand how water flows in specific locations in the system. Collection system models are often used to estimate flows throughout the collection system. To use a collection system model for this purpose, however, the model needs to demonstrate that it can appropriately reproduce observed flows. Therefore, another purpose of flow metering is to provide data for calibrating and validating a collection system model.

Meter data collected for this project consisted of both depth and velocity measured at key locations, including CSO regulators. The metering configurations were installed to estimate whether an overflow occurred, and in some cases, were used to measure the overflow volume and the flow entering the regulator from upstream pipes. Figure 7-1 is a schematic of a typical flow meter configuration at a generic CSO regulator.

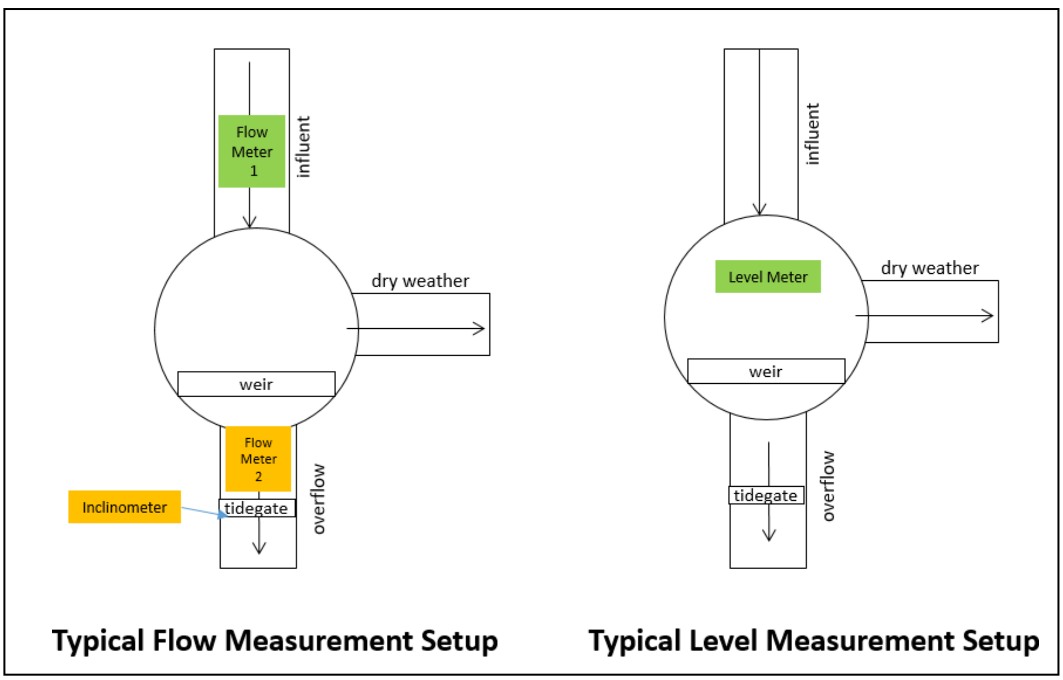


Figure 7-1. Example Meter Setup at a Generic Regulator Structure (Plan View Shown)

The regulator structure shown in Figure 7-1 consists of the following components:

- The influent is defined as the pipe or pipes conveying flow into the structure. The dry-weather flow connection, sometimes called the regulator pipe, is the path flow takes during dry weather. This flow is conveyed to the major wastewater interceptors that carry flows to the Deer Island Waste Water Treatment Plant.
- The overflow is the pipe that conveys excess flow to the receiving water. The flow conveyed to the receiving water is the flow quantified as “CSO,” or overflow.
- The weir is the vertical structure in some regulators intended to prevent dry weather flow from discharging to the outfall. Weir elevations are typically set to also capture some fraction of the wet weather flow before discharging to the overflow pipe while avoiding upstream flooding. Some regulators have no weir, and the overflow pipe is set at a higher elevation to prevent dry weather discharge and to allow for some wet weather capture.
- The tide gate is a structure placed in some overflows to prevent the receiving water from backing up into the regulator during high tide. During higher tides that push the tide gate closed, CSO discharge is prevented until the tide recedes, or the water level in the regulator exceeds the tide elevation. To indicate if a tide gate has opened releasing CSO to a receiving water, in many cases an inclinometer measuring the gate movement different from the closed position is installed on the tide gate.

The configuration at an actual regulator may differ from Figure 7-1, but the general components would be similar.

Two general metering approaches were taken for detecting overflows in a regulator: calculation of overflow volume or monitoring of depth (Figure 7-1). Where the intent was to calculate overflow volumes, velocity and depth sensors were typically installed to measure flow in both the influent and overflow lines. In some cases, directly measuring the overflow volume was impractical. As an alternative, the overflow volume can often be estimated using meter analysis techniques applied to the influent data. Another option was to monitor the dry weather connection and compute the overflow volume by subtraction from the influent volume. In some configurations where a tide gate was present, an inclinometer was used to establish when an activation was occurring. This device monitored the angle of the tide gate relative to the tide gate frame and indicated when a tide gate moved. Inclinometers could also indicate when the tide gate may have been in need of maintenance to check that the gate was seated properly.

Where previous analysis indicated that overflows were not likely to occur at a regulator (e.g. no activation predicted for a 2-year storm), a single level sensor was placed within the structure to measure the activation frequency based on depth of flow in the regulator relative to the overflow elevation (e.g. weir crest or high outlet pipe elevation).

The remainder of this section describes the metering data collected and the procedures used to review the data.

7.3 Metering Plan and Approach

The flow meters used for this program included a combination of existing MWRA meters, community meters, and project meters. The following subsections describe each type of meter.

7.3.1 MWRA Collection System Meters and Operational Data

Existing MWRA meter and system operation data were collected and used to monitor CSO activations. Data were provided for 32 interceptor meters. In addition, the project utilized data for the stormwater and CSO regulators associated with outfalls BOS081, 082, 084, 085, and 086, the North Dorchester Bay Storage Tunnel, DeLauri Pump Station, and Caruso Pump Station.

Storm reports generated by MWRA provided additional operational data for storm events that resulted in a CSO activation. Those storm reports included information on the Somerville Marginal CSO Facility (MWR205), Prison Point CSO Facility (MWR203), Union Park CSO Facility (MWR215), Cottage Farm CSO Facility (MWR201), Chelsea Creek Headworks, Ward Street Headworks, Columbus Park

Headworks, BOS019 Storage Facility, outfall MWR003, the North Dorchester Bay CSO Storage Tunnel, and the Alewife Brook Pump Station Bypass system, which was operational through 2018 as MWRA completed rehabilitation of the pumping station.

7.3.2 Community Meters

Data from existing meters in CSO communities were provided by the Cambridge Department of Public Works (DPW), BWSC, Somerville DPW and Chelsea DPW. Data were provided for a total of 25 community meters listed in Table 7-1.

Table 7-1. Community Meters

Outfall	Regulator	Number of Meters	Owner
BOS003	RE03-12	4	BWSC
BOS057	RE057	3	BWSC
BOS065	RE065-2	2	BWSC
BOS070	RE070/7-2	2	BWSC
BOS073	RE073-4	2	BWSC
CAM001	RE011	1	Cambridge
CAM002	RE021	2	Cambridge
CAM005	RE051	1	Cambridge
CAM007	RE071	1	Cambridge
CAM017	CAM017	1	Cambridge
CAM401A	RE-401	1	Cambridge
CAM401B	RE-401B	1	Cambridge
CHE003	RE031	1	Chelsea
CHE004	RE041	1	Chelsea
CHE008	RE081	1	Chelsea
SOM001A	RE01A	1	Somerville
Total	**16**	**25**	

7.3.3 CSO Project Meters

The existing MWRA collection system meters, community meters, and operational data were supplemented by temporary project meters. A flow metering plan was developed and documented for each of the flow meter locations.

Project meters were installed at 64 regulator locations. The installations included a total of 81 meters, 106 depth and velocity sensors, 20 level sensors, and 16 inclinometers. In general, if an overflow was predicted for either a typical year storm or the 2-year, 24-hour design storm then flow was measured; otherwise a level sensor was installed. Temporary meters were installed by April 15, 2018 and remained in place with adjustments to the metering program made in March, 2019 and June, 2020 as discussed in Section 7.5.3.

Figure 7-2 presents the locations of each of the project meters used for calibration and for quantifying CSO activation frequency, duration and volume. This figure also shows the locations of the permanent MWRA interceptor meters which were only used to support model calibration. The meters located at the regulators were used for calibration, to quantify CSO activations, or in some cases both. Table 7-2 presents a description of the equipment installed at each meter location and the purpose of each meter.

Table 7-2 also indicates if a meter was identified as a trigger meter. For these meters, if the water exceeded a previously identified depth, it indicated the flow might have been going over the weir or into a high pipe overflow. These meters were important for identifying if an overflow occurred. This table also identifies if a CSO community owns and maintains the meters at a particular location.

For each location the following information was developed:

- A schematic showing location of meters, and the equipment type (level, flow, inclinometer)
- A paragraph summarizing the intent of each meter
- The meter installation and inspection sheet.

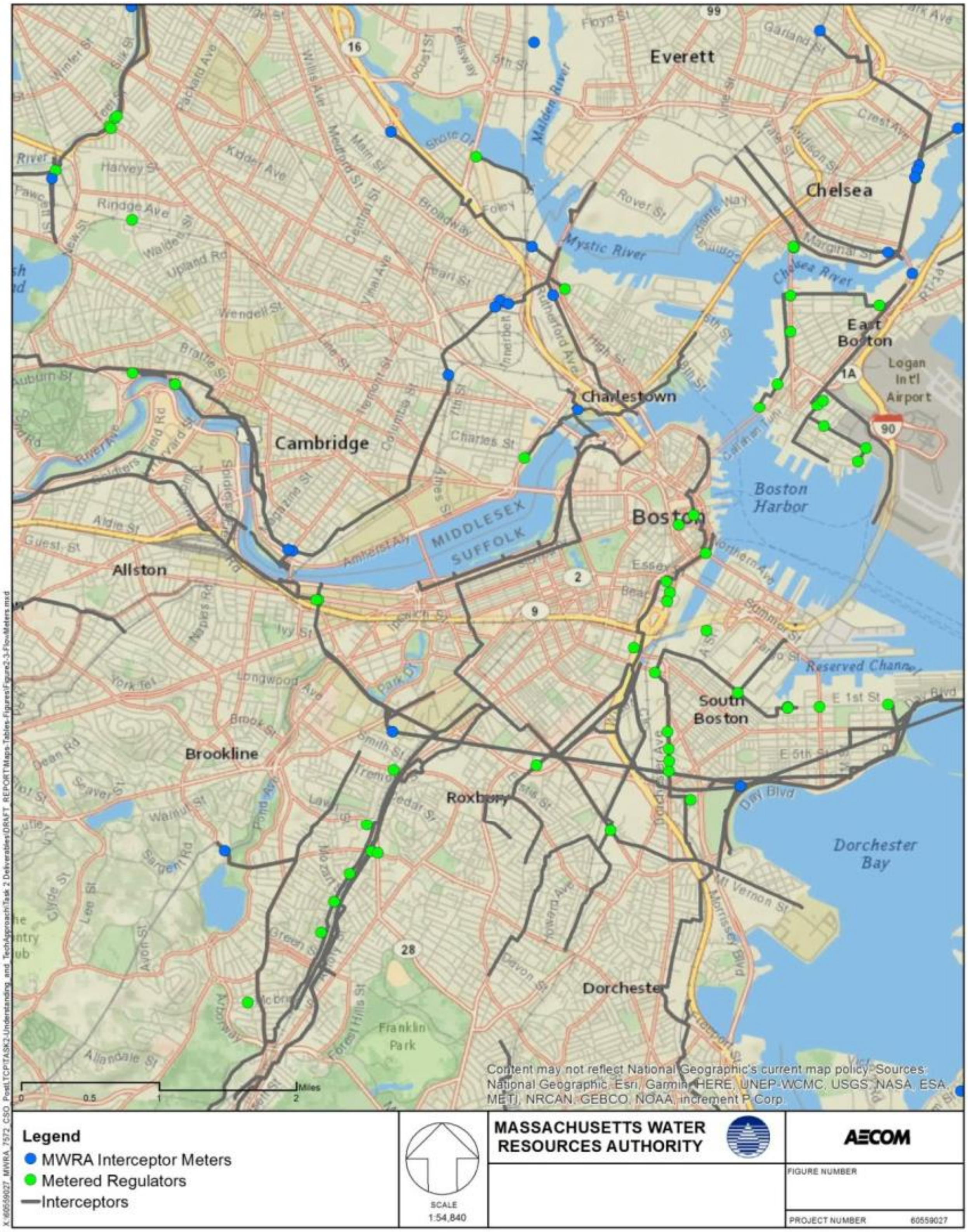


Figure 7-2. Flow Meter Locations

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 1 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters: To identify if overflow activation occurred and for model calibration	Purpose of Meters: For model calibration only	Purpose of Meters: For calculating CSO volumes and model calibration	Purpose of Meters: Trigger Meter[1]
Alewife Brook							
CAM001	RE011	RE011_M1	Influent Line #1	X			
		RE011_M1(2)	Depth only		X		Yes
		CAM001	Cambridge meter on overflow line	X			
CAM002	RE021	RE021_M1	Effluent line		X		
		RE021_M1(2)	Depth only	X			Yes
		CAM002	Cambridge meter on effluent	X			
MWR003	RE-031	RE031_M1	Influent Line #1	X			Yes
		RE031_M2	Influent Line #2		X		
		RE031_M2(2)	Influent Line #3		X		
		RE031_M3	Overflow Line (DS of weir)+Inclinometer			X	
CAM401A	RE-401	RE401a_M1	Influent Line #1	X			Yes
		RE401_M3	DWF Line - Cambridge Owned		X		
CAM401B	RE-401B	RE401b_M3	Overflow line			X	N/A[2]
		CAM401B	MWRA influent meter		X		
SOM001A	RE-01A	RE01a_M1	Influent Line #1		X		
		RE01a_M1(2)	Influent Line #2		X		
		SOM01A	Somerville overflow meter	X		X	Yes
Upper Mystic River							
SOM007A/MWR205A		MWRA205a_M3	Overflow to 205a	X			Yes
		MWRA Meter	Incoming flow		X		

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 2 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters: To identify if overflow activation occurred and for model calibration	Purpose of Meters: For model calibration only	Purpose of Meters: For calculating CSO volumes and model calibration	Purpose of Meters: Trigger Meter(1)
Mystic River/Chelsea Confluence							
BOS013	RE013-1	RE013-1_M1	Influent line #1	X			Yes
		RE013-1_M1(2)	Influent line #2		X		
		RE013-1_M3	Influent line #3		X		
		RE013-1_M3(2)	Overflow Line (DS of weir) + Inclinometer			X	
BOS014	RE014-2	RE014-2_M1	Influent line #1	X			Yes
		RE014-2_M1(2)	Influent line #2		X		
		RE014-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
		RE014-2_M1	Influent line #1	X			Yes
BOS017	RE017-3	RE017-3_M1	Influent Line #1		X		
		RE017-3_M2	Influent Line #2	X			Yes
		RE017-3_M3	Overflow Line (DS of weir)			X	
CHE003	RE-031	CHE003	Chelsea	X	X	X	Yes
CHE004	RE-041	CH004_M1	MWRA	X			Yes
		CH004_M1(2)	MWRA		X		
		CH004_M3	Chelsea			X	
CHE008	RE-081	CH008_M1	MWRA	X			Yes
		CHE008	Chelsea		X		
Upper Inner Harbor							
BOS009	RE009-2	RE009-2_M1	Influent line #1	X			Yes
		RE009-2_M1(2)	Influent line #2		X		
		RE009-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS010	RE010-2	RE010-2_M1	Influent line #1	X			Yes
		RE010-2_M1(2)	Influent line #2		X		
		RE010-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS012	RE012-2	RE012-2_M1	Influent Line	X			Yes
		RE012-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS057	RE057	RE057-6_M1	Influent Line #1		X		
		RE057-6_M3	Overflow Line			X	
		RE057-6_M3(2)	Influent Line #2	X			Yes
BOS060	RE060-7	RE060_7	Influent Line #1 + Inclinometer	X			Yes
	RE060-20	RE060-20	Influent Line #1	X		X	Yes

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 3 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters: To identify if overflow activation occurred and for model calibration	Purpose of Meters: For model calibration only	Purpose of Meters: For calculating CSO volumes and model calibration	Purpose of Meters: Trigger Meter[1]
Upper Inner Harbor							
BOS009	RE009-2	RE009-2_M1	Influent line #1	X			Yes
		RE009-2_M1(2)	Influent line #2		X		
		RE009-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS010	RE010-2	RE010-2_M1	Influent line #1	X			Yes
		RE010-2_M1(2)	Influent line #2		X		
		RE010-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS012	RE012-2	RE012-2_M1	Influent Line	X			Yes
		RE012-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS057	RE057	RE057-6_M1	Influent Line #1		X		
		RE057-6_M3	Overflow Line			X	
		RE057-6_M3(2)	Influent Line #2	X			Yes
BOS060	RE060-7	RE060_7	Influent Line #1 + Inclinometer	X			Yes
	RE060-20	RE060-20	Influent Line #1	X		X	Yes
Lower Inner Harbor							
BOS003	RE003-2	RE003-2_M1	Influent Line	X			Yes
		RE003-2_M3	Overflow Line (DS of weir) + Inclinometer			X	
	RE003-7	RE003-7_M1	Influent Line		X		
		RE003-7_M3	Overflow Line (DS of weir) + Inclinometer	X			N/A[2]
	RE003-12	RE003-12_M1	Influent line #1		X		
		RE003-12_M1(2)	Influent line #2	X			Yes
		RE003-12_M2	Influent line #3		X		
BOS003	RE003-12	RE003-12_M3	Overflow Line (DS of weir) + Inclinometer			X	
BOS004	RE004-6	RE004_6_M1	Influent Line	X			Yes
BOS005	RE005-1	RE005_1_M1	Influent Line	X			Yes
Fort Point Channel							
BOS062	RE062-4	RE062-4_M1	Influent Line #1	X			Yes
		RE062-4 M1(2)	Overflow Line (DS Weir) +Inclinometer			X	

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 4 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters			
				To identify if overflow activation occurred and for model calibration	For model calibration only	For calculating CSO volumes and model calibration	Trigger Meter[(1)]
BOS064	RE064-4	RE064-4_M1	Influent Line #1	X			Yes
		RE064-4_M2	Influent Line #2		X		
		RE064-4_M3	Overflow Line (DS Weir) +Inclinometer			X	
	RE064-5	RE064-5	Incoming combined sewer- Level Only	X			Yes
BOS065	RE065-2	RE065-2_M1	Influent Line #1	X			Yes
		RE065-2_M3	Overflow Line (DS Weir) +Inclinometer			X	
BOS068	RE068-1A	RE068-1A_M1	Incoming combined sewer- Level Only	X			Yes
BOS070 RCC	RE070/5-3	RE070_5-3	Incoming combined sewer- Level Only	X			Yes
BOS070	RE070/7-2	RE070-7-2_M1	Influent Line #1	X			Yes
		RE070-7-2_M1(2)	Overflow Line (DS Weir) +Inclinometer			X	
	RE070/8-3	RE070_8-3_M1	Influent Line #1	X			Yes
		RE070_8-3_M3	Overflow Line (DS Weir) +Inclinometer			X	
BOS070 DBC	RE070/8-6	RE070_8-6_M1	Level Only	X			
BOS070	RE070/8-7	RE070_8-7	Incoming combined sewer- Level Only	X			Yes
	RE070/8-8	RE070_8-8	Incoming combined sewer- Level Only	X			Yes
	RE070/8-13	RE070_8-13	Incoming combined sewer- Level Only	X			Yes
	RE070/8-15	RE070_8-15	Incoming combined sewer- Level Only	X			Yes
	RE070/9-4	RE070_9-4_M1	Influent Line #1	X			Yes
		RE070_9-4_M1(2)	Influent Line #2		X		
		RE070_9-4_M3	Overflow Line (DS Weir) +Inclinometer			X	
	RE070/10-5	RE070_10-5_M1	Influent Line #1		X		
		RE070_10-5_M2	Influent Line #2	X			Yes
		RE070_10-5_M2(2)	Overflow Line (DS Weir)			X	
BOS073	RE073-4	RE073-4_M3	Influent Line #1	X			Yes
		RE073-4_M3(2)	Overflow Line (DS Weir)			X	

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 5 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters: To identify if overflow activation occurred and for model calibration	Purpose of Meters: For model calibration only	Purpose of Meters: For calculating CSO volumes and model calibration	Purpose of Meters: Trigger Meter[(1)]
Reserved Channel							
BOS076	RE076/2-3	RE076_2-3_M1	Influent Line #1		X		Yes
		RE076_2-3_M2	Influent Line #2	X			
		RE076_2-3_M3	Overflow Line (DS Weir)			X	
	RE076/4-2	RE076_4-2	Influent Line #1		X		Yes
	RE076/4-3	RE076_4-3	Influent Line #1		X		Yes
		RE076_4-3(2)	Overflow Line(DS Weir)			X	
BOS078	RE078-1	RE078-1_M1	Influent Line #1	X			Yes
		RE078-1_M1(2)	Influent Line #2		X		
	RE078-2	RE078-2_M1	Dry weather Flow Line	X			Yes
	TG78	RE078_M3	Overflow Line (DS Weir) +Inclinometer			X	Yes
BOS079	RE079-3	RE079-3	Incoming combined sewer- Level Only	X			Yes
BOS080	RE080-2B	RE080-2B	Incoming combined sewer- Level Only	X			Yes
Upper Charles River							
CAM005	RE-051	RE051_M1	Influent Line #1		X		
		RE051_M1(2)	Influent Line #2		X		
		RE051_M2	Influent Line #3	X			Yes
		CAM005	Overflow line			X	
CAM007	RE-071	RE071_M1	Influent Line #1	X			Yes
		RE071_M1 (2)	Influent Line #2 (observed to be dry)		X		
		RE071_M2	Influent Line #3 (observed to be dry)		X		
		RE071_M2(2)	Overflow (DS Weir)			X	
		CAM007	Overflow meter (on Weir)			X	
Lower Charles River							
CAM017	CAM017	CAM017_M3	Overflow #1+inclonometer	X			
		CAM017_M3(2)	Overflow #2			X	
MWR010	RE37	RE037_M1	Influent Line #1	X			Yes
	RE036-9	RE036-9	Meter configuration under review	X			Yes

Table 7-2. CSO Regulator Meter Locations and Purpose of Meters (Page 6 of 6)

Outfall	Regulator	Meter Name	Description of Meter Location	Purpose of Meters			
				To identify if overflow activation occurred and for model calibration	For model calibration only	For calculating CSO volumes and model calibration	Trigger Meter(1)
MWR023	RE046-19	RE046_19	Incoming combined sewer- Level Only	X			Yes
	RE046-30	RE046_30_M1	Influent line #1	X			Yes
		RE046_30_M3	Overflow Line (DS Weir) +Inclinometer			X	
	RE046-50	RE046_50_M1	Incoming combined sewer- Level Only	X			Yes
	RE046-54	RE046_54_M1	Incoming combined sewer- Level Only	X			Yes
	RE046-55	RE046_55_M1_MP1	Incoming combined sewer- Level Only	X			Yes
	RE046-62A	RE046_62A_M1	Incoming combined sewer- Level Only	X			Yes
	RE046-90	RE046_90_M1	Incoming combined sewer- Level Only	X			Yes
	RE046-100	RE046_100_M1	Influent Line #1	X			Yes
		RE046_100_M1(2)	Influent Line #2		X		
		RE046_100_M3	Overflow Line (DS Weir) +Inclinometer			X	
	RE046-105	RE046_105_M1	Influent Line #1		X		
		RE046_105_M1(2)	Influent Line #2	X			Yes
		RE046_105_M3	Overflow Line (DS Weir)			X	
	RE046-192	RE046_192_M1	Incoming combined sewer- Level Only	X			Yes
	RE046-381	RE046_381_M1	Influent Line #1	X			Yes
		RE046_381_M3	Ultrasonic Depth US of Weir and DS of Weir			X	

(1) Trigger meters are used to indicate when the water level in the sewer exceeds the overflow elevation.
(2) This location does not have a trigger. Any amount of flow indicates an activation. Overflow is located downstream of the regulator. The inclinometer is used as indicator of overflow.

7.4 Monitoring Equipment

7.4.1 Flow monitors

FlowShark Triton flow monitors were used to measure flow depth and velocity at each monitoring location. Each Triton flow monitor can have two sensors connected to it. The sensors that were utilized on this project are listed in Table 7-3 below along with the manufacturer's specified accuracy.

Table 7-3. Summary of Flow Monitoring Sensors Used for Project

Sensor Type	Measurement Capabilities	Sensor Measurement Range	Sensor Accuracy Specification
Peak Combo Sensor	• Peak velocity using ultrasonic Doppler, • Flow depth with a pressure transducer • Flow depth with an up-looking ultrasonic sensor	• Peak Velocity: -30 fps to + 30 fps • Pressure Depth: – 5 psi sensor: 11.5' – 15 psi sensor: 34.5' • Up-looking Ultrasonic Depth: 1.5" to 60"	• Peak Velocity: +/- 0.2 fps or 4% of actual peak velocity, whichever is greater. • Pressure Depth: +/- 1% full scale. • Up-looking Ultrasonic Depth: The greater of 0.5% of reading or +/- 0.125"
Smart Depth Sensor (Down-looking ultrasonic depth)	• Flow depth using a down-looking ultrasonic sensor to measure the air range from the face of sensor to the surface of the flow. • The flow depth of flow (DOF) is calculated using the following equation: DOF = Pipe Height – P.O.- Air Range Where the P.O. is the physical offset (space occupied by the sensor itself).	• Maximum Air Range: 10 feet	• Down-looking Ultrasonic Depth: +/- 0.125"

The flow monitor housed a battery pack, the data collection hardware, and a modem enabling the monitor to communicate via wireless telemetry. Wireless telemetry allowed the monitor to be accessed remotely for activation, service, and data collection. Processes for the computation of flow from the meter data are described below in Section 7.5.

7.4.2 Inclinometers

Each metered CSO event was confirmed either at the regulator using a depth sensor or at the tide gate using an inclinometer. The decision of whether to use a depth sensor or an inclinometer depended on the physical attributes of the structure.

Tide gate movement was helpful to quantify overflow volumes during higher tide events. The Triton monitors used for this project could support the addition of limit switches or inclinometers to measure movement of tide gates. The limit switch recorded the movement of the tide gate as either open/closed, whereas inclinometers indicated movement, offered flexible installation and provided the angle of tide gate opening. Most MWRA applications utilized the inclinometers due to the more precise information provided and better reliability. As a rule, if the inclinometer showed more than five degrees of movement, it was assumed that flow was exiting the outfall. However, each case was reviewed individually to assess whether this assumption was appropriate. Figure 7-3 shows an inclinometer (black box) mounted on the side of a tide gate. The specifics of where and how to install a tide gate device were determined during inspection of the structure.

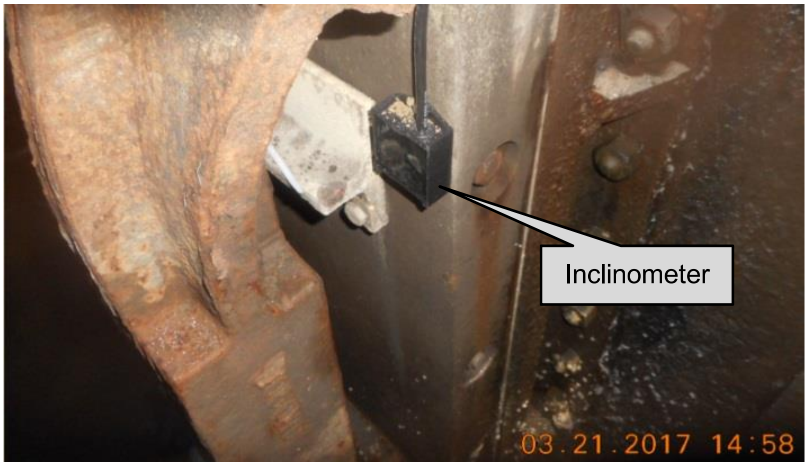


Figure 7-3. Inclinometer Installed on a Tide Gate

7.5 Meter Data Collection, Processing, and Review

This section discusses the steps taken to collect, process, and review the data for quality control purposes.

7.5.1 Meter Data Collection

Meter data were collected from the existing and temporary meters and stored in a data management system. The temporary meter data were downloaded every few hours and remotely analyzed. Meter data from community meters and existing MWRA meters were uploaded to the database on a monthly basis. Data were submitted on a 5 or 15-minute basis, depending on the frequency of data being recorded. Wireless telemetry was used to access the meters remotely for activation, service, and data collection. Raw data from the meters were evaluated three days per week during the flow monitoring period to confirm that the equipment was functioning properly. When the analyst detected irregularities in the data or a loss of wireless communication, field crews were dispatched to perform the required maintenance to achieve accuracy and maintain adequate meter uptime. Uptime is defined as the percentage of the monitoring period that is recording usable data. For example, the meter shown in Figure 7-4 would not show 100% uptime during December since meter data were not available for the entire period.

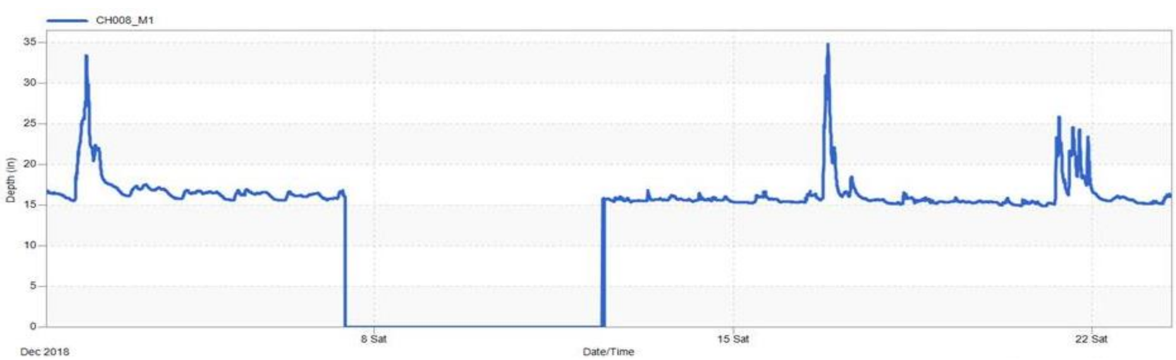


Figure 7-4. Example of Meter Data with Less than 100% Uptime

7.5.2 Meter Data Processing

Data processing consisted of a number of steps: editing of depth and velocity data identified to be inaccurate, reconstitution or use of alternate depth and velocity data, and identification of data anomalies that prevented meaningful calculations of site conditions. Processing the meter data allowed the project team to identify data that were suitable for project use versus data that should be disregarded due to quality concerns. Raw sensor data for each location were retained in the data storage system and remain unedited.

Conditions such as a build-up of debris, surcharging or hydraulic turbulence could result in the sensor equipment becoming fouled or generating incorrect data. For example, the meter in Figure 7-5 showed several spikes in depth multiple days after a storm event. When this occurred, available sensor data was used in conjunction with hydraulic theory to present a reasonable representation of the depth and/or velocity at the site. The processed data were edited to account for inaccurate data and the edited data were used in subsequent quantity calculations.

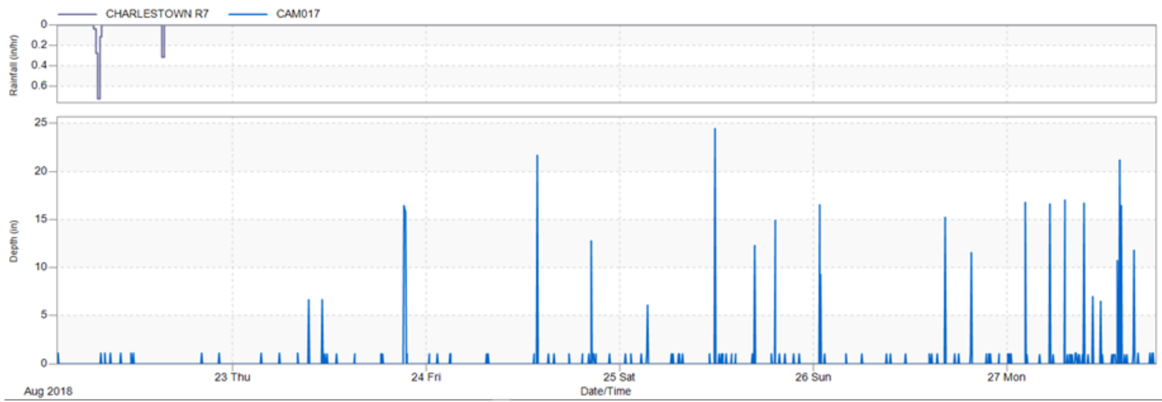


Figure 7-5. Example of Meter with Likely Incorrect Depth Measurements

Uptime is an indicator of the effectiveness and timeliness of the maintenance. In locations where a meter was not functional for most or the entire duration of a storm event, a volume was not reported and the event was flagged for missing data. If the meter was functioning for most, but not all of a storm event, the meter was flagged but volume was reported. It was understood that in this case, a portion of the volume may not have been accounted for fully.

Depth and velocity were measured and flow was calculated from these data. Depth was measured with pressure sensors (Dp) and ultrasonic sensors (Du). Depth measurements were used to assess if the water level exceeded the height of a weir or other trigger elevation (e.g., a high pipe outlet), indicating an overflow. Invalid depth data were identified through scattergraph analysis and/or hydrograph analysis. Data that did not indicate a repeatable depth versus velocity relationship or a standard hydraulic condition were further investigated.

Velocity was measured with the peak velocity sensor that was deployed in two modes: V = Doppler Velocity, with sensor facing into the flow (positive), and Vi = Intrusion Velocity, with sensor facing a tide gate to spot reverse flow through the gate. Invalid velocity data were spotted and flagged by using scattergraph and hydrograph analyses.

Velocity and depth 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 measurement multiplied by the velocity measurement. The weir equation (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 Manning's equation or the scattergraph method. If the capacity of the dry-weather flow connection was consistent throughout the storm, the overflow could be estimated using the scattergraph method by using a single flow meter in the influent line. Scattergraphs, consisting of plotted velocity versus depth recorded by the influent meter, were used to estimate the amount of flow going through the dry-weather flow connection.

The volume of discharge to the outfall was calculated by subtracting the flow through the dry-weather flow connection from the influent flow measurement. In locations where the Manning's equation or scattergraph methods were not applicable, the overflow was reported as duration only.

After initial review of the data, differences between metered and actual flow conditions still existed at some locations. Remaining differences required additional review before making model adjustments since in some cases the meter data could have been questionable. Flow measurement in hydraulically complex structures such as regulators was challenging due to turbulence in and around the structure. Turbulence could affect both depth and velocity measurements, especially during times when the flow was rapidly changing – such as during a CSO event. The presence of tidal conditions could also interfere with outfall measurements. Additional information, such as field inspections or use of a third source of data, was sometimes required to check the meter data.

7.5.3 Adjustment of Metering Program

By March 2019, sufficient meter data had been collected for model calibration and to develop a general understanding of the rainfall depth, intensity, and duration that typically resulted in the activation of each regulator. As a result, on March 1, 2019, flow metering was discontinued at 21 locations listed in Table 7-4. Data continued to be collected and analyzed at the remaining 43 regulator locations that could impact the Variance waters (Alewife Brook, Upper Mystic River, Charles River), as well as at regulators where further investigations were required given higher-than-anticipated activation frequency and volume. These meters continued to collect data to identify CSO activation frequency, duration, and volumes through June 2020.

Table 7-4. Meters Removed from the Metering Program or Converted to Permanent Meter (Page 1 of 3)

Outfall	Regulator	Meter Removed March 1, 2019	Meter Removed June 30, 2020	Temporary Meter Converted to Permanent Meter
Alewife Brook				
CAM001	RE011		X	
CAM002	RE021		X	
MWR003	RE-031			X
CAM401A	RE-401		X	
CAM401B	RE-401B		X	
SOM001A	RE-01A		X	
Upper Mystic River				
SOM007A/MWR205A				X
Mystic/Chelsea Confluence				
BOS013	RE013-1	X		
BOS014	RE014-2	X		
BOS017	RE017-3	X		
CHE003	RE-031		X	
CHE004	RE-041		X	
CHE008	RE-081		X	
Upper Inner Harbor				
BOS009	RE009-2	X		
BOS010	RE010-2	X		
BOS012	RE012-2	X		
BOS057	RE057		X	
BOS060	RE060-7		X	
	RE060-20		X	

Table 7-4. Meters Removed from the Metering Program or Converted to Permanent Meter (Page 2 of 3)

Outfall	Regulator	Meter Removed March 1, 2019	Meter Removed June 30, 2020	Temporary Meter Converted to Permanent Meter
Lower Inner Harbor				
BOS003	RE003-2	X		
	RE003-7	X		
	RE003-12		X	
BOS004	RE004-6	X		
BOS005	RE005-1	X		
Fort point Channel				
BOS062	RE062-4	X		
BOS064	RE064-4	X		
	RE064-5	X		
BOS065	RE065-2		X	
BOS068	RE068-1A	X		
BOS070 RCC	RE070/5-3	X		
BOS070	RE070/7-2		X	
	RE070/8-3		X	
BOS070 DBC	RE070/8-6		X	
BOS070	RE070/8-7		X	
	RE070/8-8		X	
	RE070/8-13		X	
	RE070/8-15		X	
	RE070/9-4		X	
	RE070/10-5		X	
BOS073	RE073-4		X	
Reserved Channel				
BOS076	RE076/2-3		X	
	RE076/4-2	X		
	RE076/4-3		X	
BOS078	RE078-1	X		
	RE078-2	X		
	TG78	X		
BOS079	RE079-3	X		
BOS080	RE080-2B	X		
Upper Charles				
CAM005	RE-051		X	
CAM007	RE-071		X	

Table 7-4. Meters Removed from the Metering Program or Converted to Permanent Meter (Page 3 of 3)

Outfall	Regulator	Meter Removed March 1, 2019	Meter Removed June 30, 2020	Temporary Meter Converted to Permanent Meter
Lower Charles				
CAM017	CAM017		X	
MWR010	RE037			X
	RE036-9			X
MWR023	RE046-19			X
	RE046-30			X
	RE046-50		X	
	RE046-54		X	
	RE046-55		X	
	RE046-62A		X	
	RE046-90		X	
	RE046-100			X
	RE046-105			X
	RE046-192		X	
	RE046-381			X

As of July 1, 2020, with the model calibration efforts complete and a substantial post-calibration metering period available to compare modeled and metered CSO discharges, the remaining temporary project meters were removed as indicated in Table 7-4. Also indicated in Table 7-4 are the locations where MWRA converted temporary project meters to permanent meters.

MWRA continues to monitor all open CSO outfalls that are owned and operated by MWRA. MWRA will continue to employ CSO metering technology at 11 CSO regulators, as well as at five outfalls associated with CSO treatment facilities, and six outfalls associated with the CSO storage facilities at the South Boston beaches and Outfall BOS019 (Table 7-5). These locations are now part of the CSO Notification program described further below.

Table 7-5. MWRA Monitoring Locations

CSO Outfalls and Regulators	CSO Treatment Facility Outfalls	Outfalls with Storage Facilities
MWR003	Somerville Marginal- MWR205	BOS019
MWR010 RE36-9/RE037	Somerville Marginal- SOM007A/MWR205A	BOS081, BOS082, BOS084, BOS085, BOS086
MWR018	Prison Point (MWR203)	
MWR019	Union Park (MWR215)	
MWR020	Cottage Farm (MWR201)	
MWR023 (RE046-19, RE046-30, RE046-100, RE046-105, RE046-381)		

MWRA will continue to collect, analyze and use data from these permanent CSO meters, along with data from permanent meters in MWRA's interceptor system. The CSO communities (BWSC and the cities of Cambridge, Chelsea and Somerville) have equipment in place to measure CSO activations and/or volumes at regulators associated with their permitted outfalls.

7.5.4 CSO Notification Program

MWRA has implemented a "CSO Alert Notification" using a subscriber-based system to provide details of an MWRA CSO discharge within four hours of activation, including information on location and start time and a link to additional details on MWRA's website. This program was initiated in July 2020 (in advance of the requirement in the CSO variances to have the system in place by December 31, 2020). This program provides rapid notification for the six untreated and five treated MWRA CSO outfalls and the BWSC outfalls associated with the MWRA storage facilities at Little Mystic Channel (BOS019) and the South Boston beaches (BOS081-BOS086). The notification program provides subscribers with text and/or email notifications of CSO activations. Table 7-6 identifies the CSO outfalls that MWRA monitors and that are part of the CSO notification program. An example of the CSO notification website is shown in Figure 7-6 with the locations monitored (see Table 7-6 for letter key).

Table 7-6. MWRA Monitored CSOs in the MWRA Notification Program

CSO Outfall	Outfall Location	Potentially Affected Area	Location (Figure 7-6)
SOM007A/ MWR205A (Somerville Marginal)	Baxter Park/Assembly Row, just downstream of Rte. 28 Bridge	Mystic River	A
MWR205 (Somerville Marginal)	Draw Seven Park	Lower Mystic River (marine)	B
BOS019	Charlestown, near mouth of Little Mystic Channel	Little Mystic Channel and confluence of Mystic and Chelsea Rivers	C
MWR203 (Prison Point)	Upper Inner Harbor, upstream of N. Washington St. bridge	Boston Inner Harbor	D
MWR215 (Union Park)	Head of Fort Point Channel near the Broadway Street Bridge	Fort Point Channel	E
BOS081-086	South Boston beaches along Day Boulevard	South Boston beaches, North Dorchester Bay	F
MWR020	Downstream end of Charles R. Esplanade	Charles River between Esplanade and Science Museum	G
MWR019	Middle of Charles River Esplanade	Charles River between Esplanade and Science Museum	H
MWR018	Upstream end of Charles R. Esplanade	Charles River between Esplanade and Science Museum	I
MWR023	Boston side of river, near Fenway exit from Storrow Drive	Charles River from just upstream of Harvard Bridge (Mass. Ave.) to Science Museum	J
MWR010	Charles River near Boston University	Charles River between the Boston University Bridge and Science Museum	K
MWR201 (Cottage Farm)	Cottage Farm CSO Storage and Treatment Facility, Between Magazine Park and BU Bridge	Charles River from just upstream of the Boston University Bridge to Science Museum	L
MWR003	Alewife Brook Reservation near Alewife T station	Little River and Alewife Brook	M

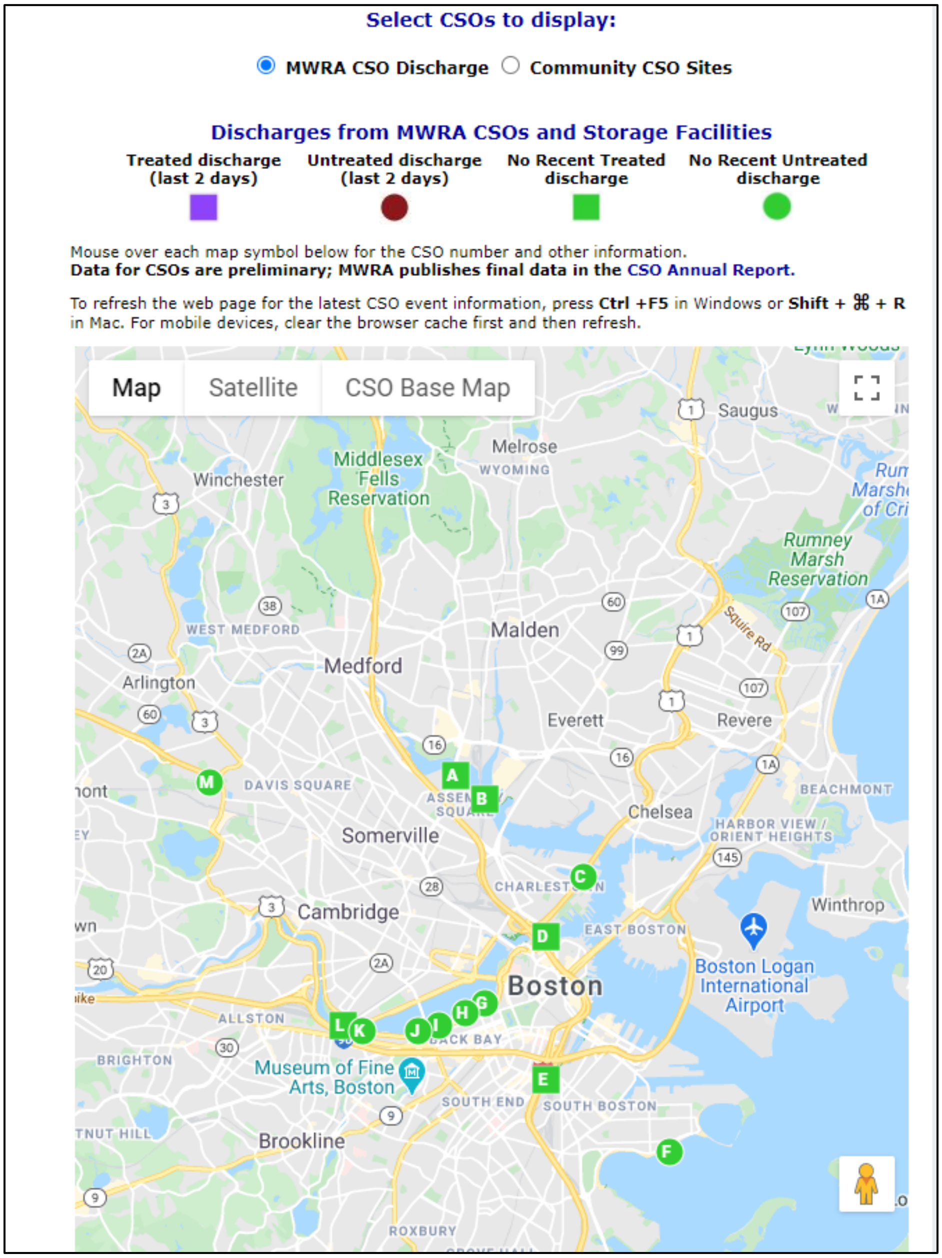


Figure 7-6. MWRA CSO Notification Reporting

8. Summary of Metered CSO Discharges

8.1 Chapter Synopsis

Meter data collected at each CSO regulator were used to assess whether a CSO activation occurred and if so to estimate the discharge volume if feasible based on meter configuration. Various methods were used to review the accuracy and reasonableness of the measured CSO activations.

Overall, the meter data was of good quality and the majority of the data was able to be used to assess CSO activation frequency and volume for comparison to the model results.

8.2 Summary of Methods Used for Metered CSO Discharge

This section describes the methods used to check metered CSO activations. 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 assessment of measured CSO activations may have included one or more of the following methods:

- Direct measurement from 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;
- Chalking of level-only meter configurations to assess how well the meter depth compared with depth recorded by the chalk;
- Correlation of CSO activation with rainfall depth and intensity;
- Calculation of CSO discharge using alternate methods; and
- Evaluation of reasonableness of meter data.

Each of these methods is discussed further below.

8.2.1 Direct Measurement

When the meters were installed, and at site visits, direct measurements of the depth recorded by the meter were made using a ruler and deviations were corrected. The depth measurements were made during dry weather due to safety concerns related to entering the manhole during storm events. Confirmation of depth measurements during dry weather provided an indication that the meter was functioning properly.

8.2.2 Comparison with Other Meters

In many cases, multiple meters were installed at a regulator. For example, influent meters may have been installed on each of two influent pipes at a particular regulator, and comparison of the depth measurements recorded by the two meters provided an indication that the depth sensors were operating properly. In other cases, a depth sensor may have been located upstream of the overflow weir and a flow meter installed downstream in the overflow line. The depth sensor upstream of the weir was used as a “trigger” meter to identify if the water level exceeded the overflow elevation. In this case, comparison of the times when the water level upstream of the weir exceeded the weir elevation with the flow recorded downstream in the overflow line increased confidence that flow recorded by the flow meter was reasonable.

Comparing inclinometer readings to overflow meters provided another useful comparison. If the flow meter was located downstream of a tide gate and the inclinometer showed the tide gate did not open, then the flow recorded by the flow meter was likely not due to CSO but due to some other source such as stormwater entering downstream of the tide gate.

8.2.3 Assessment of How Flow Meters Conform to Hydraulic Theory

Scattergraphs of velocity versus depth were analyzed to assess if data collected by the flow meters on the influent lines adhered to hydraulic theory, forming expected hydraulic patterns. If the data conformed to hydraulic theory, then the data were considered reasonable. An example of a velocity versus depth scattergraph is shown in Figure 8-1 for regulator RE04-6 (BOS004). This scattergraph shows a repeatable pattern in open channel depths where the data predominately followed the expected hydraulic theory (Manning's equation) as represented by the solid black line. If the data did not conform to hydraulic theory, then the data would need to be checked by other means.

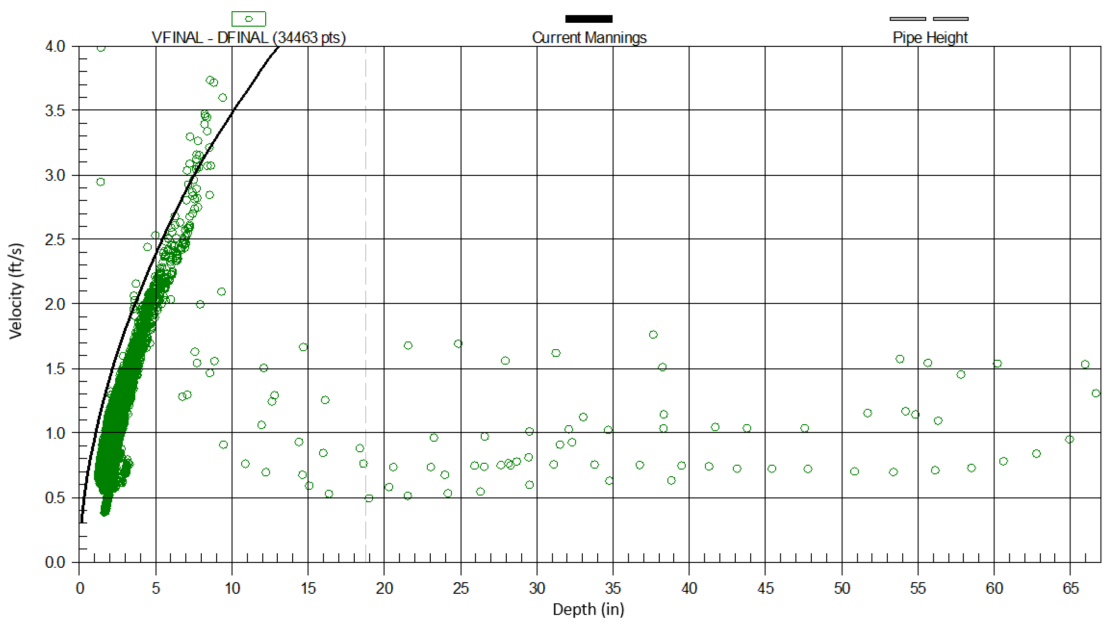


Figure 8-1. Scattergraph for RE04-6 (BOS004) Showing Meter Conforms to Hydraulic Theory

8.2.4 Correlation of Influent Flow Volume with Rainfall

Flow in influent lines was expected to be correlated with rainfall. In general terms, the higher the rainfall, the higher the flow. Plots of flow volume versus rainfall depth were analyzed at regulator sites with flow meters installed on incoming lines. An example is shown in Figure 8-2 for regulator RE030-7. This evaluation was not applied at sites that did not have metering of incoming lines. For example, meter results for overflow lines would not be expected to show a strong correlation between rainfall and flow because of the variable fraction of flow passing through the dry weather flow connection. If influent flow volume was correlated with rainfall, that provided additional confirmation that the results were reasonable. If the influent flow volume was not reasonably correlated, then additional investigation was required. For example, poor correlation could be due to factors such as seasonal variation, in which a storm in the spring produced more flow than a similar storm in the summer or fall.

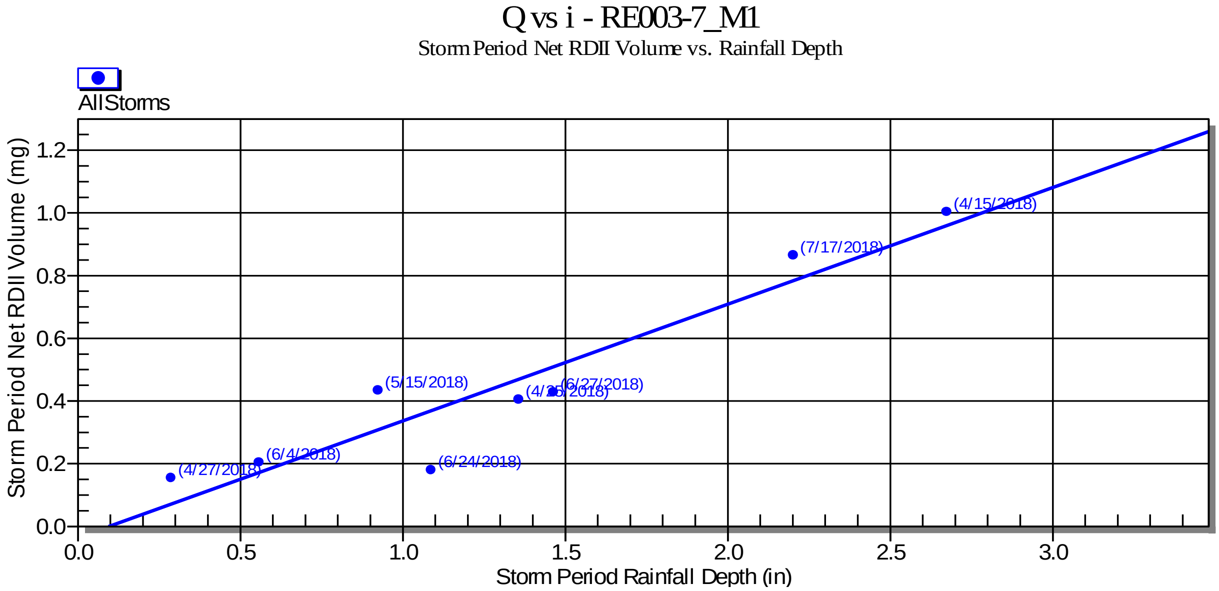


Figure 8-2. Plot of Wet Weather Volume versus Storm Depth for RE03-7 (BOS003)

8.2.5 Chalking

Chalking was another method used to confirm whether level sensors were operating correctly. This method was applied at sites where only level was measured and where meter data indicated an overflow occurred, but the field inspection observations indicated that no overflow occurred.

Chalk was applied in the upstream invert of the overflow pipe or weir structure. Figure 8-3 shows an example of chalking at regulator RE070/8-8. Following a storm event, the regulator structure was re-visited to identify if the chalk in the overflow pipe had been washed away by an overflow. However, in many locations where chalking was applied, results were inconclusive. Chalk may have been washed away by non-CSO activity, such as groundwater or tidal water leaking into the regulator structure.

Figure 8-3. Chalking Applied to the Overflow Pipe at RE070/8-8

8.2.6 Correlation of CSO Activation with Rainfall Depth and Intensity

Scattergraphs correlating rainfall intensity and rainfall volume were used to identify if a CSO was triggered by rainfall intensity or volume and to check the reasonableness of metered CSO discharges. A scattergraph which plotted rainfall depth against rainfall intensity for each monitored storm event was created for each regulator. Within the plots, solid circles represented storms with metered activations, and hollow circles represented storms with no activation per the meters. The scattergraphs included the rain events for the period in which meter data was collected. Figure 8-4 presents an example scattergraph for regulator RE03-7. This figure shows that the regulator appeared to activate when a rainfall event had an intensity of 0.6 in/hr or greater, while rainfall depth did not appear to be a clear indicator of activations. Activation at this regulator therefore appeared to be driven by rainfall intensity as opposed to rainfall depth. The scattergraphs for each of the metered regulator locations are provided in Semiannual Reports Nos. 1 through 5.

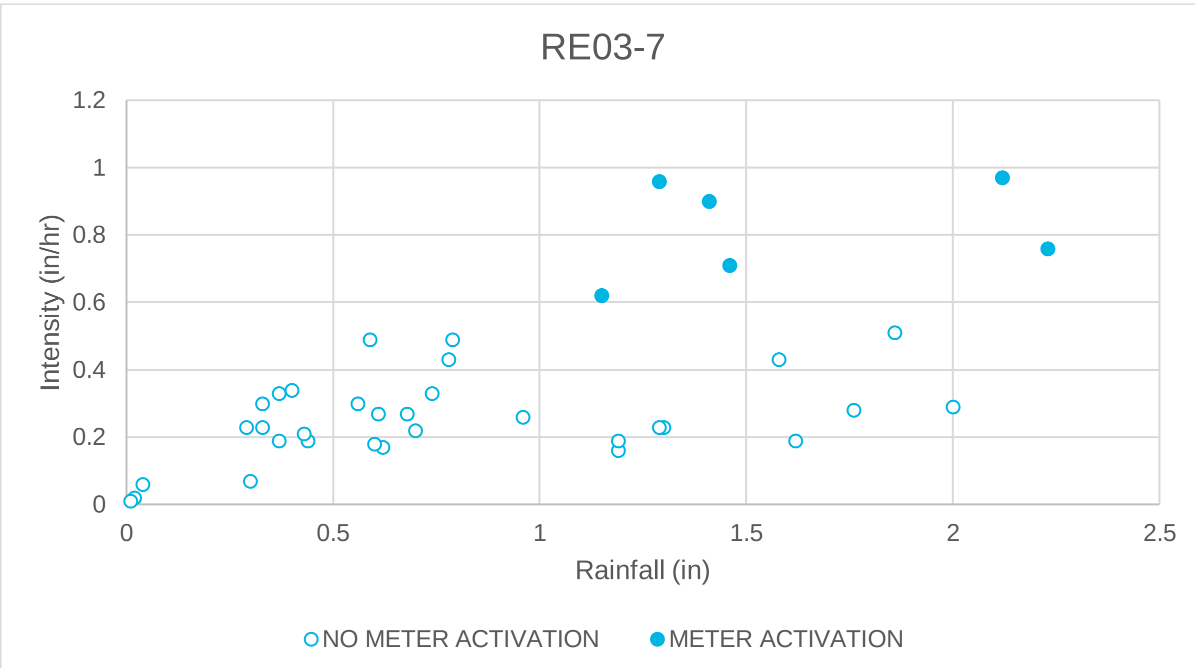


Figure 8-4. Meter Review Scattergraph for Regulator RE030-7

Each of the scattergraphs prepared was reviewed to see if a meter showed an activation for a rainfall event in which the intensity and/or rainfall depth were not consistent with the other plotted activations. If this were the case, then the data point would be considered potentially suspect. Suspect meter results were reviewed. In some instances, this review assisted in identifying locations where the trigger level was not applied properly or where the meter configuration needed to be adjusted to improve capture of CSO activations. If metering data were suspect or missing for part or all of a storm event, the point was excluded from the scattergraph analysis.

8.2.7 Calculation of CSO Discharge

When the meter data indicated that an activation occurred, the CSO volume was calculated using various methods depending on the meter configuration. As described above under Section 7.5.2 Meter Data Processing, the methods included continuity, continuity by subtraction, or a weir equation. Refer to Section 7.5.2 for more detail on these methods. Table 8-1 identifies the locations where CSO calculation methods other than the continuity equation were applied. In locations where the continuity methods or alternative methods could not be used, then the overflow was reported as duration only.

Table 8-1. Locations where Alternative (non-Continuity Equation) CSO Calculation Methods were Used

Outfall	Regulator	Calculation Method
BOS014	RE014-2	Scattergraph Method
BOS009	RE090-2	Scattergraph Method
BOS010	RE010-2	Scattergraph Method
BOS057	RE057-6	Weir Equation
BOS060	RE060-7	Scattergraph Method
BOS004	RE040-6	Scattergraph Method

9. Summary of Rainfall and Rainfall Analyses

9.1 Chapter Synopsis

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 depth during storm events. Rainfall data is also the primary input for the collection system model which is used to assess CSO performance in the MWRA sewer system.

Rainfall data from April 15, 2018 to June 30, 2021 were collected, reviewed and analyzed. The analysis included the characterization of the return period of each storm event and a comparison of measured rainfall for each period to the rainfall included in the Typical Year.

Rainfall was quantified using 15-minute rainfall data collected at 20 rain gauges distributed over the MWRA system, generally within the Interstate I-95 belt. Three of the 20 rain gauges were removed on June 30, 2020 because they were temporary meters installed for model calibration. Data from the remaining 17 continued to be collected and for this report, were analyzed through June 30, 2021.

The rainfall data were used to support model calibration activities as well in developing model predictions of CSO discharges for comparison to measured CSO volumes and activations during the monitoring period.

While the rainfall data from the monitoring periods varied somewhat from the Typical Year as would be expected, in general the rainfall was not radically different. Table 9-1 presents the total depth and number of storms within various depth ranges for each monitoring period in comparison to the Typical Year. Normalized annual averages for the monitoring period are also presented. The normalized annual averages were computed by summing the values from the individual periods, dividing by 39 (the number of months from April 2018 to June 2021), and multiplying by 12. Looking at the normalized values, the total annual rainfall and total number of storms were both slightly higher than the Typical Year. The number of storms within each depth category were generally similar. The total number of storms greater than one inch was exactly the same (14), although the normalized data from the monitoring period had more storms in the 1.0 to 2.0-inch range, and fewer storms in the greater-than 2.0-inch range. Storms in the greater-than 2.0-inch range would tend to generate the highest CSO volumes.

Table 9-1. Comparison of Total Depth and Number of Storms for Each Period Compared to Typical Year

Monitoring Period	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**
April 15-December 2018	42.45	78	34	14	15	13	2
January -December 2019	49.07	112	58	24	14	12	4
January to December 2020	40.47	87	41	17	17	8	3
January to June 2021	22.82	42	20	7	10	4	2
Normalized Average for Period	48	98	47	19	17	11	3

Note: For metered data the average of the gauges is provided.

Peak rainfall intensities can also drive CSO activations and volumes. The number of storms with peak intensities greater than 0.4 inches per hour in the Typical Year was generally similar to the annual numbers from the monitoring periods, although four storms in the monitoring period had peak intensities that exceeded the maximum peak intensity in the Typical Year.

After analyzing the rainfall for these periods it is apparent that the rainfall is highly variable which shows the importance of using the Typical Year as a way to assess performance. In addition, when evaluating differences between meter and model at certain locations, it was observed that some storms during the monitoring period exhibited variability in the location and timing of the rainfall across the project area, while other storms were more uniform. The Typical Year is conservative in that respect because it assumes uniform rainfall across the project area.

Overall the rainfall data was of good quality and the majority of the data were able to be used to support the collection system model calibration and the meter versus model comparisons for the monitoring period.

9.2 Introduction

This chapter presents the methodology for collecting and reviewing the rainfall data measured during the Post Construction Compliance Monitoring Report period, along with the results of the rainfall analysis. The rainfall data from April 15, 2018 through June 30, 2021 were analyzed. The analysis of data is broken down into four annual or partial-year periods:

- April 15, 2018 to December 31, 2018
- January 1, 2019 to December 31, 2019
- January 1, 2020 to December 31, 2020
- January 1, 2021 to June 30, 2021

The analysis included the characterization of the return period of each storm event and a comparison of measured rainfall for each period to the Typical Year rainfall. An overall summary of the data set in comparison to the Typical Year is presented at the end of this chapter (and was included in the Synopsis above).

9.3 Methodology for Rainfall Data Collection and Analysis

Rainfall was quantified using 15-minute rainfall data collected at 20 rain gauges distributed over the MWRA system, generally within the Interstate I-95 belt. The rain gauges are listed in Table 9-2 and the locations are shown in Figure 9-1. Following the guidelines outlined in the EPA's 1999 *Combined Sewer Overflow Guidance for Monitoring and Modeling* (EPA, 1999), existing rain gauges were selected to provide spacing of approximately three miles apart across the project area. The rain gauges were operated and maintained by MWRA, the BWSC, and the United States Geological Survey (USGS). Based on the geographic distribution of the existing rain gauges, three additional project gauges were needed to achieve the three mile rain gauge density recommended in the EPA's 1999 guidance document. The three added gauges were the Lexington Farm, Spot Pond and Waltham Farm gauges.

While data from each of the 20 rain gauges listed in Table 9-2 were analyzed, four rain gauges in the combined sewer areas were analyzed in greater detail to characterize the storms that occurred during the monitoring period and to assess how they compared to the Typical Year rainfall. These four rain gauges were the MWRA gauges located at the Ward Street, Columbus Park, and Chelsea Creek Headworks, and the USGS gauge located at Fresh Pond.

Quality assurance and quality control were 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 was reviewed for irregularities. Rain gauges with significantly higher or lower total rainfall depths than other gauges, and unusual hyetograph shapes, were flagged as suspect and further reviewed.

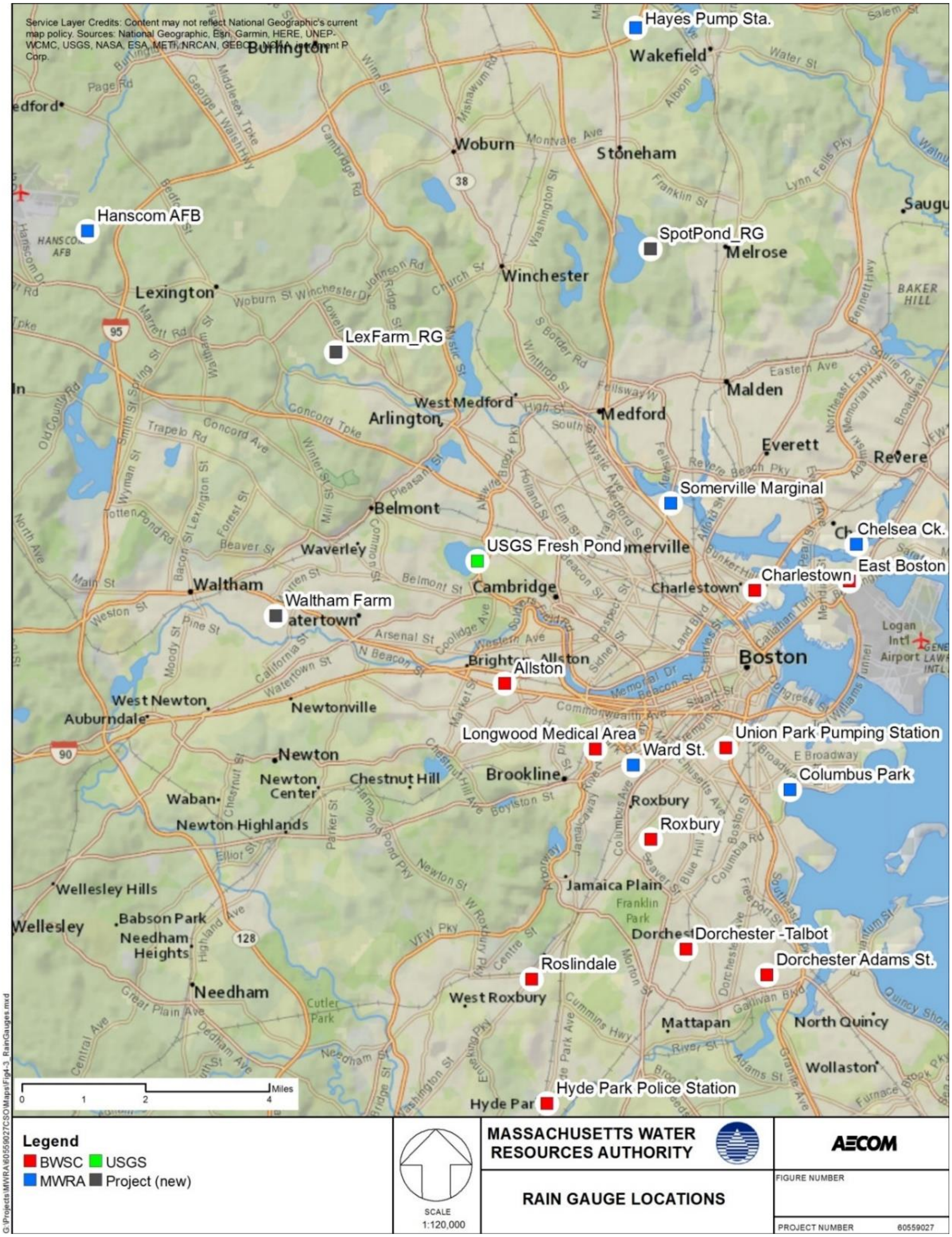


Figure 9-1. Rain Gauge Location Plan

Table 9-2. Rain Gauges

Gauge Code	Name	Owner
BO-DI-1	Ward St.	MWRA
BO-DI-2	Columbus Park	MWRA
BWSC001	Union Park Pump Station	BWSC
BWSC002	Roslindale	BWSC
BWSC003	Dorchester Adams St.	BWSC
BWSC004	Allston	BWSC
BWSC007	Charlestown	BWSC
EB	East Boston	BWSC
BWSC008	Longwood Medical	BWSC
BWSC005	Hyde Park	BWSC
BWSC006	Dorchester -Talbot	BWSC
Rox	Roxbury	BWSC
CH-BO-1	Chelsea Creek	MWRA
FRESH_POND	USGS Fresh Pond	USGS
HF-1C	Hanscom AFB	MWRA
RG-WF-1	Hayes Pump Station	MWRA
SOM	Somerville Remote	MWRA
Lex	Lexington Farm	Project
SP	Spot Pond	Project
WF	Waltham Farm	Project

Suspect or missing rain gauge data were replaced with data from the rain gauge in closest linear proximity (Table 9-3). If the closest gauge also had suspect data, the second closest rain gauge was used. Rainfall data used for the analysis for each period are provided in the semiannual report for that period.

As of July 1, 2020, with the model calibration efforts complete and a substantial post-calibration metering period available to compare modeled and metered CSO discharges, the project rain gauges (Lexington Farm, Spot Pond, and Waltham Farm) were removed from operation. In accordance with the procedure of replacing suspect or missing rainfall data, the project gauges were replaced with the next closest gauge still in operation.

Table 9-3. Closest Rain Gauges for Data Substitution (Page 1 of 2)

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

Table 9-3. Closest Rain Gauges for Data Substitution (Page 2 of 2)

Origin Gauge		Closest Gauge		Second Closest Gauge	
Gauge Name	**Gauge Code**	**Gauge Code**	**Distance (mi)**	**Gauge Code**	**Distance (mi)**
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	Rox	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

Intensity-Duration-Frequency (IDF) analysis was used to characterize the return period for each storm event. 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) (Hershfield, 1963), and *Technical Paper 49, Two-To Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States* (TP-49) (Miller, 1964), with values extrapolated for the 3- and 6-month storms. These methods were used to be consistent with previous planning efforts. Table 9-4 presents the rainfall intensities for 1-hour, 24-hour, and 48-hour duration storms with recurrence intervals ranging from 3 months to 100 years based on TP-40 and TP-49.

Table 9-4: Rainfall Intensity-Duration-Frequency Data from TP-40/TP-49

	Intensity for Recurrence Interval (in/hr)								
Duration	**3-Month(1)**	**6-Month(1)**	**1-Year**	**2-Year**	**5-Year**	**10-Year**	**25-Year**	**50-Year**	**100-Year**
1-Hour	0.570	0.710	0.900	1.180	1.550	1.800	2.100	2.420	2.700
24-Hour	0.079	0.096	0.104	0.129	0.163	0.188	0.225	0.246	0.271
48-Hour	N/A(2)	N/A(2)	N/A(2)	0.078	0.102	0.121	0.141	0.160	0.177

(1) Denotes extrapolated values

(2) TP-40 does not provide 3-month, 6-month, or 1-year recurrence intervals for 48-hour duration storms

The following sections present the analysis of rainfall broken down into the four time periods noted above in Section 9.2.

9.4 April 15, 2018 to December 31, 2018

This section presents the analysis of rainfall from the period of April 15, 2018 through December 31, 2018.

9.4.1 Rainfall Data Collection and Processing

As described in Section 9.3, 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 9-3). Replacement of suspect data from the period of April 15, 2018 through

December 31, 2018 is summarized in Table 9-5. Rainfall data used for the analysis are provided in Semiannual Report No. 2.

Table 9-5. Summary of Rainfall Data Replacement from the period of April 15, 2018 through December 31, 2018

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Ward St. (BO-DI-1)	05/21/2018 9:00	05/21/2018 10:30	Longwood Medical
	07/17/2018 9:00	07/17/2018 10:00	
	07/17/2018 22:45	07/23/2018 11:30	
Columbus Park (BO-DI-2)	07/17/2018 12:00	07/17/2018 13:00	Union Park Pumping Station
	07/29/2018 6:30	07/31/2018 11:30	
Chelsea Ck. (CH-BO-1)	06/05/2018 0:00	06/30/2018 23:45	East Boston
	07/01/2018 0:00	07/20/2018 0:00	
	09/17/2018 10:00	09/17/2018 11:00	
	10/22/2018 7:30	10/22/2018 10:30	
	12/14/2018 13:00	12/14/2018 14:00	
Hanscom AFB (HF-1C)	4/15/2018 0:00	12/31/2018 23:45	Lexington Farm
Allston	10/08/2018 0:00	12/31/2018 23:45	Longwood Medical
Dorchester Adams	11/23/2018 0:00	12/31/2018 23:45	Roxbury
Dorchester Talbot	09/26/2018 0:00	10/21/2018 0:00	Dorchester Adams
	11/20/2018 0:00	12/31/2018 23:45	Roxbury
USGS Fresh Pond	10/30/2018 10:30	10/30/2018 12:30	Longwood Medical (1)
	12/28/2018 0:00	12/28/2018 23:45	
Somerville	04/15/2018 0:00	12/31/2018 23:45	Charlestown

(1) Replacement gauges for USGS Fresh Pond were unavailable for the period. The third closest gauge, Longwood Medical, was used as the replacement.

9.4.2 Monitored Storms and Comparison with Typical Year

For the period of April 15 to December 31, 2018, 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 shown in Table 9-4. An algorithm was used to interpolate between recurrence intervals. Storm events were defined as having a minimum inter-event time of 12 hours and a threshold of 0.01 in/hr. Storm recurrence intervals were only calculated for 48-hour storms if the duration was greater than or equivalent to 48 hours. Table 9-6 presents the summary of storm events for Ward Street Headworks for the period of April 15 to December 31, 2018. These data show that 74 storm events occurred in that 8.5-month period at the Ward Street rain gauge. Most of the events had recurrence intervals of less than 3 months, while two events reached a 3-month recurrence interval at 24-hour duration. Two events reached 2-year recurrence intervals at 1-hour duration, but had lower recurrence intervals at 24-hour duration. Tables summarizing the storm events from April 15 - December 31, 2018 for the other rain gauges are provided in Semiannual Report No. 2.

Table 9-6. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for April - December 2018 (Page 1 of 3)

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	04/15/2018 21:45	22	2.43	0.11	0.47	0.10	0.05	<3m	6m	<3m
2	04/19/2018 7:00	8.75	0.24	0.03	0.09	0.01	0.01	<3m	< 3m	<3m
3	04/25/2018 6:30	25.5	1.07	0.04	0.29	0.04	0.02	<3m	<3m	<3m
4	04/27/2018 13:30	4.5	0.42	0.09	0.15	0.02	0.02	<3m	<3m	<3m
5	04/29/2018 9:00	2.5	0.05	0.02	0.03	0.00	0.01	<3m	<3m	<3m
6	04/30/2018 11:00	12	0.17	0.01	0.05	0.01	0.00	<3m	<3m	<3m
7	05/03/2018 15:30	0.5	0.04	0.08	0.04	0.00	0.00	<3m	<3m	N/A
8	05/04/2018 5:15	6	0.02	0.00	0.01	0.00	0.00	<3m	<3m	N/A
9	05/06/2018 21:00	4	0.24	0.06	0.17	0.01	0.01	<3m	<3m	N/A
10	05/10/2018 4:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
11	05/12/2018 12:15	7.25	0.25	0.03	0.12	0.01	0.01	<3m	<3m	N/A
12	05/15/2018 17:15	3	0.98	0.33	0.67	0.04	0.02	3-6m	<3m	N/A
13	05/19/2018 13:00	14.75	0.28	0.02	0.06	0.01	0.01	<3m	<3m	N/A
14	05/20/2018 15:45	3	0.04	0.01	0.03	0.01	0.01	<3m	<3m	N/A
15	05/22/2018 19:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
16	05/23/2018 20:30	1.25	0.05	0.04	0.04	0.00	0.00	<3m	<3m	N/A
17	05/27/2018 18:15	12.5	0.08	0.01	0.02	0.00	0.00	<3m	<3m	N/A
18	06/02/2018 15:30	1	0.03	0.03	0.03	0.00	0.00	<3m	<3m	N/A
19	06/04/2018 5:30	10.75	0.76	0.07	0.22	0.03	0.00	<3m	<3m	N/A
20	06/05/2018 13:30	6.25	0.26	0.04	0.18	0.01	0.00	<3m	<3m	N/A
21	06/18/2018 19:15	2.5	0.21	0.08	0.17	0.01	0.00	<3m	<3m	N/A
22	06/24/2018 19:00	10.25	0.48	0.05	0.22	0.02	0.00	<3m	<3m	N/A
23	06/27/2018 23:15	15.5	1.21	0.08	0.68	0.05	0.00	3-6m	<3m	N/A
24	07/06/2018 10:30	1.75	0.37	0.21	0.26	0.02	0.01	<3m	<3m	N/A
25	07/11/2018 0:00	6.75	0.13	0.02	0.12	0.01	0.00	<3m	<3m	N/A
26	07/14/2018 22:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
27[2]	07/17/2018 13:15	13	2.39	0.18	1.14	0.10	0.05	2yr	6m	N/A
28[2]	07/22/2018 4:00	33.5	0.38	0.01	0.12	0.01	0.01	<3m	<3m	N/A
29	07/25/2018 2:30	38.5	0.68	0.02	0.36	0.02	0.01	<3m	<3m	N/A
30	08/03/2018 13:00	0.25	0.1	0.40	0.1	0.00	0.00	<3m	<3m	N/A
31	08/04/2018 9:30	2.5	0.66	0.26	0.52	0.03	0.02	<3m	<3m	N/A
32	08/08/2018 13:45	16.25	0.73	0.04	0.32	0.03	0.02	<3m	<3m	N/A
33	08/11/2018 10:30	34.75	2.36	0.07	1.46	0.09	0.05	4yr	3-6m	N/A
34	08/13/2018 17:00	6.75	0.28	0.04	0.2	0.01	0.04	<3m	<3m	N/A
35	08/14/2018 12:30	0.25	0.01	0.04	0.01	0.01	0.01	<3m	<3m	N/A

Table 9-6. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for April - December 2018 (Page 2 of 3)

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
36	08/17/2018 16:15	9	0.2	0.02	0.16	0.01	0.00	<3m	<3m	N/A
37	08/18/2018 16:00	7.25	0.15	0.02	0.08	0.01	0.01	<3m	<3m	N/A
38	08/19/2018 21:45	0.25	0.02	0.08	0.02	0.00	0.00	<3m	<3m	N/A
39	08/22/2018 6:45	8.75	0.12	0.01	0.1	0.01	0.00	<3m	<3m	N/A
40	09/06/2018 15:45	2.25	0.11	0.05	0.08	0.00	0.00	<3m	<3m	N/A
41	09/07/2018 7:15	0.25	0.01	0.04	0.01	0.01	0.00	<3m	<3m	N/A
42	09/10/2018 16:30	15.75	1.31	0.08	0.32	0.05	0.03	<3m	<3m	N/A
43	09/12/2018 10:45	18.25	0.9	0.05	0.44	0.04	0.03	<3m	<3m	N/A
44	09/18/2018 1:30	12.75	1.18	0.09	0.63	0.05	0.02	3-6m	<3m	N/A
45	09/19/2018 3:30	0.25	0.01	0.04	0.01	0.05	0.02	<3m	<3m	N/A
46	09/22/2018 2:00	0.75	0.06	0.08	0.06	0.00	0.00	<3m	<3m	N/A
47	09/25/2018 11:00	18.25	1.82	0.10	0.84	0.08	0.04	6m-1yr	3m	N/A
48	09/26/2018 22:15	10.5	0.36	0.03	0.27	0.02	0.05	<3m	<3m	N/A
49	09/28/2018 5:45	5.5	0.44	0.08	0.16	0.02	0.02	<3m	<3m	N/A
50	10/01/2018 15:45	37.25	0.67	0.02	0.15	0.02	0.01	<3m	<3m	N/A
51	10/07/2018 17:00	2	0.03	0.02	0.02	0.00	0.00	<3m	<3m	N/A
52	10/08/2018 16:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
53	10/11/2018 13:30	18.5	0.71	0.04	0.28	0.03	0.01	<3m	<3m	N/A
54	10/13/2018 7:45	4.25	0.14	0.03	0.05	0.01	0.02	<3m	<3m	N/A
55	10/15/2018 14:00	11	0.11	0.01	0.06	0.00	0.00	<3m	<3m	N/A
56	10/21/2018 7:00	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
57	10/23/2018 13:00	5.25	0.29	0.06	0.13	0.01	0.01	<3m	<3m	N/A
58	10/24/2018 10:15	2.75	0.04	0.01	0.03	0.01	0.01	<3m	<3m	N/A
59	10/27/2018 6:00	26	1.65	0.06	0.27	0.07	0.03	<3m	<3m	N/A
60	10/29/2018 4:15	8.5	0.77	0.09	0.41	0.03	0.04	<3m	<3m	N/A
61	11/01/2018 8:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
62	11/02/2018 3:15	33.75	1.91	0.06	0.53	0.07	0.04	3m	3m	N/A
63	11/05/2018 17:45	26.75	1.2	0.04	0.17	0.05	0.03	<3m	<3m	N/A
64	11/09/2018 18:30	19.75	1.6	0.08	0.45	0.07	0.03	<3m	<3m	N/A
65	11/13/2018 1:00	13	1.23	0.09	0.18	0.05	0.03	<3m	<3m	N/A
66	11/16/2018 1:45	7.75	1.43	0.18	0.39	0.06	0.03	<3m	<3m	N/A
67	11/19/2018 1:45	40	0.63	0.02	0.09	0.02	0.01	<3m	<3m	N/A
68	11/25/2018 1:00	10.5	0.84	0.08	0.39	0.04	0.02	<3m	<3m	N/A
69	11/26/2018 8:45	22.25	1.58	0.07	0.19	0.07	0.04	<3m	<3m	N/A
70	12/02/2018 2:45	15.75	0.8	0.05	0.16	0.03	0.00	<3m	<3m	N/A

Table 9-6. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for April - December 2018 (Page 3 of 3)

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
71	12/16/2018 11:45	16.75	0.65	0.04	0.18	0.03	0.01	<3m	<3m	N/A
72	12/21/2018 5:45	18.75	0.77	0.04	0.13	0.03	0.02	<3m	<3m	N/A
73	12/28/2018 8:00	11.25	0.33	0.03	0.11	0.01	0.01	<3m	<3m	N/A
74	12/31/2018 19:45	4	0.4	0.10	0.18	0.02	0.01	<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 was replaced with Longwood Medical rainfall data from July 17, 2018 9:00 through July 17, 2018 10:00 and July 17, 2018 22:45 through July 23, 2018 11:30.

9.4.3 Comparison of Monitored Storms to Typical Year Storms

The characteristics of the rain events that occurred in the April 15 to December 31, 2018 monitoring period were compared to rainfall characteristics from the Typical Year to help interpret the measured CSO activations and volumes in that period in comparison to Typical Year performance.

The total rainfall and number of storms at each rain gauge were identified for the period of April through December 2018, and the number of storms by volume were identified. These values were then compared to the values from the Typical Year. Table 9-7 presents this comparison. It should be noted that Table 9-7 summarizes the entirety of April instead of starting on April 15th. This was to allow for easier comparison against the typical year (nine months representing approximately 75% of the year). As indicated in Table 9-7, the rainfall depth and number of storms for most of the rain gauges from the period of April 15 to December 31 were approximately four-fifths of the values for the Typical Year, suggesting that the period of rainfall was slightly wetter than the Typical Year. The greatest difference in number of storms was in smaller storms (<0.25-inch volume). Most of the gauges had a similar number of storms in the 0.25 to 1.0 inch range, while the number of storms in the 1.0 to 2.0 inch range were much higher, and the number of storms in the greater-than 2.0 inch range was significantly lower than the Typical Year. Thus, although the numbers of larger storms were lower, the impact of those 1.0 to 2.0-inch storms on CSO volumes could have been greater due to the wetter soil conditions, particularly in areas affected by high groundwater.

Table 9-7. Frequency of Events within Selected Ranges of Total Rainfall for April 15 - December, 2018 (Page 1 of 2)

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	46.80	93	49	14	16	8	6
April - December 2018 Rain Gage Data							
Average of 20 Rain Gauges							
Average	42.45	78	34	14	15	13	2

Table 9-7. Frequency of Events within Selected Ranges of Total Rainfall for April 15 - December, 2018 (Page 2 of 2)

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
MWRA Rain Gauges							
Ward Street(1)	43.07	78	35	13	15	12	3
Columbus Park(2)	42.97	76	34	10	17	12	3
Chelsea Creek(3)	42.69	80	37	14	13	13	3
Hanscom Air(4) Force Base	39.82	81	38	14	17	10	2
Hayes PS	40.96	70	30	13	13	11	3
BWSC Rain Gauges							
Allston(5)	42.02	79	33	16	15	13	2
Charlestown	40.21	78	32	16	15	12	3
Dorchester-Adams (6)	44.26	79	30	17	15	16	1
Dorchester-Talbot (7)	43.62	77	31	15	14	15	2
Hyde Park	43.53	81	35	12	17	16	1
East Boston	41.47	77	32	14	16	12	3
Longwood	40.52	79	36	13	15	14	1
Roslindale	45.3	76	31	15	13	15	2
Roxbury	44.3	76	31	15	13	15	2
Union Park	41.32	79	36	13	15	13	2
USGS Rain Gauge							
Fresh Pond(8)	41.10	75	31	12	17	13	2
Project Gauges							
Lexington Farm	41.17	79	37	14	17	11	2
Spot Pond	44.14	75	33	11	15	13	3
Somerville(9)	40.21	78	32	16	15	12	3
Waltham Farm	46.30	85	39	15	13	15	3

(1) Rainfall data replaced with Longwood Medical from 5/21/2018 9:00 through 5/21/2018 10:30, July 17, 2018 9:00 through July 17, 2018 10:00 and July 17, 2018 22:45 through July 23, 2018 11:30
(2) Rainfall data replaced with Union Park Pumping Station from July 17, 2018 12:00 through July 17, 2018 13:00 and July 29, 2018 6:30 through July 31, 2018 11:30
(3) Rainfall data replaced with East Boston from June 6, 2018 0:00 through June 30, 2018 23:45, July 1, 2018 0:00 through July 20, 2018 0:00, September 17, 2018 10:00 through September 17, 2018 11:00, October 22, 2018 7:30 through October 22, 2018 10:30, and December 14, 2018 13:00 through December 14, 2018 14:00
(4) Rainfall data replaced with Lexington Farm from 4/15/2018 0:00 through 6/30/2018 23:45 and July 1, 2018 0:00 through December 31, 2018 23:45
(5) Rainfall data replaced with Longwood Medical from October 8, 2018 0:00 through December 31, 2018 23:45
(6) Rainfall data replaced with Roxbury from November 23, 2018 0:00 through December 31, 2018 23:45
(7) Rainfall data replaced with Dorchester Adams from September 26, 2018 0:00 through October 21, 2018 0:00 and with Roxbury from November 20, 2018 0:00 through December 31, 2018 23:45
(8) Rainfall data replaced with Allston from October 30, 2018 10:30 through October 30, 2018 12:30 and December 28, 2018 0:00 through December 28, 2018 23:45
(9) Rainfall data replaced with Charlestown from April 15, 2018 0:00 through June 30, 2018 23:45 and Longwood Medical from July 1, 2018 0:00 through December 31, 2018 23

Storms with greater than 2 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 2 inches of total rainfall in the Typical Year (Table 9-8). Experience has shown that large storms often account for a disproportionate volume of CSO. Table 9-8 indicates four storm events (April 15, 2018, July 17, 2018, August 11, 2018, and October 27, 2018) observed in the monitoring period with greater than 2 inches of rainfall for at least one of the four gauges assessed.

The April 15, 2018 and July 17, 2018 storm events 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 October 27, 2018 storm which recorded 2.03 inches of rain only at Columbus Park. The 2018 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 2.95 inches of rainfall. The largest storm in the Typical Year had 3.89 inches of rainfall. While the rainfall depths for the largest storms in 2018 were smaller than the largest storms in the Typical Year, the average intensities and peak intensities were generally higher, and the storm durations were generally shorter.

Table 9-8. Comparison of Storms Between April 15 and December 31, 2018 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	1yr
	8/15/1992	72	2.91	0.04	0.66	3m
	9/22/1992	23	2.76	0.12	0.65	1yr
	11/21/1992	84	2.39	0.03	0.31	3m
	05/31/1992	30	2.24	0.07	0.37	3m-6m
	10/9/1992	65	2.04	0.03	0.42	<3m
April-December 2018 Metering Data						
Ward Street (1) (BO-DI-1)	04/15/2018	24.75	2.32	0.11	0.47	6m
	07/17/2018	13	2.39	0.18	1.14	6m
	08/11/2018	34.75	2.36	0.07	1.46	3m-6m
Columbus Park (2) (BO-DI-2)	04/15/2018	22.25	2.15	0.10	0.40	3-6m
	07/17/2018	13.5	2.44	0.18	0.92	6m
	10/27/2018	25.25	2.03	0.08	0.35	3m
Chelsea Creek (3) (CH-Bo-1)	04/15/2018	25.5	2.23	0.09	0.28	3-6m
	07/17/2018	11.25	2.12	0.19	0.97	3-6m
	08/11/2018	62.25	2.95	0.05	0.82	3-6m
Fresh Pond (USGS)	04/15/2018	22.75	2.06	0.091	0.40	3-6m
	07/17/2018	17.25	2.03	0.12	0.67	3m

(1) Rainfall data replaced with Longwood Medical from July 17, 2018 9:00 through July 17, 2018 10:00 and July 17, 2018 22:45 through July 23, 2018 11:30

(2) Rainfall data replaced with Union Park Pumping Station from July 17, 2018 12:00 through July 17, 2018 13:00 and July 29, 2018 6:30 through July 31, 2018 11:30

(3) Rainfall data replaced with East Boston from July 1, 2018 0:00 through July 20, 2018 0:00, September 17, 2018 10:00 through September 17, 2018 11:00, October 22, 2018 7:30 through October 22, 2018 10:30, and December 14, 2018 13:00 through December 14, 2018 14:00

Storms with greater than 0.40 in/hr of peak rainfall intensity 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 9-9). Storms with intensities greater than 0.40 in/hr are of importance because higher intensity storms have been found to produce more CSO than lower intensity storms. Results from the period of April 15 to December 31, 2018 indicate that within the 8.5-month monitoring period, the number of storms with intensities greater than 0.4 in/hr was slightly higher than annual number of storms in the Typical Year. The 8.5-month monitoring period had two rain gauges with 12 storms, one gauge with 11 storms and one gauge with 13 storms exceeding 0.4 in/hr, while the Typical Year had nine storms with intensities greater than 0.4 in/hr.

Table 9-9. Comparison of Storms with Peak Intensities Greater than 0.40 inches/hour Between April 15 and December 31, 2018 versus the Full Typical Year (Page 1 of 2)

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
Typical Year	10/23/1992	4	1.18	0.29	1.08	1-2yr
	08/11/1992	11	0.87	0.08	0.75	6m-1yr
	08/15/1992	72	2.91	0.04	0.66	3m-6m
	09/22/1992	23	2.76	0.12	0.65	3m-6m
	05/02/1992	7	1.14	0.16	0.63	3m-6m
	09/09/1992	1	0.57	0.57	0.57	3m
	09/03/1992	13	1.19	0.09	0.51	<3m
	06/05/1992	18	1.34	0.07	0.44	<3m
	10/09/1992	65	2.04	0.03	0.42	<3m
April-December 2018 Metering Data						
Ward Street Headworks (BO-DI-1) (1)	04/15/2018	22	2.43	0.11	0.47	<3m
	05/15/2018	3	0.98	0.33	0.67	3-6m
	06/27/2018	15.5	1.21	0.08	0.68	3-6m
	07/17/2018	13	2.39	0.18	1.14	1.8yr
	08/04/2018	2.5	0.66	0.26	0.52	<3m
	08/11/2018	34.75	2.36	0.07	1.46	4 yr
	09/12/2018	18.25	0.90	0.05	0.44	<3m
	09/18/2018	12.75	1.18	0.09	0.63	3-6m
	09/25/2018	18.25	1.82	0.10	0.84	6m-1yr
	10/29/2018	8.5	0.77	0.09	0.41	<3m
	11/02/2018	33.75	1.91	0.06	0.53	3m
	11/09/2018	19.75	1.60	0.08	0.45	<3m
Columbus Park Headworks (BO-DI-2) (2)	04/15/2018	22.25	2.15	0.10	0.40	3m
	05/15/2018	3.75	1.06	0.28	0.73	6m
	06/27/2018	15.75	1.22	0.08	0.73	6m
	07/17/2018	13.5	2.44	0.18	0.92	1yr
	07/26/2018	1.75	0.64	0.37	0.59	3m
	08/04/2018	3.25	0.88	0.27	0.66	3-6m
	08/08/2018	16	0.94	0.06	0.70	6m
	08/11/2018	37	1.43	0.04	0.59	3m
	09/18/2018	13.25	1.29	0.10	0.67	3-6m
	09/25/2018	19.25	1.42	0.07	0.74	6m-1yr
	11/02/2018	35.75	1.98	0.06	0.64	3-6m
	11/09/2018	15.75	1.72	0.11	0.45	<3m

Table 9-9. Comparison of Storms with Peak Intensities Greater than 0.40 inches/hour Between April 15 and December 31, 2018 versus the Full Typical Year (Page 2 of 2)

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
Chelsea Creek Headworks (CH-BO-1) (3)	05/15/2018	4	1.29	0.32	0.96	1yr
	06/27/2018	15.5	1.15	0.07	0.62	3-6m
	07/17/2018	11.25	2.12	0.19	0.97	1yr
	07/26/2018	1.75	0.56	0.32	0.53	3m
	08/04/2018	4	0.58	0.15	0.46	<3m
	08/11/2018	62.25	2.95	0.05	0.82	6m-1yr
	08/17/2018	8.75	0.44	0.05	0.42	<3m
	09/18/2018	12.75	1.60	0.13	1.05	1.5yr
	09/25/2018	13	1.52	0.12	0.73	6m
	11/02/2018	33.75	1.87	0.06	0.50	<3m
	11/09/2018	16	1.65	0.10	0.47	<3m
Fresh Pond (USGS) (4)	04/15/2018	22.75	2.06	0.09	0.40	<3m
	05/15/2018	4	0.91	0.23	0.60	3m
	06/27/2018	20.5	1.46	0.07	0.62	3-6m
	07/06/2018	2	0.56	0.28	0.52	<3m
	07/17/2018	17.25	2.03	0.12	0.67	3-6m
	07/25/2018	37.75	0.75	0.01	0.50	<3m
	08/11/2018	38	1.87	0.05	0.78	6m-1yr
	08/14/2018	2.5	0.77	0.31	0.45	<3m
	08/22/2018	8.5	0.51	0.06	0.46	<3m
	09/18/2018	14	1.75	0.13	1.11	1.5yr
	09/25/2018	21.75	1.61	0.07	0.46	<3m
	10/29/2018	9	0.81	0.09	0.55	3m
	11/02/2018	34	1.79	0.05	0.41	<3m

(1) Rainfall data replaced with Longwood Medical from July 17, 2018 9:00 through July 17, 2018 10:00 and July 17, 2018 22:45 through July 23, 2018 11:30
(2) Rainfall data replaced with Union Park Pumping Station from July 17, 2018 12:00 through July 17, 2018 13:00 and July 29, 2018 6:30 through July 31, 2018 11:30
(3) Rainfall data replaced with East Boston from July 1, 2018 0:00 through July 20, 2018 0:00, September 17, 2018 10:00 through September 17, 2018 11:00, October 22, 2018 7:30 through October 22, 2018 10:30, and December 14, 2018 13:00 through December 14, 2018 14:00
(4) Rainfall data replaced with Longwood Medical from October 30, 2018 10:30 through October 30, 2018 12:30 and December 28, 2018 0:00 through December 28, 2018 23:45

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 plotted the 15-minute rainfall intensities and showed the general distribution of rainfall during the storm. Rainfall distribution during a storm can impact the behavior of system hydraulics due to soil saturation. An example hyetograph is shown in Figure 9-2 with the remaining hyetographs in Semiannual Report No. 2.

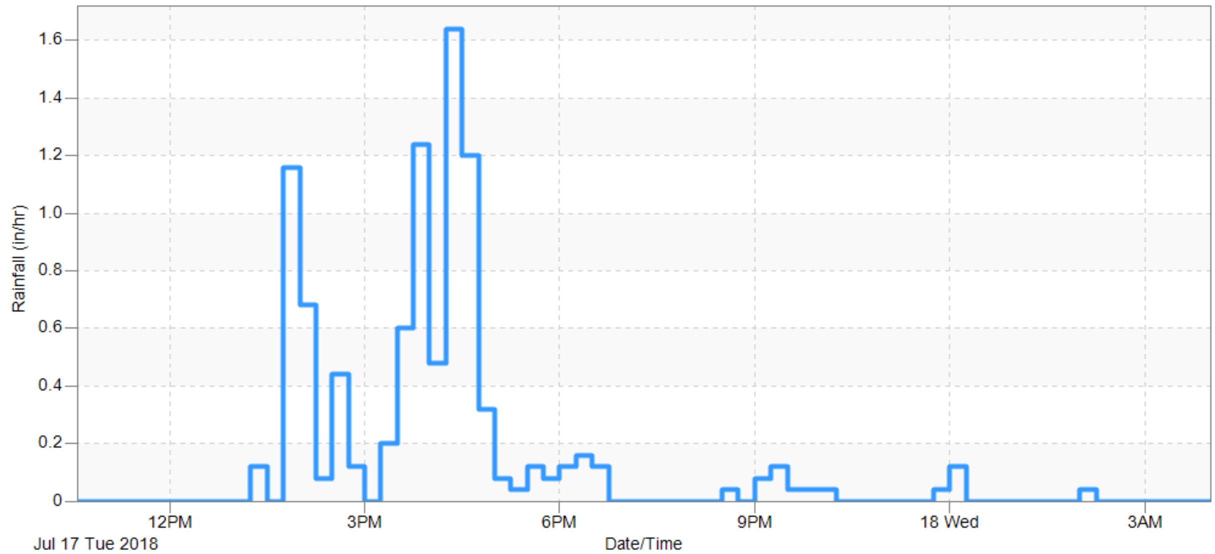


Figure 9-2. Hyetograph from the Ward Street Headworks Gauge for July 17, 2018

Comparisons of the nine-month 2018 monitoring period to the Typical Year suggest that 2018 had similar annual rainfall depth, however the larger storms in 2018 tended to be shorter in duration but higher in intensity. The following is a summary of the rainfall comparison of 2018 to the Typical Year:

- The Typical Year has 93 storm events, while the nine-month 2018 period averaged 78 storm events (Table 9-7).
- The total average rainfall depth for the nine-month 2018 period (42.45 inches) was similar to but slightly less than the Typical Year (46.80 inches) (Table 9-7).
- The nine-month 2018 period had fewer storm events with depths less than 0.25 inches than the Typical Year. The nine-month 2018 period had an average of 34 storm events with depths less than 0.25 inches while the Typical Year had 49 such storm events (Table 9-7).
- The nine-month 2018 period storm events had a higher average frequency of events with depths 1.0 to 2.0 inches than the Typical Year. The nine-month 2018 period had an average of 13 storms in that depth range while the Typical Year had eight (Table 9-7).
- The Typical Year had six storm events with depths greater than 2 inches, while the nine-month 2018 period only had an average of two such storm events (Table 9-7).
- Storm events with depths greater than 2 inches in the nine-month 2018 period tended to have shorter durations and higher intensities than storms in the same size range in the Typical Year (Table 9-8).
- Storm events with intensities greater than 0.40 in/hr in the nine-month 2018 period tended to have higher peak intensities than storms with greater than 0.40 in/hr intensities in the Typical Year (Table 9-9).

9.5 Data Collection and Analyses January 1, 2019-December 31, 2019

This section presents the analysis of rainfall from the period of January 1, 2019 through December 31, 2019.

9.5.1 Rainfall Data Collection and Processing

Replacement of suspect data from the period of January 1, 2019 through December 31, 2019 is summarized in Table 9-10. Rainfall data used for the analysis are provided in Semiannual Report No. 4.

Table 9-10. Summary of Rainfall Data Replacement, January - December 2019 (Page 1 of 2)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Allston	01/01/2019 0:00	01/01/2019 12:00	Longwood Medical
	01/05/2019 0:00	03/11/2019 0:00	USGS Fresh Pond
	03/11/2019 0:15	06/30/2019 23:45	Longwood Medical
	07/01/2019 0:00	07/07/2019 12:00	Longwood Medical Area (BWSC008)
Ward St. (BO-DI-1)	01/25/2019 9:15	01/25/2019 10:00	Chelsea Ck. (CH-BO-1)
	07/01/2019 0:00	10/01/2019 0:00	Longwood Medical
Columbus Park (BO-DI-2)	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)
	12/29/2019 18:00	12/31/2019 12:00	Roxbury
Charlestown	01/05/2019 0:00	03/11/2019 0:00	Chelsea Ck. (CH-BO-1)
Chelsea Ck. (CH-BO-1)	01/25/2019 8:00	01/25/2019 9:00	Ward St. (BO-DI-1)
	04/05/2019 18:00	04/07/2019 15:00	East Boston
	04/15/2019 11:30	04/15/2019 12:15	East Boston
	07/19/2019 5:00	07/19/2019 5:15	East Boston
	07/30/2019 13:00	07/30/2019 13:15	East Boston
	12/29/2019 18:00	12/31/2019 12:00	East Boston
Dorchester Adams St.	01/01/2019 0:00	01/01/2019 12:00	Roxbury
	01/01/2019 12:15	03/11/2019 0:00	Ward St. (BO-DI-1)
	03/11/2019 0:15	04/30/2019 23:45	Roxbury
	05/01/2019 0:00	06/30/2019 23:45	Roslindale
	07/01/2019 0:00	12/01/2019 0:00	Roxbury
Dorchester -Talbot	01/01/2019 0:00	01/01/2019 12:00	Roxbury
	01/01/2019 12:15	03/11/2019 0:00	Ward St. (BO-DI-1)
	03/11/2019 0:15	04/30/2019 23:45	Roxbury
	05/01/2019 0:00	06/30/2019 23:45	Roslindale
	07/01/2019 0:00	12/01/2019 0:00	Roxbury
Hanscom AFB (HF-1C)	01/01/2019 12:15	01/04/2019 23:45	Lexington Farm
	01/05/2019 0:00	03/11/2019 0:00	USGS Fresh Pond
	03/11/2019 0:15	04/10/2019 17:45	Lexington Farm
	04/10/2019 18:00	04/30/2019 23:45	Waltham Farm
	05/01/2019 0:00	06/30/2019 23:45	Lexington Farm
	07/01/2019 0:00	10/07/2019 17:45	Lexington Farm
	10/07/2019 18:00	10/13/2019 0:00	USGS Fresh Pond
	10/13/2019 0:15	12/31/2019 23:45	Lexington Farm
Lexington Farm	01/05/2019 0:00	03/11/2019 0:00	USGS Fresh Pond
	04/19/2019 18:00	04/30/2019 23:45	USGS Fresh Pond
	10/07/2019 18:00	10/13/2019 0:00	USGS Fresh Pond
Longwood Medical	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)
Hayes Pump Sta. (RG-WF-1)	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)
	12/29/2019 18:00	12/31/2019 12:00	Somerville
Roslindale	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)

Table 9-10. Summary of Rainfall Data Replacement, January - December 2019 (Page 2 of 2)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Roxbury	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)
	05/01/2019 0:00	05/31/2019 23:45	Ward St. (BO-DI-1)
Somerville Remote	01/01/2019 0:00	01/01/2019 12:00	Charlestown
	01/01/2019 12:15	03/11/2019 0:00	Chelsea Ck. (CH-BO-1)
	03/11/2019 0:15	04/12/2019 15:00	Charlestown
Spot Pond	01/05/2019 0:00	03/11/2019 0:00	Chelsea Ck. (CH-BO-1)
	04/14/2019 18:00	04/23/2019 18:00	Somerville
	06/20/2019 0:00	06/22/2019 0:00	Somerville
USGS Fresh Pond	11/24/2019 0:00	12/31/2019 23:45	Allston
Union Park Pumping Station	01/05/2019 0:00	03/11/2019 0:00	Ward St. (BO-DI-1)
	06/27/2019 10:15	06/27/2019 10:30	Columbus Park (BO-DI-2)
	09/23/2019 0:00	12/29/2019 17:45	Columbus Park (BO-DI-2)
	12/29/2019 18:00	12/31/2019 12:00	Roxbury
Waltham Farm	01/05/2019 0:00	03/11/2019 0:00	USGS Fresh Pond

9.5.2 Monitored Storms and Comparison with Typical Year

Table 9-11 presents the summary of storm events for Ward Street Headworks for the period of January to December 2019. These data show that 113 storm events occurred over this period at the Ward Street Headworks rain gauge (BO-DI-1). The majority of events had less than 3-month recurrence intervals at 1-hour or 24-hour durations. Two storm events had a 1-hour recurrence intervals 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 recurrence interval of 6 months-to-1 year and August 7, 2019 which had a 2.5-year 1-hour recurrence interval. All storms at Ward Street had a recurrence interval of 6 months or less based on a 24-hour duration except for the April 22, 2019 storm, which had a 24-hour recurrence interval of 1-2 years. Tables summarizing the storm events from January to December 2019 for the other rain gauges are provided in Semiannual Report No. 4.

Table 9-11. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2019 (Page 1 of 4)

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	01/01/2019 0:15	4.75	0.33	0.07	0.14	0.00	0.00	<3m	<3m	N/A
2	01/03/2019 8:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
3	01/05/2019 6:00	13.75	0.6	0.04	0.15	0.03	0.01	<3m	<3m	N/A
4	01/08/2019 8:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
5	01/08/2019 21:30	16	0.17	0.01	0.06	0.01	0.00	<3m	<3m	N/A
6	01/20/2019 5:00	15.75	0.37	0.02	0.24	0.02	0.01	<3m	<3m	N/A
7	01/22/2019 9:45	5.5	0.14	0.03	0.04	0.01	0.00	<3m	<3m	N/A
8	01/23/2019 13:15	31.5	0.69	0.02	0.09	0.03	0.02	<3m	<3m	N/A
9	01/29/2019 22:45	10.75	0.18	0.02	0.05	0.01	0.00	<3m	<3m	N/A
10	02/06/2019 20:00	11.25	0.56	0.05	0.13	0.02	0.01	<3m	<3m	N/A

Table 9-11. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2019 (Page 2 of 4)

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
11	02/07/2019 23:15	13.75	0.08	0.01	0.04	0.01	0.01	<3m	<3m	N/A
12	02/12/2019 14:30	15.5	1.28	0.08	0.23	0.05	0.03	<3m	<3m	N/A
13	02/15/2019 10:45	3	0.07	0.02	0.04	0.00	0.00	<3m	<3m	N/A
14	02/18/2019 0:45	13.25	0.28	0.02	0.09	0.01	0.01	<3m	<3m	N/A
15	02/20/2019 22:00	11.25	0.50	0.04	0.17	0.02	0.01	<3m	<3m	N/A
16	02/24/2019 5:45	9.75	0.46	0.05	0.10	0.02	0.01	<3m	<3m	N/A
17	02/28/2019 3:00	8	0.17	0.02	0.03	0.01	0.00	<3m	<3m	N/A
18	03/02/2019 7:30	6.5	0.23	0.04	0.07	0.01	0.00	<3m	<3m	N/A
19	03/03/2019 21:45	18.5	1.25	0.07	0.17	0.05	0.03	<3m	<3m	N/A
20	03/10/2019 8:30	10.5	0.53	0.05	0.10	0.02	0.01	<3m	<3m	N/A
21	03/15/2019 10:45	12.5	0.27	0.02	0.24	0.01	0.01	<3m	<3m	N/A
22	03/22/2019 0:00	28.25	0.87	0.03	0.24	0.03	0.02	<3m	<3m	N/A
23	03/29/2019 13:30	2.5	0.02	0.01	0.01	0.00	0.00	<3m	<3m	N/A
24	03/31/2019 14:15	4.75	0.13	0.03	0.05	0.01	0.00	<3m	<3m	N/A
25	04/02/2019 23:00	6.75	0.41	0.06	0.10	0.02	0.01	<3m	<3m	N/A
26	04/05/2019 20:15	6.75	0.17	0.03	0.04	0.01	0.00	<3m	<3m	N/A
27	04/08/2019 3:00	10.5	0.41	0.04	0.14	0.02	0.01	<3m	<3m	N/A
28	04/09/2019 17:30	1	0.06	0.06	0.06	0.00	0.01	<3m	<3m	N/A
29	04/12/2019 22:00	10	0.40	0.04	0.10	0.02	0.01	<3m	<3m	N/A
30	04/14/2019 21:30	17.75	0.93	0.05	0.65	0.04	0.02	3-6m	<3m	N/A
31	04/19/2019 23:15	26	0.27	0.01	0.12	0.01	0.01	<3m	<3m	N/A
32	04/22/2019 12:30	17.75	2.66	0.15	0.36	0.11	0.06	<3m	1-2yr	N/A
33	04/23/2019 22:15	2.5	0.12	0.05	0.09	0.02	0.06	<3m	<3m	N/A
34	04/26/2019 6:45	27.75	1.66	0.06	0.48	0.07	0.03	<3m	<3m	N/A
35	04/28/2019 17:45	0.75	0.02	0.03	0.02	0.00	0.03	<3m	<3m	N/A
36	04/30/2019 1:45	8	0.14	0.02	0.04	0.01	0.00	<3m	<3m	N/A
37	05/02/2019 1:15	13	0.05	0.00	0.02	0.00	0.00	<3m	<3m	N/A
38	05/03/2019 13:30	16.25	0.26	0.02	0.12	0.01	0.01	<3m	<3m	N/A
39	05/05/2019 4:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
40	05/07/2019 18:30	3.25	0.08	0.02	0.05	0.00	0.00	<3m	<3m	N/A
41	05/11/2019 1:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
42	05/12/2019 7:00	13	0.49	0.04	0.08	0.02	0.01	<3m	<3m	N/A
43	05/13/2019 16:30	16.75	0.98	0.06	0.31	0.04	0.03	<3m	<3m	N/A
44	05/16/2019 0:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
45	05/17/2019 8:15	7.75	0.24	0.03	0.07	0.01	0.01	<3m	<3m	N/A
46	05/19/2019 10:15	2	0.16	0.08	0.14	0.01	0.01	<3m	<3m	N/A
47	05/20/2019 1:15	3	0.15	0.05	0.14	0.01	0.01	<3m	<3m	N/A
48	05/23/2019 22:45	0.75	0.14	0.19	0.14	0.01	0.00	<3m	<3m	N/A
49	05/25/2019 23:30	2.25	0.30	0.13	0.24	0.01	0.01	<3m	<3m	N/A
50	05/28/2019 11:45	12	0.35	0.03	0.11	0.01	0.01	<3m	<3m	N/A
51	05/30/2019 21:45	2.75	0.31	0.11	0.18	0.01	0.01	<3m	<3m	N/A
52	06/02/2019 22:15	2.75	0.08	0.03	0.05	0.00	0.00	<3m	<3m	N/A
53	06/05/2019 23:30	0.5	0.04	0.08	0.04	0.00	0.00	<3m	<3m	N/A

Table 9-11. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2019 (Page 3 of 4)

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
54	06/10/2019 22:45	11.5	0.88	0.08	0.24	0.04	0.02	<3m	<3m	N/A
55	06/13/2019 8:00	10	0.71	0.07	0.23	0.03	0.01	<3m	<3m	N/A
56	06/16/2019 10:00	9.25	0.09	0.01	0.03	0.00	0.00	<3m	<3m	N/A
57	06/18/2019 13:15	3.50	0.10	0.03	0.07	0.00	0.00	<3m	<3m	N/A
58	06/20/2019 5:45	6.50	0.34	0.05	0.26	0.01	0.01	<3m	<3m	N/A
59	06/21/2019 1:45	13.25	0.83	0.06	0.64	0.05	0.02	3-6m	<3m	N/A
60	06/25/2019 12:45	8	0.12	0.02	0.05	0.01	0.00	<3m	<3m	N/A
61	06/29/2019 4:30	11.50	0.74	0.06	0.36	0.03	0.02	<3m	<3m	N/A
62	06/30/2019 14:00	4.25	0.08	0.02	0.06	0.02	0.02	<3m	<3m	N/A
63	07/06/2019 16:15	3.50	1.13	0.32	0.84	0.05	0.02	6m-1yr	<3m	N/A
64	07/11/2019 23:45	21.25	0.71	0.03	0.19	0.03	0.01	<3m	<3m	N/A
65	07/17/2019 16:30	17	1.07	0.06	0.46	0.04	0.02	<3m	<3m	N/A
66	07/22/2019 12:15	22.25	2	0.09	0.41	0.08	0.04	<3m	3m	N/A
67	07/24/2019 2:15	0.25	0.01	0.04	0.01	0.04	0.04	<3m	<3m	N/A
68	07/31/2019 14:15	1.75	0.29	0.17	0.24	0.01	0.01	<3m	<3m	N/A
69	08/07/2019 12:30	12.75	2.45	0.19	1.26	0.10	0.05	2.5yr	6m	N/A
70	08/18/2019 0:15	0.50	0.12	0.24	0.12	0.01	0.00	<3m	<3m	N/A
71	08/18/2019 15:45	0.50	0.05	0.10	0.05	0.01	0.00	<3m	<3m	N/A
72	08/19/2019 15:30	0.50	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
73	08/21/2019 15:00	1	0.09	0.09	0.09	0.00	0.00	<3m	<3m	N/A
74	08/23/2019 5:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
75	08/28/2019 15:00	11.75	1.20	0.10	0.61	0.05	0.03	3-6m	<3m	N/A
76	09/02/2019 16:15	2	0.74	0.37	0.67	0.03	0.00	3-6m	<3m	N/A
77	09/04/2019 17:45	0.25	0.01	0.04	0.01	0.00	0.01	<3m	<3m	N/A
78	09/07/2019 0:45	3	0.11	0.04	0.05	0.00	0.00	<3m	<3m	N/A
79	09/12/2019 6:45	2.25	0.04	0.02	0.02	0.00	0.00	<3m	<3m	N/A
80	09/14/2019 12:45	12.25	0.31	0.03	0.21	0.01	0.01	<3m	<3m	N/A
81	09/23/2019 22:45	2.50	0.23	0.09	0.22	0.01	0.00	<3m	<3m	N/A
82	09/26/2019 16:00	2.50	0.36	0.14	0.17	0.02	0.01	<3m	<3m	N/A
83	10/01/2019 5:00	0.50	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
84	10/02/2019 13:45	3	0.28	0.09	0.15	0.01	0.00	<3m	<3m	N/A
85	10/03/2019 22:00	9.75	0.13	0.01	0.05	0.01	0.01	<3m	<3m	N/A
86	10/07/2019 20:00	11	0.22	0.02	0.12	0.01	0.00	<3m	<3m	N/A
87	10/09/2019 16:00	17	0.12	0.01	0.06	0.01	0.01	<3m	<3m	N/A
88	10/11/2019 11:45	21.75	0.62	0.03	0.17	0.03	0.01	<3m	<3m	N/A
89	10/16/2019 20:30	11.75	1.85	0.16	0.70	0.08	0.04	6m	3m	N/A
90	10/22/2019 18:45	13	0.43	0.03	0.13	0.02	0.01	<3m	<3m	N/A
91	10/26/2019 0:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
92	10/27/2019 9:00	10.75	1.69	0.16	0.54	0.07	0.04	3m	<3m	N/A
93	10/28/2019 10:00	16	0.06	0.00	0.02	0.07	0.04	<3m	<3m	N/A
94	10/29/2019 20:45	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
95	10/30/2019 17:30	30.25	0.20	0.01	0.70	0.08	0.04	6m	3m	N/A

Table 9-11. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2019 (Page 4 of 4)

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
96	11/01/2019 2:00	3	0.05	0.02	0.02	0.00	0.00	<3m	<3m	N/A
97	11/05/2019 11:15	10.75	0.45	0.04	0.30	0.02	0.01	<3m	<3m	N/A
98	11/07/2019 17:00	17.5	0.29	0.02	0.09	0.01	0.01	<3m	<3m	N/A
99	11/12/2019 11:00	2.5	0.10	0.04	0.05	0.00	0.00	<3m	<3m	N/A
100	11/18/2019 12:30	5	0.3	0.06	0.09	0.01	0.01	<3m	<3m	N/A
101	11/19/2019 5:30	2.75	0.21	0.08	0.11	0.02	0.01	<3m	<3m	N/A
102	11/20/2019 2:15	17.5	0.21	0.01	0.05	0.01	0.01	<3m	<3m	N/A
103	11/22/2019 13:45	1.75	0.08	0.05	0.06	0.00	0.00	<3m	<3m	N/A
104	11/24/2019 3:15	17.5	1.38	0.08	0.30	0.06	0.03	<3m	<3m	N/A
105	11/27/2019 17:15	19	0.32	0.02	0.14	0.01	0.01	<3m	<3m	N/A
106	12/01/2019 22:45	42	0.99	0.02	0.12	0.02	0.02	<3m	<3m	N/A
107	12/06/2019 15:30	1.25	0.02	0.02	0.01	0.00	0.00	<3m	<3m	N/A
108	12/09/2019 7:30	18.5	0.56	0.03	0.18	0.02	0.01	<3m	<3m	N/A
109	12/10/2019 14:15	20.5	0.47	0.02	0.07	0.02	0.02	<3m	<3m	N/A
110	12/13/2019 18:15	17.5	1.54	0.09	0.26	0.06	0.03	<3m	<3m	N/A
110	12/15/2019 12:45	0.25	0.01	0.04	0.01	0.00	0.03	<3m	<3m	N/A
112	12/17/2019 6:30	14.75	0.66	0.04	0.17	0.03	0.01	<3m	<3m	N/A
113	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 was replaced with Chelsea Creek rainfall data from January 25, 2019 9:15 through January 25, 2019 10:00; 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 (Table 9-12). As indicated in Table 9-12, during 2019, rain gauges measured an average of 112 storms with a total rainfall volume of 49.07 inches, compared with 93 storms and 46.8 inches in the Typical Year. The 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.

Table 9-12. 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 9-13). Table 9-13 indicates five storm events (April 22, 2019, July 22, 2019, August 7, 2019, October 14, 2019 and December 29, 2019) occurred with rainfall depths observed at Ward Street, Columbus Park and/or USGS Fresh Pond 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 relatively 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.

Table 9-13. Comparison of Storms Between January 1 and December 31, 2019 and Typical Year with >2 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	1yr
	08/15/1992	72	2.91	0.04	0.66	3m
	09/22/1992	23	2.76	0.12	0.65	1yr
	11/21/1992	84	2.39	0.03	0.31	3m
	05/31/1992	30	2.24	0.07	0.37	3m-6m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-December 2019 Metering Data						
Ward Street (BO-DI-1)	04/22/2019	17.75	2.66	0.15	0.36	1-2yr
	08/07/2019	12.75	2.45	0.19	1.26	6m
Columbus Park (BO-DI-2)	04/22/2019	17	2.59	0.15	0.40	6m-1yr
	07/22/2019	23.75	2.34	0.10	0.55	6m
	08/7/2019	13.25	2.05	0.15	0.87	3-6m
Chelsea Creek (CH-BO-1)	04/22/2019	18.75	2.63	0.14	0.44	6m-1yr
Fresh Pond (USGS)	08/07/2019	13	2.98	0.23	1.41	1.5yr
	04/22/2019	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 9-14). The Typical Year has nine storm events with intensities greater than 0.40 inches per hour, while the 2019 monitoring period had more than nine storm events with intensities greater than 0.40 inches per hour at each of the four gauges noted.

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 plot the 15-minute rainfall intensities and show the distribution of rainfall during the storm. The hyetographs for 2019 can be found in Semiannual Report No. 4.

Table 9-14. Comparison of Storms Between January 1 and December 31, 2019 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour (Page 1 of 2)

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	1-2yr
	08/11/1992	11	0.87	0.08	0.75	6m-1yr
	08/15/1992	72	2.91	0.04	0.66	3m-6m
	09/22/1992	23	2.76	0.12	0.65	3m-6m
	05/02/1992	7	1.14	0.16	0.63	3m-6m
	09/09/1992	1	0.57	0.57	0.57	3m
	09/03/1992	13	1.19	0.09	0.51	<3m
	06/05/1992	18	1.34	0.07	0.44	<3m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-December 2019 Metering Data						
Ward Street Headworks (BO-DI-1)	08/07/2019	12.75	2.45	0.19	1.26	2.5yr
	07/06/2019	3.5	1.13	0.32	0.84	6m-1yr
	10/16/2019	11.75	1.85	0.16	0.70	6m
	09/02/2019	2	0.74	0.37	0.67	3-6m
	04/14/2019	17.75	0.93	0.05	0.65	3-6m
	06/21/2019	13.25	0.83	0.06	0.64	3-6m
	08/28/2019	11.75	1.20	0.10	0.61	3-6m
	10/27/2019	10.75	1.69	0.16	0.54	3m
	04/26/2019	27.75	1.66	0.06	0.48	<3m
	07/17/2019	17	1.07	0.06	0.46	<3m
	07/22/2019	22.25	2	0.09	0.41	<3m
Columbus Park Headworks (BO-DI-2)	07/31/2019	2.25	1.69	0.75	1.61	6yr
	07/06/2019	3.5	1.42	0.41	1.14	2yr
	08/07/2019	13.25	2.05	0.15	0.87	6m-1yr
	10/16/2019	8.5	1.91	0.22	0.84	6m-1yr
	06/21/2019	13	1.03	0.08	0.79	6m-1yr
	07/22/2019	23.75	2.34	0.10	0.55	3m
	04/14/2019	17.5	0.77	0.04	0.54	3m
	09/02/2019	1.5	0.58	0.39	0.53	3m
	11/24/2019	17.5	1.84	0.11	0.53	3m
	07/17/2019	18.5	1.28	0.07	0.52	<3m
	08/28/2019	10.5	1.26	0.12	0.48	<3m
	10/27/2019	11.75	1.48	0.13	0.48	<3m
	04/22/2019	17	2.59	0.15	0.4	<3m
	6/29/2019	11.5	1.82	0.16	1.67	7yr

Table 9-14. Comparison of Storms Between January 1 and December 31, 2019 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour (Page 2 of 2)

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Hourly Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
Chelsea Creek Headworks (CH-BO-1)	07/06/2019	4	1.69	0.42	1.26	2.5yr
	08/07/2019	13.5	1.92	0.14	0.88	6m-1yr
	09/02/2019	1.75	0.93	0.53	0.8	6m-1yr
	06/21/2019	13	1.03	0.08	0.79	6m-1yr
	10/16/2019	9	1.62	0.18	0.69	6m
	6/20/2019	33.5	1.28	0.04	0.68	3-6m
	07/17/2019	5.75	0.71	0.12	0.63	3-6m
	04/14/2019	17.5	0.77	0.04	0.54	3m
	4/14/2019	17.5	0.77	0.04	0.54	3m
	4/26/2019	21.75	1.47	0.07	0.48	<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
	08/28/2019	13	1.02	0.08	0.42	<3m
	04/22/2019	17	2.59	0.15	0.4	<3m
	4/22/2019	17	2.59	0.15	0.4	<3m
Fresh Pond (USGS)	08/07/2019	13	2.98	0.23	1.41	3.5yr
	09/02/2019	6.5	1.41	0.22	1.25	2.5yr
	07/06/2019	3.75	1.09	0.29	0.82	6m-1yr
	07/17/2019	9	0.75	0.08	0.67	3-6m
	10/16/2019	9	2.07	0.23	0.66	3-6m
	04/15/2019	17.25	0.86	0.05	0.65	3-6m
	07/31/2019	1.5	0.64	0.43	0.62	3-6m
	08/28/2019	10.25	1.37	0.13	0.6	3m
	04/22/2019	18.5	2.15	0.12	0.47	<3m
	06/20/2019	33	1.02	0.03	0.44	<3m
	07/12/2019	20.25	1.05	0.05	0.41	<3m

In summary, 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 9-12).
- The total average rainfall depth for 2019 (49.07 inches) was similar to but slightly greater than the Typical Year (46.80 inches) (Table 9-12).
- 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 9-12).

- 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 9-12).
- 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 9-13).
- 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 9-13).
- 2019 had more storm events with intensities greater than 0.40 in/hr than the Typical Year, and the 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 9-14).

9.6 Data Collection and Analyses January 1, 2020-December 31, 2020

This section presents the analysis of rainfall from the period of January 1, 2020 through December 31, 2020.

9.6.1 Rainfall Data Collection and Processing

Replacement of suspect data from the period of January 1, 2020 through December 31, 2020 is summarized in Table 9-15. Rainfall data used for the analysis are provided in Semiannual Report No. 6.

Table 9-15. Summary of Rainfall Data Replacement, January - December 2020 (Page 1 of 3)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Dorchester Adams St.	01/01/2020 0:00	03/31/2020 23:59	Chelsea Creek (CH-BO-1)
	04/01/2020 0:00	05/31/2020 23:45	Dorchester -Talbot
	06/01/2020 0:00	06/30/2020 23:45	Roxbury
	07/01/2020 0:00	12/01/2020 0:00	Roxbury
Dorchester -Talbot	01/01/2020 0:00	03/31/2020 23:59	Ward St. (BO-DI-1)
	06/01/2020 0:00	06/30/2020 23:45	Roxbury
	07/01/2020 0:00	12/01/2020 0:00	Roxbury
Charlestown	02/01/2020 0:00	04/30/2020 23:45	East Boston
	09/01/2020 0:00	12/31/2020 0:00	East Boston
Chelsea Ck. (CH-BO-1)	03/01/2020 0:00	03/31/2020 23:59	East Boston
	08/02/2020 16:30	08/16/2020 12:30	East Boston
	09/14/2020 5:15	09/14/2020 10:00	East Boston
	10/04/2020 7:45	10/04/2020 8:00	East Boston
	10/23/2020 7:00	10/23/2020 7:15	East Boston
	11/01/2020 0:00	12/01/2020 23:45	East Boston
Roslindale	09/16/2020 10:00	09/16/2020 10:15	Roxbury
Columbus Park (BO-DI-2)	01/01/2020 0:00	01/10/2020 6:45	Ward St. (BO-DI-1)
	08/09/2020 16:15	08/09/2020 16:30	Union Park Pumping Station
	08/28/2020 6:15	08/28/2020 6:30	Union Park Pumping Station
	10/20/2020 10:00	10/20/2020 10:15	Union Park Pumping Station
	10/23/2020 0:00	10/29/2020 0:00	Union Park Pumping Station
	11/01/2020 15:15	11/04/2020 23:45	Union Park Pumping Station
	11/30/2020 7:30	11/30/2020 7:45	Union Park Pumping Station

Table 9-15. Summary of Rainfall Data Replacement, January - December 2020 (Page 2 of 3)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Ward St. (BO-DI-1)	08/15/2020 19:15	08/15/2020 19:30	Roxbury
	10/24/2020 5:15	10/24/2020 5:30	Roxbury
	11/01/2020 15:15	11/02/2020 6:00	Roxbury
	11/30/2020 10:00	11/30/2020 10:15	Roxbury
Somerville Remote	12/02/2020 0:00	12/11/2020 23:45	Chelsea Ck. (CH-BO-1)
Longwood Medical	06/12/2020 5:45	06/30/2020 23:45	Ward St. (BO-DI-1)
	07/01/2020 0:00	09/30/2020 23:45	Ward St. (BO-DI-1)
	10/01/2020 0:00	10/31/2020 23:45	Ward St. (BO-DI-1)
	11/01/2020 15:15	11/01/2020 22:15	Roxbury
	11/02/2020 22:30	12/31/2020 23:45	Ward St. (BO-DI-1)
	11/30/2020 10:00	11/30/2020 10:15	Roxbury
Hyde Park	10/06/2020 6:00	10/06/2020 6:15	Roslindale
	10/18/2020 5:30	10/18/2020 5:45	Roslindale
USGS Fresh Pond	01/01/2020 0:00	05/31/2020 23:45	Allston
	07/01/2020 0:00	10/31/2020 23:45	Allston
	11/01/2020 15:15	11/01/2020 22:00	Allston
Hanscom AFB (HF-1C)	01/01/2020 0:00	04/30/2020 23:45	Allston
	05/01/2020 0:00	06/30/2020 23:45	Lexington Farm
	07/01/2020 0:00	07/31/2020 23:45	Allston
	09/28/2020 13:00	09/28/2020 13:15	Allston
	10/01/2020 1:45	10/01/2020 2:00	Somerville Remote
	10/24/2020 10:45	10/31/2020 23:45	Somerville Remote
	11/01/2020 14:45	11/01/2020 22:00	Somerville Remote
	11/01/2020 22:15	12/24/2020 23:45	USGS Fresh Pond
Lexington Farm	01/01/2020 0:00	04/30/2020 23:45	Allston
	07/01/2020 0:00	07/31/2020 23:45	USGS Fresh Pond
	08/01/2020 0:00	08/31/2020 23:45	Somerville Remote
	09/01/2020 0:00	09/30/2020 23:45	Allston
	10/01/2020 0:00	10/31/2020 23:45	Somerville Remote
	11/01/2020 15:15	11/01/2020 22:00	Allston
	11/01/2020 22:15	12/31/2020 23:45	USGS Fresh Pond
Hayes Pump Sta. (RG-WF-1)	01/01/2020 0:00	01/13/2020 11:30	Allston
	07/01/2020 0:00	12/31/2020 23:45	Somerville Remote
	08/01/2020 0:00	08/31/2020 23:45	Allston
	12/2/2020 0:00	12/11/2020 23:45	Chelsea Creek (CH-BO-1)
	12/12/2020 0:00	12/31/2020 23:45	Somerville Remote
Spot Pond	01/01/2020 0:00	04/30/2020 23:45	Somerville Remote
Waltham Farm	01/01/2020 0:00	04/30/2020 23:45	Allston
	07/01/2020 0:00	07/31/2020 23:45	USGS FRESH POND
	08/01/2020 0:00	10/31/2020 23:45	Allston
	11/01/2020 15:15	11/01/2020 22:00	Allston
	11/02/2020 22:00	12/31/2020 23:45	USGS Fresh Pond

Table 9-15. Summary of Rainfall Data Replacement, January - December 2020 (Page 3 of 3)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Union Park Pumping Station	01/01/2020 0:00	01/31/2020 23:45	Ward St. (BO-DI-1)
	02/01/2020 0:00	03/31/2020 23:59	Columbus Park (BO-DI-2)
Roxbury	01/02/2020 19:45	03/31/2020 23:59	Ward St. (BO-DI-1)

9.6.2 Monitored Storms and Comparison with Typical Year

Table 9-16 presents the summary of storm events for Ward Street Headworks for the period of January to December 2020. These data show that 89 storm events occurred in this period. The majority of events had less than 3-month recurrence intervals at 1-hour or 24-hour durations. One storm event had a 1-hour recurrence interval of 3 months (June 6, 2020). One storm had a 1-hour recurrence interval of 6 months (August 2, 2020). Five storm events had a 24-hour recurrence interval of 3 months (March 23, 2020, June 28, 2020, October 16, 2020, November 23, 2020, and December 4, 2020). The largest storm event based on the 1-hour recurrence interval was on June 28, 2020, with a 2-year recurrence interval. Tables summarizing the storm events from January to December 2020 for the other rain gauges are provided in Semiannual Report No. 6.

Table 9-16. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2020 (Page 1 of 3)

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	01/08/2020 1:30	22.5	0.28	0.01	0.05	0.01	0.01	<3m	<3m	N/A
2	01/12/2020 4:00	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
3	01/16/2020 3:30	6.5	0.06	0.01	0.04	0.00	0.00	<3m	<3m	N/A
4	01/18/2020 18:30	5.75	0.08	0.01	0.04	0.00	0.00	<3m	<3m	N/A
5	01/25/2020 17:30	16.75	0.3	0.02	0.09	0.01	0.01	<3m	<3m	N/A
6	02/05/2020 1:45	4.75	0.63	0.13	0.21	0.03	0.01	<3m	<3m	N/A
7	02/06/2020 2:45	4	0.04	0.01	0.02	0.00	0.00	<3m	<3m	N/A
8	02/10/2020 4:30	35	0.8	0.02	0.15	0.02	0.02	<3m	<3m	N/A
9	02/11/2020 5:15	10	0.15	0.02	0.08	0.01	0.00	<3m	<3m	N/A
10	02/13/2020 1:15	14.25	0.17	0.01	0.07	0.01	0.01	<3m	<3m	N/A
11	02/18/2020 15:00	13.5	0.55	0.04	0.16	0.02	0.01	<3m	<3m	N/A
12	02/25/2020 20:45	7.25	0.46	0.06	0.10	0.02	0.01	<3m	<3m	N/A
13	02/27/2020 1:15	6.25	0.42	0.07	0.11	0.02	0.01	<3m	<3m	N/A
14	03/03/2020 19:45	8	0.84	0.11	0.25	0.04	0.03	<3m	<3m	N/A
15	03/13/2020 1:00	6.5	0.04	0.01	0.02	0.00	0.00	<3m	<3m	N/A
16	03/17/2020 8:15	14	0.35	0.03	0.12	0.01	0.01	<3m	<3m	N/A
17	03/19/2020 4:30	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
18	03/23/2020 14:30	26.5	0.68	0.03	0.17	0.03	0.01	<3m	<3m	N/A
19	03/28/2020 20:15	15	2.00	0.13	0.50	0.08	0.04	<3m	3m	N/A
20	03/30/2020 14:00	26.75	0.97	0.04	0.15	0.04	0.02	<3m	<3m	N/A
21	04/02/2020 13:30	5.5	0.1	0.02	0	0.00	0.00	<3m	<3m	N/A
22	04/08/2020 5:15	37.25	1.31	0.04	0.18	0.04	0.03	<3m	<3m	N/A

Table 9-16. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2020 (Page 2 of 3)

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
23	04/09/2020 10:00	3.25	0.06	0.02	0.24	0.00	0.00	<3m	<3m	N/A
24	04/10/2020 15:15	8.5	0.65	0.08	0.24	0.03	0.01	<3m	<3m	N/A
25	04/13/2020 4:30	0.5	0.02	0.04	0.03	0.01	0.01	<3m	<3m	N/A
26	04/18/2020 0:00	15.25	0.89	0.06	0.24	0.03	0.02	<3m	<3m	N/A
27	04/21/2020 15:15	9	0.72	0.08	0.15	0.02	0.01	<3m	<3m	N/A
28	04/24/2020 3:45	2.75	0.41	0.15	0.24	0.02	0.01	<3m	<3m	N/A
29	04/26/2020 13:45	11.75	0.2	0.02	0.04	0.01	0.00	<3m	<3m	N/A
30	04/30/2020 10:00	32.25	0.85	0.03	0.08	0.03	0.02	<3m	<3m	N/A
31	05/01/2020 2:15	0.25	0.01	0.04	0	0.00	0.00	<3m	<3m	N/A
32	05/06/2020 23:00	24.5	0.9	0.04	0.29	0.04	0.00	<3m	<3m	N/A
33	05/08/2020 18:00	4	0.02	0.01	0.01	0.00	0.00	<3m	<3m	N/A
34	05/11/2020 16:15	14.5	0.39	0.03	0.07	0.02	0.01	<3m	<3m	N/A
35	05/15/2020 1:15	4.75	0.36	0.08	0.26	0.02	0.01	<3m	<3m	N/A
36	05/15/2020 20:00	1.75	0.05	0.03	0.04	0.00	0.00	<3m	<3m	N/A
37	05/30/2020 2:15	5	0.7	0.14	0.40	0.03	0.02	<3m	<3m	N/A
38	06/02/2020 18:30	1	0.2	0.20	0	0.00	0.00	<3m	<3m	N/A
39	06/05/2020 3:45	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
40	06/06/2020 14:30	2.5	0.12	0.05	0.11	0.01	0.00	<3m	<3m	N/A
41	06/11/2020 12:15	6.5	0.69	0.11	0.6	0.03	0.02	3m	<3m	N/A
42	06/24/2020 18:30	5.75	0.67	0.12	0.47	0.03	0.01	<3m	<3m	N/A
43	06/27/2020 15:15	0.25	0.01	0.04	0.01	0.00	0.00	<3m	<3m	N/A
44	06/28/2020 12:30	0.5	0.02	0.04	0.02	0.00	0.00	<3m	<3m	N/A
45	07/01/2020 6:15	48.5	2.04	0.04	1.09	0.08	0.04	2yr	3m	3m
46	07/05/2020 21:15	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
47	07/10/2020 17:00	1.5	0.19	0.13	0.17	0.01	N/A	<3m	<3m	N/A
48	07/13/2020 13:15	6.25	0.11	0.02	0.10	0.00	N/A	<3m	<3m	N/A
49	07/14/2020 9:45	0.25	0.19	0.76	0.19	0.01	N/A	<3m	<3m	N/A
50	07/15/2020 4:00	0.5	0.11	0.22	0.11	0.01	N/A	<3m	<3m	N/A
51	07/17/2020 5:15	1	0.03	0.03	0.03	0.01	N/A	<3m	<3m	N/A
52	07/22/2020 5:30	2	0.15	0.08	0.10	0.01	N/A	<3m	<3m	N/A
53	07/23/2020 15:30	17	0.42	0.02	0.33	0.02	N/A	<3m	<3m	N/A
54	07/31/2020 8:30	0.75	0.49	0.65	0.49	0.04	N/A	<3m	<3m	N/A
55	08/02/2020 16:15	0.25	0.69	2.76	0.69	0.03	N/A	6m	<3m	N/A
56	08/04/2020 15:30	0.25	0.03	0.12	0.03	0.00	N/A	<3m	<3m	N/A
57	08/16/2020 18:00	1.25	0.19	0.15	0.17	0.01	N/A	<3m	<3m	N/A
58	08/18/2020 1:15	5.25	0.22	0.04	0.11	0.01	N/A	<3m	<3m	N/A
59	08/19/2020 17:45	1.25	0.07	0.06	0.06	0.00	N/A	<3m	<3m	N/A
60	08/23/2020 15:45	0.25	0.03	0.12	0.03	0.00	N/A	<3m	<3m	N/A
61	08/27/2020 12:30	4	0.62	0.16	0.50	0.03	N/A	<3m	<3m	N/A
62	08/29/2020 9:30	2.25	0.25	0.11	0.20	0.01	N/A	<3m	<3m	N/A

Table 9-16. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2020 (Page 3 of 3)

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
63	09/02/2020 11:00	2.5	0.07	0.03	0.04	0.00	N/A	<3m	<3m	N/A
64	09/10/2020 13:45	25.25	0.25	0.01	0.12	0.01	0.01	<3m	<3m	<3m
65	09/30/2020 1:45	6	0.32	0.05	0.15	0.01	N/A	<3m	<3m	N/A
66	10/07/2020 16:45	8.25	0.98	0.12	0.47	0.04	N/A	<3m	<3m	N/A
67	10/13/2020 4:30	0.5	0.17	0.34	0.17	0.01	N/A	<3m	<3m	N/A
68	10/16/2020 12:00	17.5	1.69	0.10	0.41	0.07	N/A	<3m	<3m	N/A
69	10/20/2020 9:00	20	1.94	0.10	0.30	0.08	N/A	<3m	3m	N/A
70	10/21/2020 4:30	0.25	0.19	0.76	0.19	0.01	N/A	<3m	<3m	N/A
71	10/28/2020 3:45	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
72	10/29/2020 8:15	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
73	10/31/2020 10:00	22.75	0.17	0.01	0.03	0.01	N/A	<3m	<3m	N/A
74	11/01/2020 15:15	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
75	11/11/2020 23:30	7.25	0.63	0.09	0.23	0.00	N/A	<3m	<3m	N/A
76	11/13/2020 0:15	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
77	11/15/2020 20:45	17.5	0.34	0.02	0.08	0.01	N/A	<3m	<3m	N/A
78	11/23/2020 4:00	4.5	0.51	0.11	0.34	0.02	N/A	<3m	<3m	N/A
79	11/25/2020 20:15	9	1.80	0.20	0.44	0.08	N/A	<3m	3m	N/A
80	11/30/2020 11:45	17.5	0.27	0.02	0.08	0.01	N/A	<3m	<3m	N/A
81	12/04/2020 22:45	26	1.77	0.07	0.23	0.04	N/A	<3m	<3m	N/A
82	12/12/2020 12:30	23	2.01	0.09	0.25	0.08	N/A	<3m	3m	N/A
83	12/14/2020 9:45	7.5	0.45	0.06	0.16	0.02	N/A	<3m	<3m	N/A
84	12/16/2020 23:30	7.25	0.04	0.01	0.01	0.00	N/A	<3m	<3m	N/A
85	12/19/2020 10:15	39.25	0.59	0.02	0.11	0.02	0.01	<3m	<3m	<3m
86	12/20/2020 10:45	4	0.09	0.02	0.04	0.00	N/A	<3m	<3m	N/A
87	12/25/2020 2:45	6.75	0.19	0.03	0.04	0.01	N/A	<3m	<3m	N/A
88	12/31/2020 4:30	15.75	1.63	0.10	0.30	0.07	N/A	<3m	<3m	N/A
89	12/31/2020 4:30	2	0.11	0.06	0.09	0.00	N/A	<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.

The total rainfall and number of storms at each rain gauge were identified for the period of January 1 through December 31, 2020, and the number of storms by depth identified. These values were then compared to the values from the Typical Year (Table 9-17). As indicated in Table 9-17, during 2020, rain gauges measured an average of 87 storms with total rainfall volume of 40.5 inches, compared with 93 storms and 46.8 inches in the Typical Year. Storm frequencies for the 0.5 to 1.0-inch and 1.0 to 2.0-inch ranges were equal to the Typical Year, while the numbers of storms in the greater than 2-inch range were less than the Typical Year. Significantly fewer storm events occurred in the less than 0.25-inch range in 2020 as compared to the Typical Year, while slightly more storm events in the 0.25 to 0.5-inch range occurred in 2020 as compared to the Typical Year.

Storms with greater than 2 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 2 inches of total rainfall in the Typical Year (Table 9-18). Table 9-18 indicates that five storm events (March 23, 2020, June 28, 2020, October 16, 2020, November 30, 2020, and December 4-5, 2020) had rainfall depths observed at Ward Street, Columbus Park, Chelsea Creek and/or USGS Fresh Pond greater than 2 inches.

Table 9-17. Frequency of Events within Selected Ranges of Total Rainfall for January-December, 2020

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 2020 Metering Data							
Average of 20 Rain Gauges							
Average	40.47	87	41	17	17	8	3
MWRA Rain Gauges							
Ward Street	40.30	89	44	16	20	6	3
Columbus Park	37.93	84	39	16	20	7	2
Chelsea Creek	35.41	92	51	16	16	6	3
Hanscom Air	38.54	77	36	14	17	6	4
Hayes PS	36.77	84	42	13	19	10	0
BWSC Rain Gauges							
Allston	38.71	89	45	18	16	8	2
Charlestown	39.47	85	38	18	17	10	2
Dorchester-Adams	43.3	85	35	22	14	9	5
Dorchester-Talbot	43.3	85	38	19	14	9	5
Hyde Park	50.32	99	48	21	16	7	7
East Boston	40.08	86	40	17	18	9	2
Longwood	40.24	89	44	16	20	7	2
Roslindale	47.17	92	43	21	13	10	5
Roxbury	42.95	88	39	21	15	9	4
Union Park	40.79	84	38	17	17	10	2
USGS Rain Gauge							
Fresh Pond	38.45	79	37	13	19	8	2
MWRA Rain Gauges							
Lexington Farm	40.07	82	39	13	17	11	2
Spot Pond	37.95	91	46	19	13	12	1
Somerville	36.04	92	48	19	17	6	2
Waltham Farm	41.60	81	36	18	14	9	4

Table 9-18. Comparison of Storms Between January 1 and December 31, 2020 and Typical Year with >2 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	1yr
	08/15/1992	72	2.91	0.04	0.66	3m
	09/22/1992	23	2.76	0.12	0.65	1yr
	11/21/1992	84	2.39	0.03	0.31	3m
	05/31/1992	30	2.24	0.07	0.37	3m-6m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-December 2020 Gauge Data						
Ward Street (BO-DI-1)	06/28/2020	48.50	2.04	0.04	1.09	3m
	12/04/2020	23	2.01	0.09	0.25	3m
Columbus Park (BO-DI-2)	03/23/2020	23.25	2.15	0.09	0.55	3m-6m
	10/16/2020	19.50	2.11	0.11	0.31	3m-6m
Chelsea Creek (CH-BO-1)	06/28/2020	48.25	2.11	0.04	0.70	3m
	10/16/2020	20	2.20	0.11	0.32	3m-6m
	12/05/2020	18.50	2.10	0.11	0.32	3m-6m
Fresh Pond (USGS)	11/30/2020	14.25	2.08	0.15	0.34	<3m
	12/05/2020	17.50	2.03	0.12	0.22	3m

The December 4-5, 2020 storm had recorded rain depths greater than 2 inches at Ward Street, Chelsea Creek, and USGS Fresh Pond rain gauges, indicating a storm event with relatively uniform rainfall in contrast to the March 23, 2020 storm for which 2.15 inches of rain was recorded only at Columbus Park. This suggests that the March storm was a more geographically isolated rain event. The 2020 monitoring period had a lower frequency of 2-inch or greater storm events compared to the Typical Year. In addition, while the largest storm for the rain gauges presented below recorded 2.20 inches of rainfall, the Typical Year had five storms with greater than 2.20 inches, and the largest storm in the Typical Year had 3.89 inches of rainfall.

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 9-19). The Typical Year has nine storm events with intensities greater than 0.40 inches per hour, while the 2020 monitoring period had 12 storm events with intensities greater than 0.40 inches per hour. However, while the Typical Year had five storms with greater than 0.60 inches/hour peak intensity, the frequency of those higher-intensity storms was lower for 2020. For example, as shown in Table 9-19, the Ward Street Headworks gage had one storm greater than 0.60 inches/hour; Columbus Park Headworks and Chelsea Creek Headworks gauges each had three storms greater than 0.60 inches/hour, and the Fresh Pond gauge had two storms greater than 0.60 inches/hour.

For storms with peak rainfall intensities greater than 0.40 in/hr at Ward Street Headworks, Columbus Park Headworks, Chelsea Creek Headworks, and USGS Fresh Pond rain gauges, hyetographs were developed. These hyetographs plot the 15-minute rainfall intensities and show the distribution of rainfall during the storm, and can be found in Semiannual Report No. 6.

Table 9-19. Comparison of Storms Between January 1 and December 31, 2020 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour

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	1-2yr
	08/11/1992	11	0.87	0.08	0.75	6m-1yr
	08/15/1992	72	2.91	0.04	0.66	3m-6m
	09/22/1992	23	2.76	0.12	0.65	3m-6m
	05/02/1992	7	1.14	0.16	0.63	3m-6m
	09/09/1992	1	0.57	0.57	0.57	3m
	09/3/1992	13	1.19	0.09	0.51	<3m
	06/05/1992	18	1.34	0.07	0.44	<3m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-December 2020 Metering Data						
Ward Street Headworks (BO-DI-1)	03/23/2020	15	2	0.13	0.50	<3m
	06/06/2020	6.50	0.69	0.11	0.60	3m
	06/11/2020	5.75	0.67	0.12	0.47	<3m
	06/28/2020	48.50	2.04	0.04	1.09	1-2yr
	07/23/2020	0.75	0.49	0.65	0.49	<3m
	07/31/2020	0.25	0.69	2.76	0.69	6m
	08/23/2020	4	0.62	0.16	0.50	<3m
	09/30/2020	8.25	0.98	0.12	0.47	<3m
	10/13/2020	17.50	1.69	0.10	0.41	<3m
	11/23/2020	9	1.80	0.05	0.44	<3m
Columbus Park Headworks (BO-DI-2)	03/23/2020	23.25	2.15	0.09	0.55	3m
	06/06/2020	6.75	0.67	0.10	0.62	3m-6m
	06/11/2020	5.50	0.57	0.10	0.43	<3m
	06/28/2020	48.50	1.33	0.03	0.60	3m
	07/23/2020	0.50	0.72	1.44	0.72	6m
	08/23/2020	4	0.82	0.21	0.70	6m
	11/23/2020	9	1.76	0.05	0.50	<3m
	12/25/2020	15.75	1.37	0.02	0.41	<3m
Chelsea Creek Headworks (CH-BO-1)	03/23/2020	14.50	1.78	0.12	0.49	<3m
	06/28/2020	48.25	2.11	0.04	0.70	6m
	07/14/2020	18.25	1.10	0.06	0.90	1yr
	08/23/2020	4	0.97	0.24	0.93	1-2yr
	12/25/2020	20.50	1.45	0.02	0.42	<3m
Fresh Pond (USGS)	03/23/2020	15	1.96	0.13	0.48	<3m
	06/11/2020	22.75	0.68	0.03	0.50	<3m
	06/28/2020	29.25	1.32	0.05	1.05	1-2yr
	07/23/2020	0.75	0.61	0.81	0.61	3m-6m
	08/23/2020	4	0.54	0.14	0.46	<3m
	09/30/2020	8	0.56	0.07	0.43	<3m
	11/23/2020	8.75	1.77	0.05	0.43	<3m

In summary, comparisons of the 2020 monitoring period to the Typical Year suggest that 2020 was similar, but slightly drier than the Typical Year rainfall and had fewer larger storms. The following is a summary of the rainfall comparison of January to December 2020 to the Typical Year:

- The Typical Year has 93 storm events, while the 2020 averaged 87 storm events (Table 9-17).
- The total average rainfall depth for 2020 (40.47 inches) was less than the Typical Year (46.8 inches) (Table 9-17).
- 2020 had a similar number of storm events with depths between 0.5 to 2.0 inches compared to the Typical Year. (Table 9-17).
- 2020 had fewer storm events with a total rainfall depth greater than 2 inches than the Typical year. In addition, while the largest storm for the rain gauges presented in Table 9-18 had 2.20 inches of rainfall, the Typical Year had five storms with greater than 2.20 inches, and the largest storm in the Typical Year had 3.89 inches of rainfall.
- 2020 had a generally similar number of events with intensities greater than 0.40 inches per hour compared with the Typical Year. However, while the Typical Year had five storms with greater than 0.60 inches/hour peak intensity, the frequency of those higher-intensity storms was lower for 2020 (Table 9-19).

9.7 Data Collection and Analyses January 1, 2021-June 30, 2021

This section presents the analysis of rainfall from the period of January 1, 2021 through June 30, 2021.

9.7.1 Rainfall Data Collection and Processing

Replacement of suspect data from the period of January 1, 2021 through June 30, 2021 is summarized in Table 9-20. Rainfall data used for the analysis are provided in Semiannual Report No. 7.

Table 9-20. Summary of Rainfall Data Replacement, January - June 2021 (Page 1 of 2)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Ward Street (BO-DI-1)	02/18/2021 10:15	02/18/2021 10:15	Columbus Park (BO-DI-2)
	03/11/2021 9:00	03/11/2021 9:15	Columbus Park (BO-DI-2)
	05/24/2021 8:30	05/24/2021 8:30	Columbus Park (BO-DI-2)
Columbus Park (BO-DI-2)	02/18/2021 9:45	02/18/2021 9:45	Ward Street (BO-DI-1)
	03/11/2021 9:45	03/11/2021 10:15	Ward Street (BO-DI-1)
	03/12/2021 8:45	03/12/2021 8:45	Ward Street (BO-DI-1)
	05/25/2021 8:45	05/25/2021 8:45	Ward Street (BO-DI-1)
Union Park Pumping Station	01/26/2021 18:45	01/27/2021 18:00	Columbus Park (BO-DI-2)
	02/18/2021 16:30	02/21/2021 16:30	Columbus Park (BO-DI-2)
Roslindale	01/26/2021 17:45	01/27/2021 18:00	Ward Street (BO-DI-1)
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
	06/29/2021 16:15	06/29/2021 19:00	Ward Street (BO-DI-1)
Dorchester Adams St.	01/01/2021 0:00	01/03/2021 0:00	Roxbury
	01/03/2021 0:00	01/31/2021 23:45	Ward Street (BO-DI-1)
	02/01/2021 0:00	04/30/2021 6:00	Dorchester Talbot
	4/30/2021 6:00	06/30/2021 23:45	Roslindale
Allston	01/26/2021 17:45	01/27/2021 18:00	Ward Street (BO-DI-1)
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
Hyde Park Police Station	01/26/2021 17:45	01/27/2021 18:00	Ward Street (BO-DI-1)
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)

Table 9-20. Summary of Rainfall Data Replacement, January - June 2021 (Page 2 of 2)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Dorchester -Talbot	01/01/2021 0:00	01/03/2021 0:00	Roxbury
	01/03/2021 0:00	01/31/2021 23:45	Ward Street (BO-DI-1)
	02/18/2021 16:30	02/21/2021 16:30	Columbus Park (BO-DI-2)
	4/30/2021 6:00	06/30/2021 23:45	Roslindale
Charlestown	01/01/2021 0:00	06/30/2021 23:45	East Boston
Longwood Medical	01/01/2021 0:00	06/30/2021 23:45	Ward Street (BO-DI-1)
Chelsea Creek	01/26/2021 18:45	01/27/2021 18:00	Columbus Park (BO-DI-2)
	02/18/2021 16:30	02/21/2021 16:30	Columbus Park (BO-DI-2)
East Boston	01/26/2021 18:45	01/27/2021 18:00	Columbus Park (BO-DI-2)
	02/18/2021 16:30	02/21/2021 16:30	Columbus Park (BO-DI-2)
USGS Fresh Pond	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
	05/30/2021 9:15	05/31/2021 7:30	Somerville Remote
Hanscom AFB (HF-1C)	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond
Lexington Farm	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond
Hayes Pump Sta. (RG-WF-1)	01/26/2021 18:45	01/27/2021 18:00	Fresh Pond
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
	06/29/2021 15:30	06/29/2021 15:45	Fresh Pond
Roxbury	01/03/2021 0:30	06/30/2021 23:45	Ward Street (BO-DI-1)
Somerville Remote	01/16/2021 20:00	1/27/2021 18:00	Chelsea Creek (CH-BO-1)
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
Spot Pond	01/01/2021 0:00	06/30/2021 23:45	Somerville Remote
Waltham Farm	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond

9.7.2 Monitored Storms and Comparison with Typical Year

Table 9-21 presents the summary of storm events for Ward Street Headworks for the period of January to June 2021. These data show that 45 storm events occurred in the 6-month period January to June 2021 at the Ward Street Headworks rain gauge (BO-DI-1). The majority of events had less than 3-month recurrence intervals at 1-hour or 24-hour durations. Two storm events had a 24-hour recurrence interval of 3 months or greater (April 15, 2021, and May 28, 2021). Tables summarizing the storm events from January to June 2021 for the other rain gauges are provided in Semiannual Report No. 7.

Table 9-21. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to June 2021 (Page 1 of 2)

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity	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	1/1/2021 22:15	12	0.56	0.05	0.12	0.02	N/A	<3m	<3m	N/A
2	1/3/2021 17:00	2.75	0.06	0.02	0.04	0.00	N/A	<3m	<3m	N/A
3	1/14/2021 14:30	6.25	0.09	0.01	0.03	0.00	N/A	<3m	<3m	N/A
4	1/16/2021 3:45	9.25	1.42	0.15	0.34	0.06	N/A	<3m	<3m	N/A
5	1/26/2021 17:45	15	0.25	0.02	0.06	0.01	N/A	<3m	<3m	N/A

Table 9-21. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to June 2021 (Page 2 of 2)

Event	Date & Start Time	Duration (hr)	Volume (in)	Average Intensity	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
6	1/28/2021 5:00	10	0.07	0.01	0.02	0.00	N/A	<3m	<3m	N/A
7	2/1/2021 14:15	20	1.12	0.06	0.14	0.05	N/A	<3m	<3m	N/A
8	2/6/2021 10:45	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
9	2/7/2021 12:15	25.5	0.37	0.01	0.07	0.01	0.01	<3m	<3m	<3m
10	2/9/2021 12:30	24.75	0.11	0.00	0.03	0.00	0.0	<3m	<3m	<3m
11	2/15/2021 12:00	27	0.67	0.02	0.17	0.03	0.02	<3m	<3m	<3m
12	2/18/2021 16:45	41.25	0.41	0.01	0.04	0.01	0.01	<3m	<3m	<3m
13	2/22/2021 15:45	4.25	0.16	0.04	0.08	0.01	N/A	<3m	<3m	N/A
14	2/27/2021 9:00	7.25	0.17	0.02	0.07	0.01	N/A	<3m	<3m	N/A
15	3/1/2021 0:15	18.25	0.18	0.01	0.07	0.01	N/A	<3m	<3m	N/A
16	3/11/2021 14:15	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
17	3/18/2021 14:15	9	0.75	0.08	0.13	0.03	N/A	<3m	<3m	N/A
18	3/25/2021 0:00	6	0.12	0.02	0.04	0.01	N/A	<3m	<3m	N/A
19	3/26/2021 4:15	5	0.02	0.00	0.01	0.00	N/A	<3m	<3m	N/A
20	3/28/2021 12:00	12	0.85	0.07	0.35	0.04	N/A	<3m	<3m	N/A
21	3/31/2021 21:30	13.25	1.06	0.08	0.27	0.04	N/A	<3m	<3m	N/A
22	4/12/2021 10:45	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
23	4/15/2021 17:30	41.5	2.74	0.07	0.24	0.11	0.06	<3m	6m-1yr	1yr
24	4/20/2021 12:45	0.25	0.01	0.04	0.01	0.00	N/A	<3m	<3m	N/A
25	4/21/2021 13:00	4.75	0.29	0.06	0.11	0.01	N/A	<3m	<3m	N/A
26	4/25/2021 8:15	2.5	0.1	0.04	0.05	0.00	N/A	<3m	<3m	N/A
27	4/28/2021 1:15	2.25	0.22	0.10	0.14	0.01	N/A	<3m	<3m	N/A
28	4/28/2021 19:45	0.25	0.01	0.04	0.01	0.01	N/A	<3m	<3m	N/A
29	4/29/2021 10:00	16	0.85	0.05	0.21	0.03	N/A	<3m	<3m	N/A
30	4/30/2021 22:15	3	0.15	0.05	0.07	0.00	N/A	<3m	<3m	N/A
31	5/2/2021 2:15	2	0.02	0.01	0.01	0.00	N/A	<3m	<3m	N/A
32	5/4/2021 0:15	11.5	0.87	0.08	0.17	0.04	N/A	<3m	<3m	N/A
33	5/5/2021 1:15	21.75	0.6	0.03	0.26	0.03	N/A	<3m	<3m	N/A
34	5/10/2021 0:45	4.5	0.35	0.08	0.13	0.01	N/A	<3m	<3m	N/A
35	5/16/2021 15:30	0.5	0.05	0.10	0.05	0.00	N/A	<3m	<3m	N/A
36	5/26/2021 20:00	11.5	0.33	0.03	0.17	0.01	N/A	<3m	<3m	N/A
37	5/28/2021 18:30	20	2.38	0.12	0.29	0.10	N/A	<3m	6m	N/A
38	5/30/2021 8:45	23	1	0.04	0.12	0.04	N/A	<3m	<3m	N/A
39	6/9/2021 0:00	2	0.04	0.02	0.03	0.00	N/A	<3m	<3m	N/A
40	6/11/2021 21:45	13.25	0.74	0.06	0.17	0.03	N/A	<3m	<3m	N/A
41	6/14/2021 8:30	21	0.62	0.03	0.22	0.03	N/A	<3m	<3m	N/A
42	6/15/2021 18:15	0.25	0.03	0.12	0.03	0.00	N/A	<3m	<3m	N/A
43	6/22/2021 14:00	8.25	1.75	0.21	1.23	0.07	N/A	2yr	<3m	N/A
44	6/25/2021 1:30	4.25	0.07	0.02	0.03	0.00	N/A	<3m	<3m	N/A
45	6/30/2021 17:15	4.5	0.4	0.09	0.24	0.02	N/A	<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.

The total rainfall and number of storms at each rain gauge were identified for the period of January 1 through June 30, 2021, and the number of storms by depth identified. To allow for a comparison of a half-year of data, the total rainfall statistics for the Typical Year were divided by two, to create "Half Typical Year" statistics. Table 9-22 presents the comparison of the January-June 2021 data to the Half Typical Year. As indicated in Table 9-22, during the first half of 2021, rain gauges measured an average of 42 storms with total rainfall volume of 22.82 inches, compared with 47 storms and 23.4 inches in the Half

Table 9-22. Frequency of Events within Selected Ranges of Total Rainfall for January-June, 2021

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
Half Typical Year(1)	23.40	47	25	7	8	4	3
January - June 2021 Metering Data							
Average of Rain Gauges							
Average	22.82	42	20	7	10	4	2
MWRA Rain Gauges							
Ward Street	22.09	45	22	7	9	5	2
Columbus Park	23.17	45	20	6	11	6	2
Chelsea Creek	20.81	46	24	5	11	4	2
Hanscom Air	17.12	36	14	9	10	2	1
Hayes PS	19.47	41	19	6	12	3	1
BWSC Rain Gauges							
Allston	20.73	46	23	7	12	2	2
Charlestown	22.02	42	21	4	9	6	2
Dorchester-Adams	23.98	42	20	4	12	4	2
Dorchester-Talbot	23.97	42	20	4	12	4	2
Hyde Park	23.11	44	22	8	8	3	3
East Boston	22.02	42	21	4	9	6	2
Longwood	22.09	45	22	7	9	5	2
Roslindale	22.98	45	24	6	10	3	2
Roxbury	22.04	44	21	7	9	5	2
Union Park	22.26	48	24	8	9	5	2
USGS Rain Gauge							
Fresh Pond	17.12	36	14	9	10	2	1
MWRA Rain Gauges							
Lexington Farm	17.12	36	14	9	10	2	1
Spot Pond	18.55	40	17	8	11	3	1
Somerville	18.55	40	17	8	11	3	1
Waltham Farm	17.12	36	14	9	10	2	1

(1) "Half Typical Year" values were calculated by dividing the full Typical Year statistics by two.

Typical Year. Storm frequencies for the 0.25 to 0.5-inch and 1.0 to 2.0-inch ranges were equal to the Half Typical Year, while the numbers of storms in less than 0.25-inch and greater than 2-inch ranges were less than the Half Typical Year. The number of storms in the 0.5 to 1.0-inch range were higher than the Half Typical Year. In general, the breakdown of numbers of storms by rainfall depth categories for the first half of 2021 were relatively close to the values for the Half Typical Year.

Storms with greater than 2 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 2 inches of total rainfall in the full Typical Year (Table 9-23). Table 9-23 indicates that two storm events (April 15, 2021, and May 28, 2021) had rainfall depths at Ward Street, Columbus Park, Chelsea Creek and/or USGS Fresh Pond of greater than 2 inches. At the USGS Fresh Pond rain gauge, the April 15 storm had greater than 2 inches, while the May 28 storm had 1.92 inches (see Semiannual Report No. 7). Thus, these two storms appeared to have relatively uniform rainfall across the service area. Referring to Table 9-22, the first half of the 2021 monitoring period had a lower frequency of 2-inch or greater storm events compared to the Half Typical Year. In addition, while the largest storm for the rain gauges presented below recorded 2.74 inches of rainfall, the Typical Year storm with greatest depth had 3.89 inches of rainfall.

Table 9-23. Comparison of Storms Between January 1 and June 30, 2021 and Typical Year with >2 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	1yr
	08/15/1992	72	2.91	0.04	0.66	3m
	09/22/1992	23	2.76	0.12	0.65	1yr
	11/21/1992	84	2.39	0.03	0.31	3m
	05/31/1992	30	2.24	0.07	0.37	3m-6m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-June 2021 Rain Gauge Data						
Ward Street (BO-DI-1)	04/15/2021	41.5	2.74	0.07	0.24	6m-1yr
	05/28/2021	20	2.38	0.12	0.29	6m
Columbus Park (BO-DI-2)	04/15/2021	39	2.29	0.06	0.27	3m-6m
	05/28/2021	19.25	2.55	0.13	0.31	6m-1yr
Chelsea Creek (CH-BO-1)	04/15/2021	39.5	2.20	0.06	0.24	3m-6m
	05/28/2021	19.25	2.28	0.12	0.28	3m-6m
Fresh Pond (USGS)	04/15/2021	23.5	2.35	0.10	0.22	6m

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 9-24). The full Typical Year has nine storm events with intensities greater than 0.40 inches per hour, while the first half of the 2021 monitoring period had one storm event (June 22, 2021) in which the peak intensities ranged from 0.46 to 1.23 inches per hour at three gages (Ward Street, Columbus Park, and Chelsea Creek). The peak intensity at Fresh Pond was less than 0.40 inches per hour. This suggests that the June 22, 2021 storm had high spatial variability which is common in summer thunderstorms.

For storms with peak rainfall intensities greater than 0.4 in/hr at Ward Street Headworks, Columbus Park Headworks, and Chelsea Creek Headworks rain gauges, hyetographs were developed. These hyetographs plot the 15-minute rainfall intensities and show the distribution of rainfall during the storm, and can be found in Semiannual Report No. 7.

Table 9-24. Comparison of Storms Between January 1 and June 30, 2021 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour

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	1-2yr
	08/11/1992	11	0.87	0.08	0.75	6m-1yr
	08/15/1992	72	2.91	0.04	0.66	3m-6m
	09/22/1992	23	2.76	0.12	0.65	3m-6m
	05/02/1992	7	1.14	0.16	0.63	3m-6m
	09/09/1992	1	0.57	0.57	0.57	3m
	09/03/1992	13	1.19	0.09	0.51	<3m
	06/05/1992	18	1.34	0.07	0.44	<3m
	10/09/1992	65	2.04	0.03	0.42	<3m
January-June 2021 Rain Gauge Data						
Ward Street Headworks (BO-DI-1)	06/22/2021	8.25	1.75	0.21	1.23	2yr
Columbus Park Headworks (BO-DI-2)	06/22/2021	6.25	1.09	0.17	0.46	<3m
Chelsea Creek Headworks (CH-BO-1)	06/22/2021	6.5	1.70	0.26	1.02	1-2yr
Fresh Pond (USGS)	No storm events > 0.4 in/hr					

In summary, comparisons of the first half 2021 monitoring period to the Half Typical Year suggest that Q1Q2 of 2021 was similar, but slightly drier than the Half Typical Year rainfall and had fewer larger storms. The following is a summary of the rainfall comparison of January to June 2021 to the Half Typical Year:

- The first half of 2021 averaged 42 storm events, compared to 47 storm events for the Half Typical Year (Table 9-22).
- The total average rainfall depth for the first half of 2021 (22.82 inches) was similar to but slightly less than the Half Typical Year (23.40 inches) (Table 9-22).
- In general, the breakdown of numbers of storms by rainfall depth categories for the first half of 2021 were relatively close to the values for the Half Typical Year (Table 9-22).
- In terms of larger storms, the first half of 2021 had two storm events with a total rainfall depth greater than 2 inches compared to three for the Half Typical year. The largest storm in the first half of 2021 for the rain gauges presented in Table 9-23 had 2.74 inches of rainfall, while the largest storm in the Typical Year had 3.89 inches of rainfall.
- The first half of 2021 had one storm (June 22, 2021) with a peak intensity greater than 0.40 inches per hour compared to four to five for the Half Typical Year (nine for the full Typical Year; Table 9-24). The peak intensities for the June 22, 2021 storm ranged from less than 0.40 to 1.23 inches per hour across different rain gauges, suggesting the storm exhibited high spatial variability typical of summer storms.

9.8 Overall Comparison of Rain Gauge Data from Monitoring Period to the Typical Year

The above sections compared the rain gauge data from individual years (or parts of years) to the Typical Year. While the rainfall data from the monitoring periods varied somewhat from the Typical Year as would be expected, in general the rainfall was not radically different. Table 9-25 presents the total depth and number of storms within various depth ranges for each monitoring period in comparison to the Typical Year. Normalized annual averages for the monitoring period are also presented. The normalized annual averages were computed by summing the values from the individual periods, dividing by 39 (the number of months from April 2015 to June 2021), and multiplying by 12. Looking at the normalized values, the total annual rainfall and total number of storms were both slightly higher than the Typical Year. The number of storms within each depth category were generally similar. The total number of storms greater than one inch was exactly the same (14), although the normalized data from the monitoring period had more storms in the 1.0 to 2.0-inch range, and fewer storms in the greater-than 2.0-inch range. Storms in the greater-than 2.0-inch range would tend to generate the highest CSO volumes.

Table 9-25. Comparison of Total Depth and Number of Storms for Each Period Compared to Typical Year

Monitoring Period	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**
April 15-December 2018	42.45	78	34	14	15	13	2
January -December 2019	49.07	112	58	24	14	12	4
January to December 2020	40.47	87	41	17	17	8	3
January to June 2021	22.82	42	20	7	10	4	2
Normalized Average for April 2018 to June 2021 Period	48	98	47	19	17	11	3

Note: For metered data the average of the gauges is provided.

Peak rainfall intensities can also drive CSO activations and volumes. Figure 9-3 presents a comparison of storms with peak intensities greater than 0.4 inches per hour for each period compared to the Typical Year at Ward Street Headworks. This figure shows that while the number of storms with peak intensities greater than 0.4 inches per hour in the Typical Year was generally similar to the monitoring period, there were four storms in the monitoring period with peak intensities that exceeded the maximum peak intensity in the Typical Year.

After analyzing the rainfall for these periods it is apparent that the rainfall is highly variable which shows the importance of using the Typical Year as a way to assess performance. In addition, when evaluating differences between meter and model at certain locations, it was observed that some storms during the monitoring period exhibited variability in the location and timing of the rainfall across the project area, while other storms were more uniform. The Typical Year is conservative in that respect because it assumes uniform rainfall across the project area.

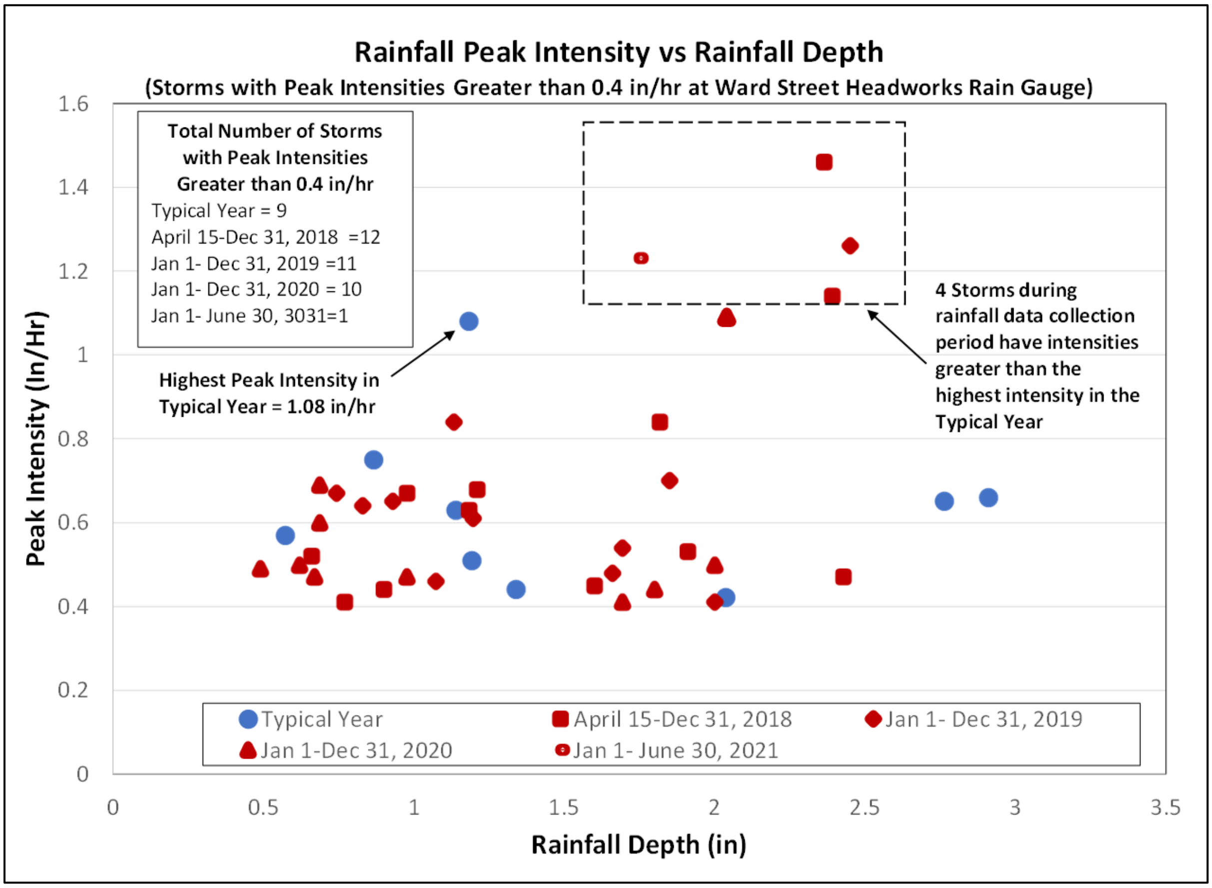


Figure 9-3. Comparison of Storms with Peak Intensities Greater than 0.4 in/hr for Each Period Compared to Typical Year

10. Summary of Collection System Model Development and Calibration

10.1 Chapter Synopsis

The MWRA's collection system 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 CSO regulators. MWRA continuously updates the model to incorporate new information about its system or the community systems that can affect CSO discharges, and to recalibrate against available new meter data. One of the primary objectives of the performance assessment was to recalibrate the model with an expanded set of meter data to improve the level of confidence in the model for predicting system conditions and CSO discharges so that the model could be used to establish system performance for the Typical Year.

Data sources for model calibration included CSO inspections, depth and velocity metering data, rim measurements, rainfall, temperature, tide, MWRA Storm Reports, SCADA data, facility operation procedures and records, record drawings and GIS records.

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 efforts simulated all 50 storm events in the calibration period, with calibration analysis focused on CSO overflow volumes as well as volumes and peak flows for the 20 larger storm events within the calibration period. The calibration process demonstrated that over the course of the calibration metering period, the model reasonably estimated the total activations and volumes measured at the CSO regulators, thereby providing a level of confidence that the model could be used to represent system performance, particularly over an extended period. The model calibration is described in Semiannual Report No. 4 with updates to the calibration described in both Semiannual Report No. 5 and Semiannual Report No. 6.

In general, the model slightly overpredicted activation frequency compared to the meter data. The number of times that the model did not predict a measured activation (2%) was much smaller than the number of times that the model predicted an activation that did not occur (28%).

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 demonstrated that over the course of the calibration metering period, the model reasonably estimated the total activations and volumes measured at the CSO regulators, thereby providing a level of confidence that the model could be used to represent system performance, particularly over an extended period. Further details on the model calibration process are included in the 2021 *Task 4.2: Model Calibration Technical Memorandum* (AECOM, 2021b).

Following completion of the calibration activities, the 2019 system conditions version of the model had a system-wide Typical Year CSO volume of 428 MG, with more outfalls not meeting the LTCP goals for annual activation and/or volume than the 2017 version of the model prior to calibration. As system changes and new information were developed over the years since the initial calibration, periodic local calibration adjustments were incorporated in specific locations. These updates were described as part of the Semiannual Reports and are discussed in Chapter 11 below.

10.2 Description, Purpose and Use of the Collection System Model

Collection system modeling has historically served as the basis for evaluating performance of the CSO system. The collection system model was first established in 1992 during early development of the LTCP using the USEPA Storm Water Management Model (SWMM) software[1]. 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 converted to InfoWorks ICM, the successor modeling software to InfoWorks CS, for this post-construction assessment. 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. 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, to replicate observed wet weather responses and measured CSO activations. This chapter details the procedures that were utilized for model calibration.

The MWRA model includes the entire MWRA regional collection system, broken into the north system (flows to Deer Island via the Columbus Park, Ward Street, Chelsea Creek and Winthrop Terminal headworks) and the 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 10-1. The north system model includes approximately 8,600 links, 8,900 nodes, and 2,900 subcatchments.

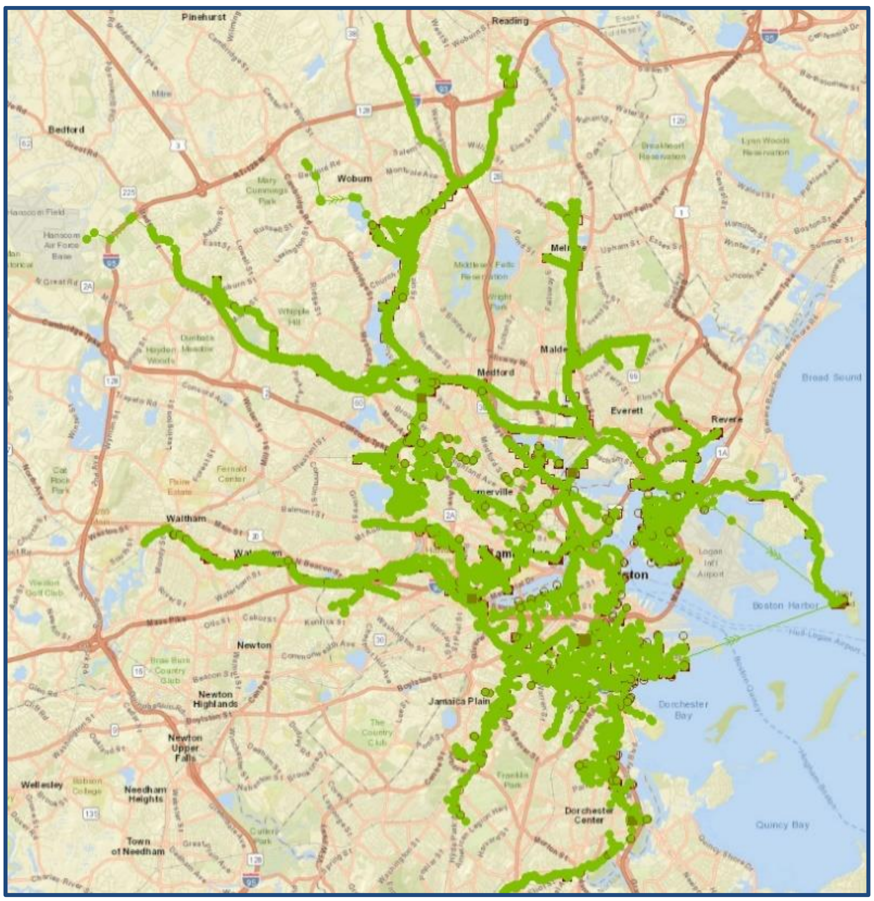


Figure 10-1. MWRA InfoWorks ICM North System Model

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

10.3 Model Calibration

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

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 included 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 reconciled 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 elements were added to the model as appropriate.

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

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 modeled flows at the overflow meters as needed to improve the match to the observed CSO activations.

While the 5-step calibration process outlined above implies a linear procedure, the calibration was an iterative process. For example, calibrating to 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.

Once the model was calibrated, it was checked against meter data from a separate verification period.

10.3.1 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.

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 were accurately represented in the collection system model (see Chapter 6). 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 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 (see Chapters 7 and 8). At some locations, only depth was measured to assess 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 (see Chapter 9). 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 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 operational anomalies or issues occurred that differed from the typical operations that were the basis for the facilities' operational settings in the collection system 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 example, 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 drawings 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. This information was 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 (see Section 7.4) before using it to adjust parameters of the collection system 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 is presented in Chapters 7, 8 and 9.

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 discrepancies. 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:

- CAM002
- CAM401A
- CAM401B
- SOM001A
- 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 regulator 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 included regulators RE003-12, RE004-6, RE010-2, RE012-2, RE013-1, and RE014-2.

10.3.2 Network Changes for Calibration

The modeled physical configuration of the regulators was updated based on site inspections, record drawings, rim measurements, and other available information.

Added/Removed Regulators

As described in Chapter 6, inspections were conducted at all remaining active regulators and the regulators that were closed under the LTCP. As noted in Chapter 6, limited differences between the field conditions and what was already in the model were discovered during these inspections, and the model was updated to reflect the findings of these field investigations.

Community Models

The BWSC, Cambridge, and Somerville community sewer system models were used as information sources 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 more detailed subcatchment delineations (subareas draining to MWRA's system).

Regulator Configuration

The physical configurations 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 based on the inspection data as part of the calibration efforts.

Facility Operation

The collection system model was configured to emulate the MWRA's CSO treatment facilities, headworks and pumping stations 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 during the calibration period.

10.3.3 Dry Weather Calibration

Dry weather calibration involved adjusting parameters in the model that affect dry weather flows to better correlate with the meter data. During dry weather conditions, the sanitary flow, as shown in Figure 10-2, is regulated through the dry weather flow connection to the interceptor where it is conveyed to the treatment facility. A continuous dry weather period from August 29, 2018 to September 2, 2018 was used as the dry weather calibration period. An example dry weather calibration plot is shown in Figure 10-3.

When a substantial 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. Groundwater calibration is discussed further in Section 10.2.6 below.

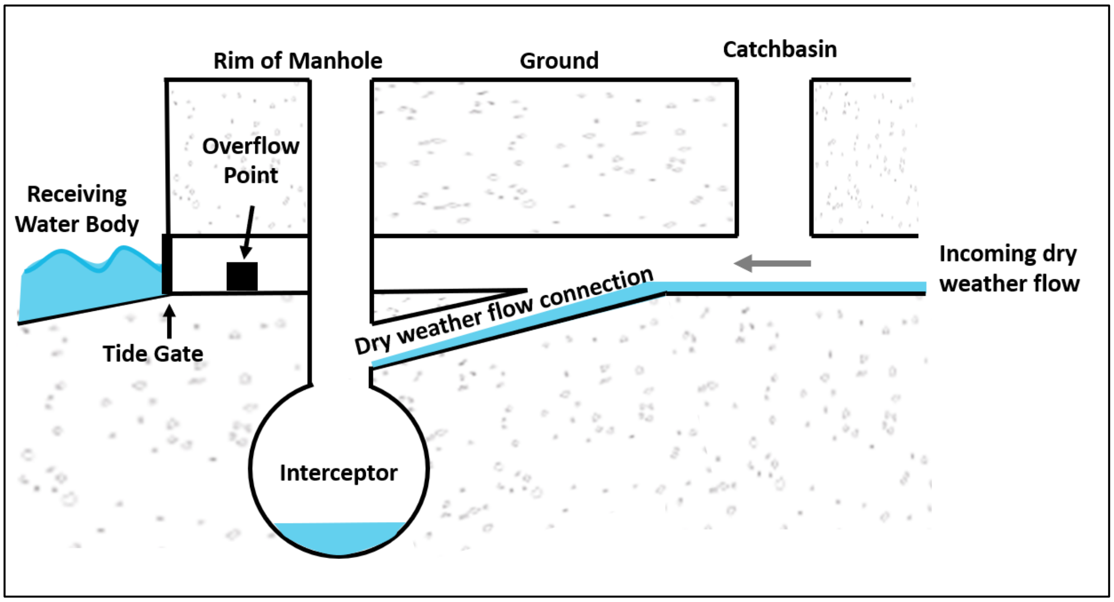


Figure 10-2. Dry Weather Flow at Regulator

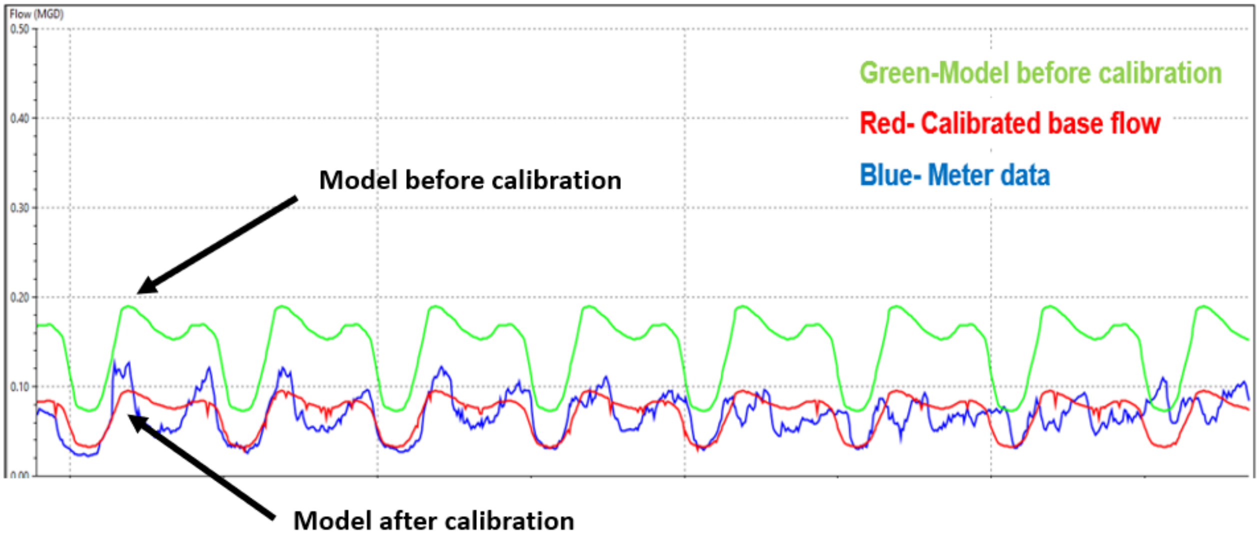


Figure 10-3. Example of Base Flow Calibration

10.3.4 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. For wet weather events that resulted in CSO discharge, modeled overflows were also checked against the overflow meter measurements. Adjustments included 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 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 10-4, the capacity of the interceptor, the size and properties of the dry weather connection, as well as the system's storm response were considered.

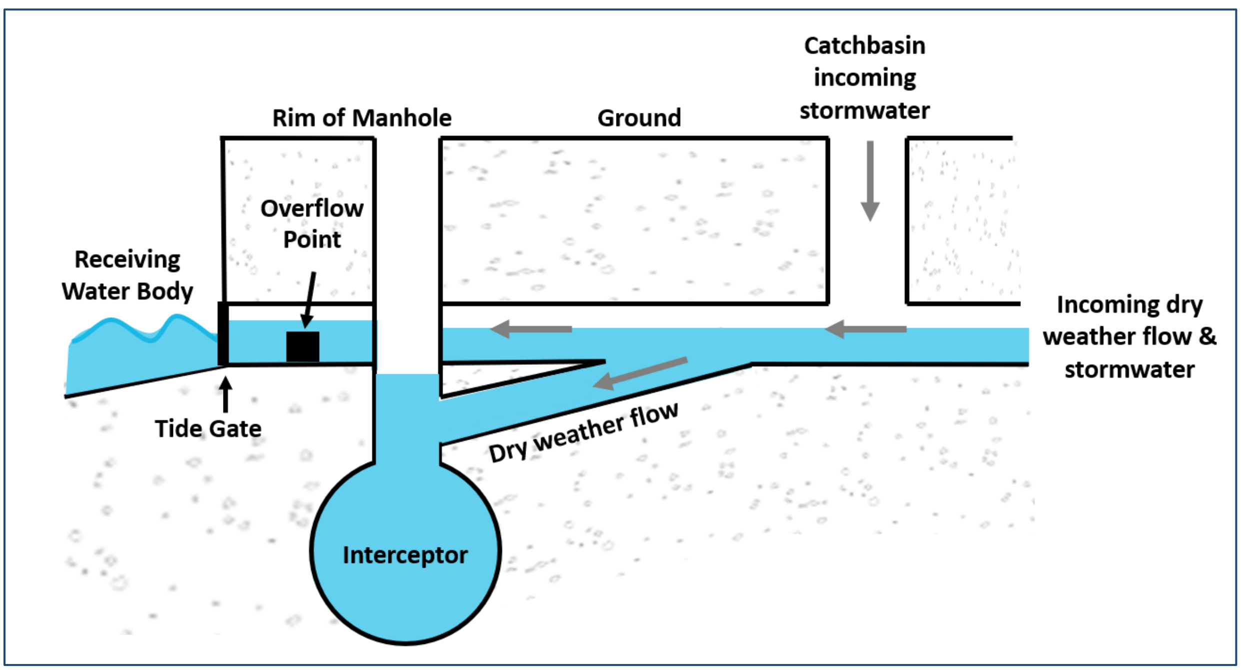
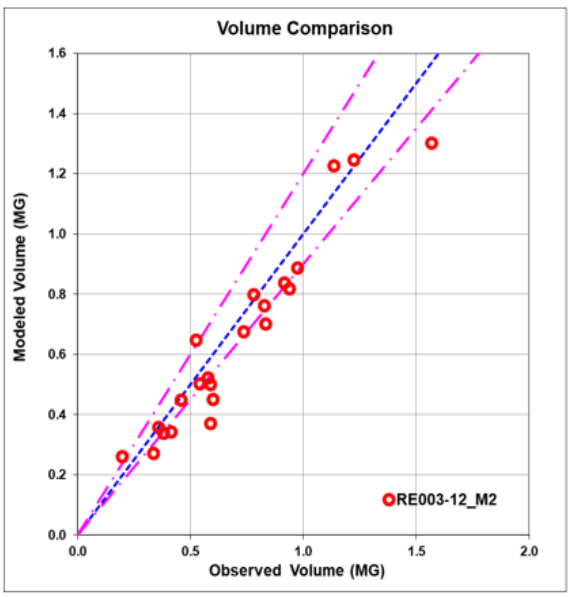


Figure 10-4. Wet Weather Flow at Regulator

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 examples shown in Figure 10-5. 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 rain 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 pink 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 10.3 below.



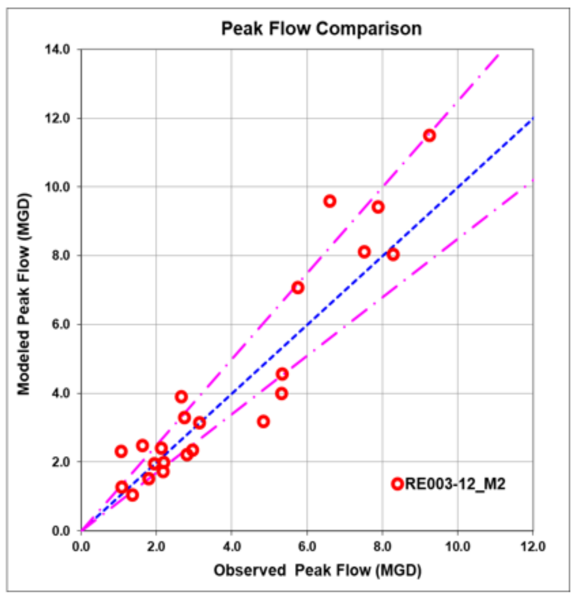


Figure 10-5. Storm Volume and Peak Flow Calibration Plots

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 10-6.

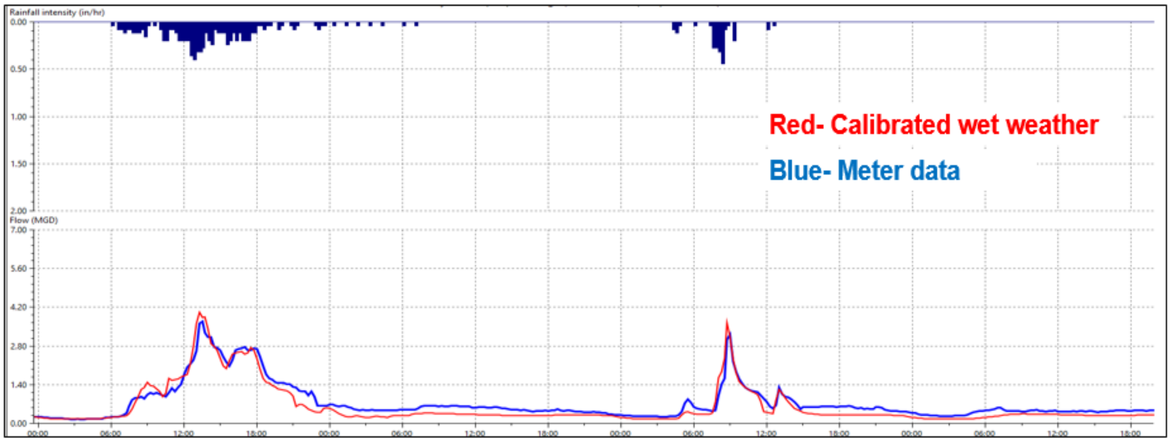
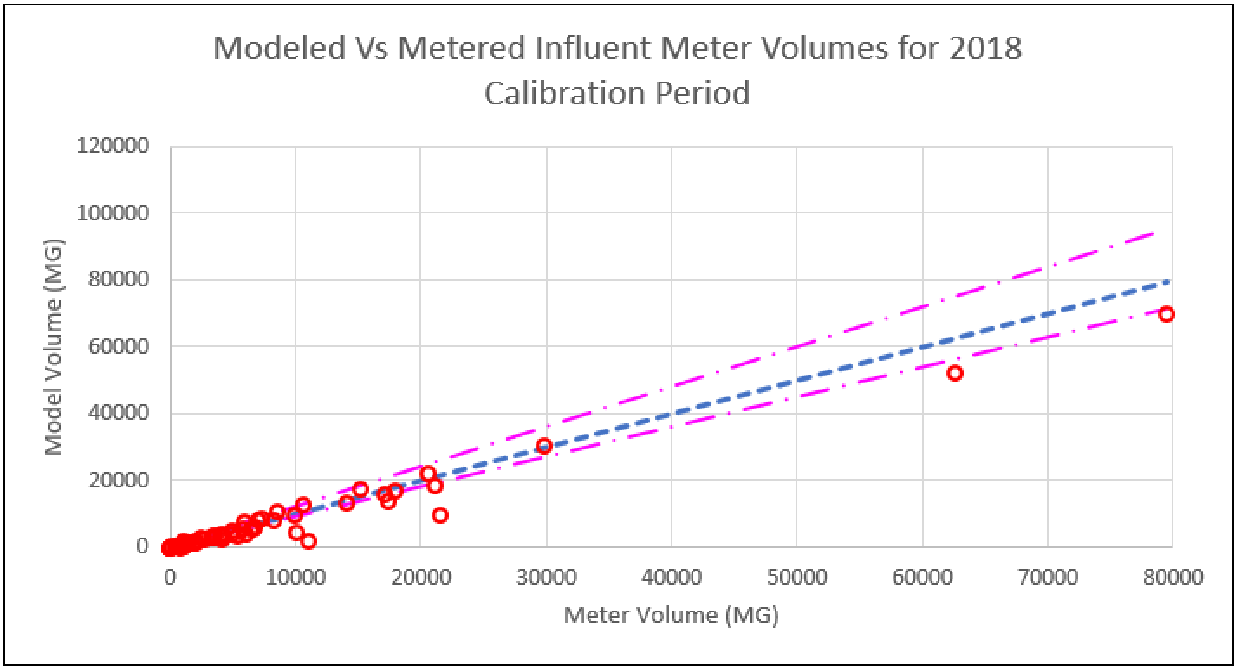


Figure 10-6. RE003-12 Influent Meter Calibration Plot

Calibration of the influent flow meters at the regulators is important to check that the model is appropriately representing the upstream hydrology and conveyance of flows to the regulators. Figure 10-7 demonstrates an overall comparison of the modeled and metered volumes for all influent calibration meters. Each point in Figure 10-7 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 entire 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 over-predicted the volume, while points below the line indicate the model under-predicted 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 affected by spatial variation in rainfall, accuracy of meter data from storm to storm, and other conditions discussed below.



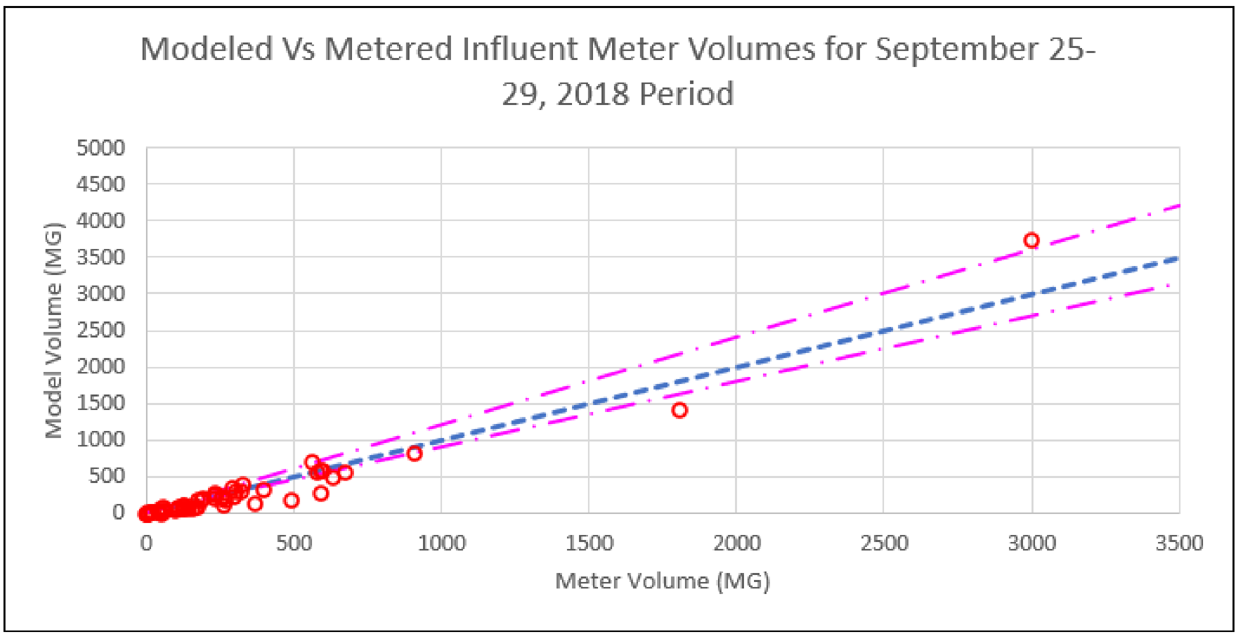


Figure 10-7. Modeled and Metered Influent Meter Volumes

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 interceptor and to the overflow pipe. Scatterplots similar to those shown in Figure 10-5 and Figure 10-7 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 could 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.

10.3.5 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. Simulating groundwater impacts improved model-predicted results for storm events during the spring and fall months where this phenomenon was observed. Figure 10-8 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 matched the meter data (blue), while the results shown with the groundwater turned off (red) showed greater variation between the meter and model predicted flows.

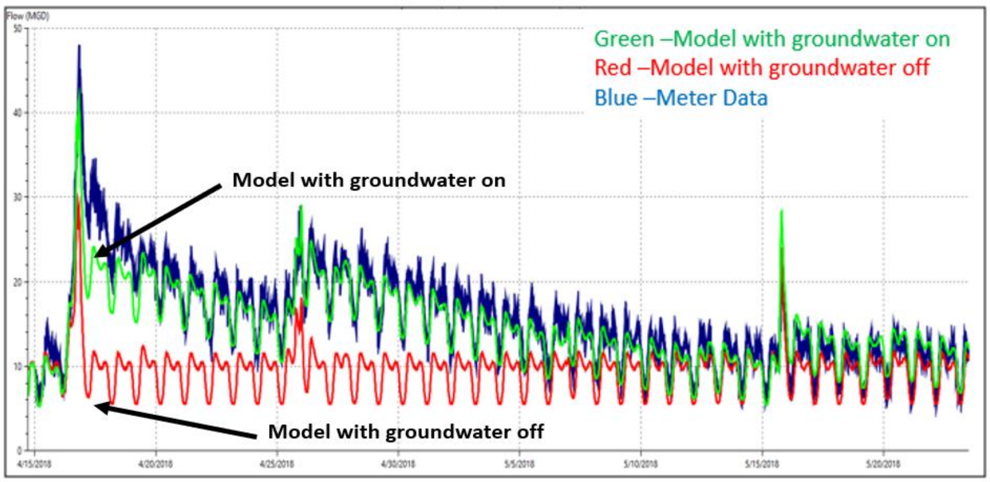


Figure 10-8. Example of Groundwater Calibration

10.3.6 Model Calibration Review and Refinements

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 for this period are presented in Sections 11.2 and 11.3. Calibration scatter plots (similar to Figure 10-5) are presented for each metered regulator in Semiannual Report No. 2, and calibration time series plots (similar to Figure 10-6) were prepared for each metered regulator.

Table 10-1 presents a summary of the metered versus modeled activations and volumes for regulator RE070/8-3 for those periods. As indicated in Table 10-1, the model was consistently conservative in predicting activation frequency. While the model slightly under-predicted CSO volume for the 2018 calibration period and the 2018 full period, the model slightly over-predicted CSO volume for both the October 1 – November 30, 2018 and January 1 – December 31, 2019 verification periods.

Table 10-1. 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	<0.005	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

Comparisons were also made on a storm-by-storm basis for the 2018 calibration period and the verification period. An example of a storm-by-storm metered and modeled comparison for regulator RE070/8-3 is presented in Table 10-2. Table 10-2 presents all storm events for which the model or meter showed an activation.

Table 10-2. Storm-by-Storm Model and Meter Comparison for RE070/8-3 (Page 1 of 2)

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

Table 10-2. Storm-by-Storm Model and Meter Comparison for RE070/8-3 (Page 2 of 2)

Storm	Storm Period [1]	Meter Volume (MG)	Meter Duration (min)	Model Volume (MG)	Model Duration (min)
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

As indicated in Table 10-2, the model under-predicted the 7/17/2018 storm event which accounted 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 indicated 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 10-9. 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 affected CSOs and measurements. Assessment of the 2018 and 2019 verification periods as presented in Table 10-1 and Table 10-2 suggest that the model was 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 10-2).

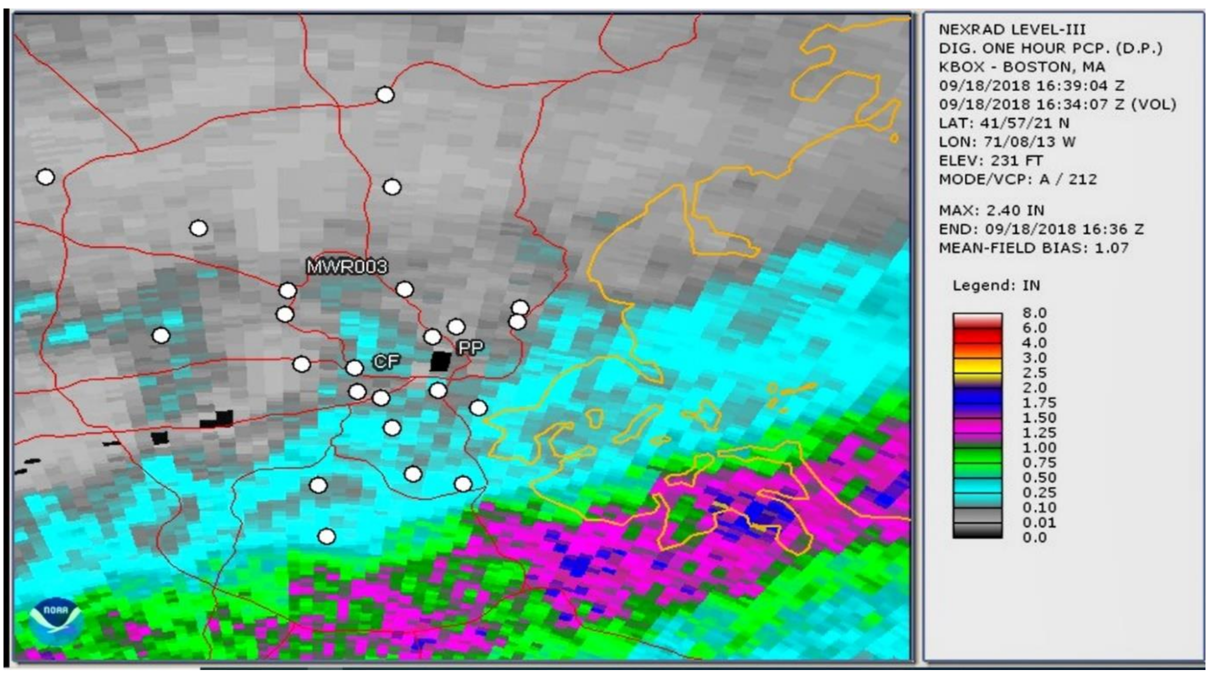


Figure 10-9. Rainfall Variation for the 9/18/2018 Storm

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 summarizes this work (WERF et al., 2015). 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; and
- Modeled approximations of hydraulic conditions in pipes and structures.

Further discussion of these factors is presented in Section 10.4 below.

Calibration Refinements

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 needed 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 10-3, with a brief description of the calibration refinement efforts. Additional information on each of these ten locations can be found in Semiannual Report No. 4, "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.

For 2018, 2019, and the first six months of 2020, metered and modeled CSO activation frequencies and CSO discharge volumes were compared. In general, the model was able to replicate the storm responses for the majority of storm events in the calibration and subsequent verification periods.

Table 10-3. Summary of Additional Calibration Activities at 10 Locations (Page 1 of 2)

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.	Adjusted the Horton infiltration value.
CAM401B	Model over-predicted activation frequency and volume	Community model had 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-inch diameter. A new field inspection was conducted and found the DWF connection to be 24-inch diameter.	Updated the DWF pipe size in the model and changed Manning's n of the dry weather flow connection to 0.33.

Table 10-3. Summary of Additional Calibration Activities at 10 Locations (Page 2 of 2)

Location	Initial Model-Meter Comparison	Summary of Investigation	Modification to Model
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.	Adjusted modeled facility operation for 4/22/18 storm event and added additional groundwater to meter CB-BO-1.
MWR018, 19, 20	Model over-predicted activation frequency (meter volume was not measured at these outfalls)	Hydraulic grade line of Prison Point affected activations. Other activations matched reasonably well with the exception of the 9/18/2018 storm that was found to have high rainfall variability.	No direct modifications made at MWR018, MWR019 or MWR020; adjustments made to Prison Point improved activation predictions.
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 affected results.	Adjusted modeled facility operation for 11/03/18 storm event. No other modifications made as rainfall variation contributed to modeled and metered differences.
BOS060, RE060-7	Model under-predicted activation frequency and volume	The modeled configuration of the regulator was further investigated.	Revised the configuration of the connection between the regulator and the interceptor 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 SOM001A 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.

10.4 Model Changes-Comparison of 2019 Conditions to 2017 Conditions

Prior to the 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. Following completion of the calibration activities described above, the 2019 system conditions version of the model had a system-wide Typical Year CSO volume of 428 MG, with more outfalls not meeting the LTCP goals for annual activation and/or volume than the 2017 version of the model prior to calibration. The predicted number of CSO activations and discharge volume increased at a number of regulator locations after recalibrating the 2017 model and updating the calibrated model to 2019 conditions.

A comparison of the 2017 and re-calibrated 2019 versions of the model was made to assess why this change in predicted performance 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. 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 10-4.

Table 10-4 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 could each 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 10-5 summarizes the percentage of regulators where changes to hydrology tributary to regulators were made between the 2017 and 2019 models.

Table 10-5. 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%

10.5 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.

10.5.1 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 up to 20 rain gauges distributed throughout the project area (see Section 9.1). 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 rain gauge 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.

10.5.2 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.

For the calibration period, each CSO regulator had a unique flow metering configuration designed to estimate CSO activations or confirm that the regulator was 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, sediment 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 Semiannual Report Nos. 1 through No. 5) 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 that 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%.

10.5.3 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 are 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.

10.5.4 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 BOS019 storage facility, outfalls MWR018, MWR019, MWR020, or locations where meters were removed on March 1, 2019. Table 10-6 summarizes the findings of this analysis. Key results from this analysis included:

- 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 number of times that the model did not predict a measured activation (2%) was much smaller than the number of times that the model predicted an activation that did not occur (28%).
- Overall, for 72% of the events when the model predicted an overflow, the measurements also indicated an overflow occurred, and for 28% of the events when the model predicted an overflow, the measurements indicated an overflow did not occur.
- 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 (as defined in Table 10-6), the percent agreement was larger, up to 91% for large events.

Table 10-6 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) The table does not include CSO Facilities and BOS019, MWR018, MWR019, MWR020, and takes into consideration meters that were removed on March 1, 2019.

(2) From April 15, 2018 to December 31, 2019: 196 Storms x 57 Regulators = 11,172 potential regulator-events. 686 + 10,486 = 11,172.

11. Summary of Meter versus Collection System Model Comparisons

11.1 Chapter Synopsis

MWRA undertook an extensive flow metering program to support development and calibration of the collection system model that was ultimately used to assess CSO performance versus the LTCP goals. The meter data were processed to tabulate activation frequency and volume at each metered outfall for each storm as described in Chapter 8. The metered and modeled activation frequency and volume results were compared to assess how well the model was simulating system conditions. Meter versus model comparisons were prepared for the following periods:

- April 15, 2018 to December 31, 2018
- January 1, 2019 to December 31, 2019
- January 1, 2020 to June 30, 2020
- July 1, 2020 to December 31, 2020
- January 1, 2021 to June 30, 2021

For each of the reporting periods, the model was updated to include changes to the MWRA's system and/or changes/updates to the collection system model that had been incorporated since the previous period, and locations where the model-predicted activations/volumes appeared to deviate from the metered values were investigated. These comparisons generally showed that the model correlated well to the meters. When making specific model versus meter comparisons only against CSO discharge volume, the difficulty in quantifying CSO discharges needs to be considered. The model is calibrated not only against these CSO discharges but also against other hydraulic parameters that are more easily measured (influent flows, levels, etc.). Many other factors affect CSO volume measurements, including most notably spatial variations in rainfall that can contribute to differences between model predictions and meter data.

11.2 Introduction

As described above in Chapter 7, the MWRA undertook an extensive flow metering program to support development and calibration of the collection system model that was ultimately used to assess CSO performance versus the LTCP goals. The initial metering program to support model calibration ran from April 2018 through February 2019. In March 2019, many of the flow meters installed for this project were removed, but some remained at regulator locations that discharged to the Variance waters, as well as at regulators where further investigations where required. In July 2020, with the model calibration efforts complete and a substantial post-calibration metering period available to compare modeled and metered CSO discharges, the remaining temporary project meters were removed. In some locations MWRA converted temporary project meters to permanent meters (see Section 7.5.3). These meters were incorporated into MWRA's CSO Notification Program.

During the course of the performance assessment program, MWRA prepared seven Semiannual Reports, summarizing the progress that had been made in six-month increments. These reports included comparisons of metered versus modeled CSO activation frequencies and volumes for the previous six-month period, with the Q3/Q4 semiannual reports typically also including an annual summary. The reports described changes to the MWRA's system and/or changes/updates to the collection system model that had been incorporated since the previous semiannual report and included discussion of locations where the model-predicted activations/volumes appeared to deviate from the metered values.

This chapter presents a summary of the meter versus model comparisons that were previously presented in the semiannual reports. Following an initial discussion of general considerations for the review of meter data and differences between model and meter results, the model versus meter comparisons are presented for the following time periods:

- April 15, 2018 to December 31, 2018
- January 1, 2019 to December 31, 2019
- January 1, 2020 to June 30, 2020
- July 1, 2020 to December 31, 2020
- January 1, 2021 to June 30, 2021

Each section summarizes the updates incorporated into the model since the previous comparison, then presents a table of meter versus model results for the period. The comparisons of modeled to metered results presented below are for measured rainfall events within the monitoring periods, to demonstrate that the model reasonably replicates measured performance in terms of CSO activations and volumes over a range of system and rainfall conditions. These comparisons were not used to assess CSO performance in relation to LTCP goals. The comparison of the CSO performance using the Typical Year rainfall versus the LTCP goals are presented in Chapter 2.

11.2.1 Review of Meter Results

Metering data were used to identify CSO activation frequency, duration, and volumes where applicable. Before the meter data was used for comparison with the model data it was reviewed. Methodologies used to review the meter data were discussed in Chapter 8. Metering data were reviewed to assess reasonableness based on neighboring meters, storm characteristics, and system conditions. In some locations, both the MWRA and a CSO community had flow meters in the same regulator. Where the data from the two meters matched reasonably well, the data from the MWRA meter was reported in the semiannual reports. In some of these cases, however, differences were consistently noted between the calculated volumes from those meters. Where the cause of these differences could not be resolved, the locations were treated as level-only measurements and only activation frequency was reported in the tables.

11.2.2 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. For each year during the assessment period differences between modeled and metered discharges were assessed on a storm-by-storm basis. The differences between metered and model predicted activations were primarily a result of one or more 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 11-1 shows an example of a meter fouling. Metering in CSO regulators is more challenging than metering in single pipe structures. The turbulence present in a CSO 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 a meter.

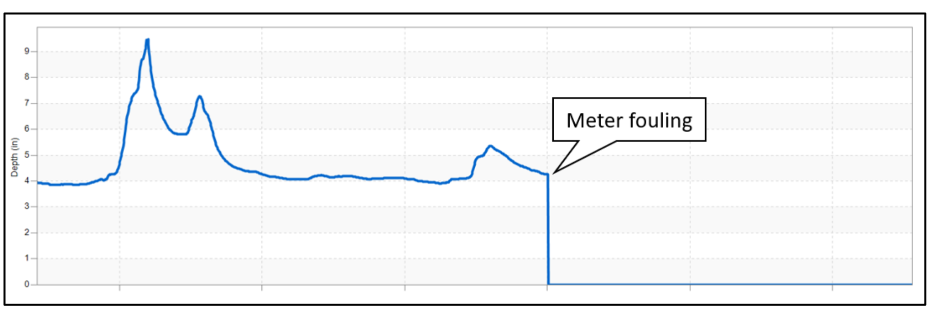


Figure 11-1. Example of Meter Fouling

- **Rainfall spatial variation:** As described in Chapter 9, rain gauges were spaced approximately three miles apart throughout the MWRA's system. Some storms, however, exhibited substantial spatial variation of rainfall, meaning that the rainfall recorded at the gauges may not have been representative of the rainfall that actually fell in parts of the system. This condition was particularly noticeable in short duration, high intensity storm events for CSO regulators with large 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 were likely different for 2019 compared to 2018, and therefore the predicted groundwater response for a model calibrated for 2018 conditions may have been higher or lower for 2019, 2020, and 2021 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 were constantly undergoing maintenance and cleaning and were 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 modeled representation of facility operation was 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, and/or other changes to facility operation could 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 was not configured to simulate snowmelt and rain gauge data during freezing weather. In addition, some of the rain gauges were not heated and may not have accurately measured the amount of precipitation during colder periods. This made the accurate measurement of precipitation and prediction of CSO more difficult during freezing conditions.

11.3 Meter-Model Comparison: April 15, 2018 to December 31, 2018

The calibrated version of MWRA's model as of the end of 2018 was used to simulate the storm events from April 15, 2018 to December 31, 2018, based on 2018 system conditions.

11.3.1 Model Updates Incorporated

Model updates to this version of the model included the incorporation of portions of the CSO community models, field investigations, flow meter comparisons, and all other aspects of the model calibration process as described in more detail in Section 10.3 Model Calibration.

11.3.2 2018 Metered and Modeled CSO Discharge Estimates

The comparison of metered and modeled CSO discharges from April 15 to December 31, 2018 is presented in Table 11-1.

Table 11-1. Summary of April 15 - December 31, 2018 Modeled and Metered CSO Discharges (Page 1 of 4)

			April 15-December 31, 2018			
			Meter		Model	
Outfall	Regulator	Level Only	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

Table 11-1. Summary of April 15 - December 31, 2018 Modeled and Metered CSO Discharges (Page 2 of 4)

Outfall	Regulator	Level Only	April 15-December 31, 2018			
			Meter		Model	
			Activation Frequency	Volume (MG) (1)	Activation Frequency	Volume (MG)
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			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		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

Table 11-1. Summary of April 15 - December 31, 2018 Modeled and Metered CSO Discharges (Page 3 of 4)

Outfall	Regulator	Level Only	April 15-December 31, 2018			
			Meter		Model	
			Activation Frequency	Volume (MG) (1)	Activation Frequency	Volume (MG)
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
Reserved Channel						
BOS076	RE076/2-3		0	0.00	3	0.06
	RE076/4-3		1	0.12	5	0.41
BOS078	RE078-1		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 (3)	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

Table 11-1. Summary of April 15 - December 31, 2018 Modeled and Metered CSO Discharges (Page 4 of 4)

			April 15-December 31, 2018			
			Meter		Model	
Outfall	Regulator	Level Only	Activation Frequency	Volume (MG) (1)	Activation Frequency	Volume (MG)
Back Bay Fens						
BOS046 (3)	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) Metered activations occurred, however the total measured volume of the activations was less than 0.005 MG.

(3) 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. For this period Boston Gatehouse 1 was opened from April 10, 2018 through September 1, 2018.

11.4 Meter-Model Comparison: January 1, 2019 to December 31, 2019

The calibrated version of MWRA's model as of the end of 2019 was used to simulate the storm events from January 1, 2019 to December 31, 2019.

11.4.1 Model Updates Incorporated

The following modifications to the 2018 version of the model were incorporated into the 2019 version of the 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.

11.4.2 Comparison of 2019 Metered and Modeled CSO Discharge Estimates

The model simulated and metered CSO discharges are presented in Table 11-2. The CSO discharges for 2019 are based on the 2018 calibrated model with 2019 system conditions.

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

Table 11-2. Summary of January 1 - December 31, 2019 Modeled and Metered CSO Discharges (Page 1 of 3)

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

Table 11-2. Summary of January 1 - December 31, 2019 Modeled and Metered CSO Discharges (Page 2 of 3)

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)
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
BOS080	RE080-2B	Y	Y	-	-	3	0.09

Table 11-2. Summary of January 1 - December 31, 2019 Modeled and Metered CSO Discharges (Page 3 of 3)

Outfall	Regulator	Level Only	Meter Removed 3/1/19(1)	January 1 - December 31, 2019 Meter Activation Frequency	Meter Volume (MG)(2)	Model Activation Frequency	Model Volume (MG)
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. For this period Boston Gatehouse 1 was closed.

11.5 Meter-Model Comparison: January 1, 2020 to June 30, 2020

The calibrated version of MWRA's model as of June 30, 2020 was used to simulate the storm events from January 1, 2020 to June 30, 2020. For 2020, a half-year assessment of modeled versus metered data is presented because a number of flow meters were removed from the system in the end of June 2020. The model was able to replicate the storm responses for the majority of storm events in this period. However, it was noted that the June 28, 2020 storm event had significant rainfall variation that was not successfully captured by both the rain gauges and the model. As a result, in some locations the model over-predicted the activations, while in other locations the model did not predict activations where the meter indicated activations occurred.

11.5.1 Model Updates Incorporated

The following modifications to the 2019 version of the model were incorporated into the June 30, 2020 ("Mid-2020 System Conditions") version of the model:

- **Alewife Brook Pump Station:** Expanding on the 2019 version of the ABPS, the wet weather pumps were separated into individual pump elements and RTC were added for each pump (two wet weather pumps and one dry weather pump). Each pump's RTC was programmed to control the pump's on-off logic. Although the pump station housed centrifugal pumps the pumps were modeled as screw pumps, allowing for explicit definition of pump performance, defined using a head versus discharge table. Each wet weather pump's performance was defined to have a maximum pumped flowrate of 37.5 MGD at 100% speed and maximum pumped flowrate of 22.5 MGD at 60% speed. The dry weather pump's performance was defined based on the field and SCADA data taken during the July 14, 2020 pump test. At 100% speed the dry weather pump was configured to produce a pumped flowrate between 15.5 MGD and 16.4 MGD, depending on wet well level. At 60% speed the dry weather pump was configured to produce a pumped flowrate of 4 MGD.
- **Alewife Brook Hydraulic System Evaluation:** In 2020, additional investigation was conducted into the regulators discharging to Alewife Brook. These efforts identified that the hydraulic grade line in the interceptor was being over-predicted by the model, and adjustments were made to improve the model's ability to predict the hydraulic grade line in the interceptor. Additionally, the connectivity at CAM401A was revised to match field conditions. Metering data from 2019 and 2020 were also used to adjust the calibration at SOM001A resulting from the removal of the cap over the drop connection from the regulator to the MWRA interceptor and removal of the temporary orifice plate that was installed in this drop connection to restrict flows until other CSO control measures were completed upstream. Additional model adjustments were made to the regulator at CAM002 resulting from the modification to the weir elevation in 2019.
- **Somerville Marginal CSO Facility:** The modeled RTC controlling the Somerville Marginal CSO Facility influent gates was updated to reflect a change in operational procedure implemented by MWRA to optimize the facility to reduce CSO discharges, where at the end of a storm the influent gates were closed at El. 106.5 ft MDC during normal operation, compared to the previous level of 105.5 MDC.
- **BOS070:** In March of 2020, the BWSC completed the removal of a maintenance weir and sediment in the South Boston Interceptor-North Branch. Post removal meter data were used to recalibrate the model to the conditions with the maintenance weir and sediment removed.
- **BOS013, RE0013-1:** As part of the review of the subcatchment areas for BWSC's three East Boston sewer separation contracts, one of the subcatchments tributary to regulator RE013-1 had to be moved in the model from one of the influent pipes to another to account for its actual location and point of entry into the model. Since this change affected the metered flows into the regulator, the influent flows were recalibrated. The recalibration slightly improved the previous match between metered and modeled flows at this location.
- **CSO Facility gate operation data:** As was done for the 2018 model calibration and 2019 model/meter comparison, the control logic in the model was adjusted to reflect actual gate operation based on data from the MWRA's SCADA system for January to June, 2020.

11.5.2 Comparison of Metered and Modeled Results

Table 11-3 presents a comparison of the modeled and metered CSO discharges for the January 1, 2020 to June 30, 2020 period. As indicated in Table 11-3, the metered and modeled discharges were reasonably close at most locations. Locations where the differences were greater are discussed in Table 11-4.

Table 11-3. Summary of January 1-June 30, 2020 Modeled and Metered CSO Discharges (Page 1 of 2)

Outfall	Regulator	Level Only	Meter Removed 3/1/19(1)	January 1 – June 30, 2020			
				Meter		Model	
				Activation Frequency	Volume (MG) (2)	Activation Frequency	Volume (MG)
Alewife Brook							
CAM001	RE-011	Y		0	0.00	1	0.02
CAM002	RE-021			0	0.00	0	0.00
MWR003	RE-031			0	0.00	1	0.29
CAM401A	RE-401			6	N/A	4	0.65
CAM401B	RE-401B			0	0.00	1	0.20
SOM001A	RE-01A			0	0.00	1	0.98
Upper Mystic River							
SOM007A/MWR205A		Y		3	N/A	1	3.82
Mystic/Chelsea Confluence							
MWR205 (Somerville				12	21.57	16	26.80
BOS013	RE013-1		Y	-	-	3	0.04
BOS014	RE014-2		Y	-	-	4	0.05
BOS017	RE017-3		Y	-	-	2	0.01
CHE003	RE-031	Y		0	0.00	0	0.00
CHE004	RE-041			2	0.43	3	0.14
CHE008	RE-081			11	0.32	6	0.62
Upper Inner Harbor							
BOS009	RE009-2		Y	-	-	11	0.07
BOS010	RE010-2		Y	-	-	2	0.08
BOS012	RE012-2		Y	-	-	6	0.31
BOS019	RE019-2	Y		0	0.00	0	0.00
BOS057	RE057-6			0	0.00	1	0.01
BOS060	RE060-7			1	0.00 (3)	0	0.00
	RE060-20			0	0.00	0	0.00
MWR203 (Prison Point)				4	49.18	3	43.82
Lower Inner Harbor							
BOS003	RE003-2		Y	-	-	0	0.00
	RE003-7		Y	-	-	2	0.23
	RE003-12			3	0.64	2	0.67
BOS004	RE004-6		Y	-	-	2	0.00
BOS005	RE005-1	Y	Y	-	-	0	0.00
Fort Point Channel							
BOS062	RE062-4		Y	-	-	4	0.08
BOS064	RE064-4		Y	-	-	0	0.00
	RE064-5	Y	Y	-	-	2	0.02
BOS065	RE065-2	Y		2	N/A	2	0.00
BOS068	RE068-1A	Y	Y	-	-	0	0.00
BOS070/DBC	RE070/8-3			2	0.44	3	0.34
	RE070/8-6	Y		0	0.00	0	0.00
	RE070/8-7	Y		2	N/A	2	0.04
	RE070/8-8	Y		0	0.00	0	0.00
	RE070/8-13	Y		0	0.00	0	0.00
	RE070/8-15	Y		3	N/A	0	0.00
	RE070/9-4			4	0.32	3	0.32
	RE070/10-5			0	0.00	0	0.00
	RE070/7-2			9(4)	0.40	12	0.02
MWR215 (Union Park)				3	3.94	2	6.46
BOS070/RCC	RE070/5-3	Y	Y	-	-	1	0.05
BOS073	RE073-4			0	0.00	0	0.00

Table 11-3. Summary of January 1-June 30, 2020 Modeled and Metered CSO Discharges (Page 2 of 2)

Outfall	Regulator	Level Only	Meter Removed 3/1/19(1)	January 1 – June 30, 2020			
				Meter		Model	
				Activation Frequency	Volume (MG) (2)	Activation Frequency	Volume (MG)
Reserved Channel							
BOS076	RE076/2-3			0	0.00	0	0.00
	RE076/4-3			0	0.00	0	0.00
BOS078	RE078-1 RE078-2		Y	-	-	0	0.00
BOS079	RE079-3	Y	Y	-	-	0	0.00
BOS080	RE080-2B	Y	Y	-	-	0	0.00
Upper Charles							
CAM005	RE-051			4	0.10	1	0.27
CAM007	RE-071			0	0.00	1	0.68
Lower Charles							
CAM017	CAM017			0	0.00	0	0.00
MWR010	RE036-9	Y		0	0.00	0	0.00
	RE037	Y		0	0.00	0	0.00
MWR018	Y			0	0.00	0	0.00
MWR019	Y			0	0.00	0	0.00
MWR020	Y			0	0.00	0	0.00
MWR201 (Cottage Farm)			1	4.03	1	0.15	
MWR023	RE046-19	Y		0	0.00	0	0.00
	RE046-30			0	0.00	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		1	N/A	0	0.00
	RE046-100			1	0.00 (3)	1	0.01
	RE046-105			0	0.00	1	0.02
	RE046-381	Y		0	0.00	0	0.00
	RE046-192	Y		0	0.00	0	0.00
Back Bay Fens							
BOS046 (5)	Boston Gatehouse #1			-	-	0	0.00
GRAND TOTAL					**-**		87.27

(1) For locations indicated with a "Y" in the meter removed column, the meter was removed on March 1, 2019 and therefore no metered results are presented.

(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) A metered volume less than 0.005 MG was recorded.

(4) Meter malfunctioned on June 28, 2020.

(5) 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 model at BOS046 did not predict CSO discharging from Fens Gatehouse #1. For this period Boston Gatehouse 1 was closed.

Table 11-4. Notable Differences between Metered and Modeled CSO Discharges, Jan 1-Jun 30, 2020

Location	Meter	Model	Comment
CHE008	11 activations 0.32 MG	6 activations 0.62 MG	The additional 5 metered activations were reviewed and found to be very short duration and small volume events.
Union Park CSO Facility	3 activations 3.94 MG	2 activations 6.46 MG	The one metered activation that the model missed only lasted 27 minutes with a volume of 0.3 MG. For the other two metered activations, the model overpredicted the volumes. These differences are believed to be due to spatial variation in rainfall.
CAM005	4 activations 0.1 MG	1 activation 0.27 MG	Meters were operated by the MWRA and the City of Cambridge at this location. Conditions within the complex regulator structure have made it difficult to correlate the MWRA meter with meters operated by the City of Cambridge. The City of Cambridge's meter showed two activations (March 23 and June 28, 2020). The March 23 activation had a volume of 0.001 MG. The model predicted the activation on June 28, 2020. The model-predicted volume for the June 28, 2020 storm was likely affected by the high degree of spatial variation in rainfall exhibited by that storm.
Cottage Farm CSO Facility	1 activation 4.03 MG	1 activation 0.15 MG	The one activation registered by both the meter and the model occurred for the June 28, 2020 storm. This storm exhibited a high degree of spatial variation in rainfall which is believed to have contributed to the differences in measured versus modeled overflow volume.

11.6 Meter-Model Comparison: July 1, 2020 to December 31, 2020

The calibrated version of MWRA's model as of December 31, 2020 was used to simulate the storm events from July 1, 2020 to December 31, 2020. As noted above in Section 11.4, for 2020, a half-year presentation of modeled versus metered data is presented because a number of flow meters were removed from the system in the end of June 2020.

11.6.1 Model Updates Incorporated

Table 11-5 describes updates to MWRA's Mid-2020 system conditions model that were incorporated to create the "Q3Q4-2020" system conditions model. The Q3Q4-2020 model was then used to simulate the storm events from July 1-December 31, 2020 with the measured rainfall.

Table 11-5. Changes made to the Mid-2020 system conditions model to create the Q3Q4-2020 System Conditions Model (Page 1 of 3)

Location	Summary of Change	Supporting Information
Full Model-CSO Facilities	Updated the RTC to include the storm by storm operation of the facilities based on MWRA provided data of facility operation.	The updated RTC was added for the July 1-December 31, 2020 period based on MWRA provided data.
Outfalls BOS060, BOS062, BOS064, and BOS065	Minor adjustments were made to the physical configuration of the regulators tributary to outfalls BOS060, BOS062, BOS064, and BOS065, and subsequent minor calibration adjustments were made.	Based on further review of the model and basemaps, minor adjustments were made to the physical configuration of the regulators tributary to outfalls BOS060, BOS062, BOS064, and BOS065. The model was re-run for the 2018 calibration and verification periods. This comparison resulted in some minor adjustments to the hydrology and roughness factors so that the model could more closely match the meters.

Table 11-5. Changes made to the Mid-2020 system conditions model to create the Q3Q4-2020 System Conditions Model (Page 2 of 3)

Location	Summary of Change	Supporting Information
Alewife Brook Pump Station	Updated wet weather pump station operation strategy.	The ABPS wet weather operation strategy was updated to incorporate the changes recommended in the Task 8.1 ABPS Optimization Evaluation.
East Boston	Incorporated Contract 1 Sewer Separation (BWSC) and BWSC model updates received on February 4, 2021.	Additional information on these modifications is documented in Chapter 4 of Semiannual Report No. 6. BWSC changes included removing the interconnection between RE010-2 and RE003-12 and adjusting rim elevations.
CAM401A	Removed sediment at CAM401A.	Cambridge completed removal of the sediment in the combined sewer between CAM401A and the Alewife Brook Branch Sewer on November 30, 2020. Sediment in the model was removed per inspection reports and field measurements taken following the sediment removal.
CHE008	Updated the representation of the regulator configuration to better reflect field conditions. Recalibrated the model to account for the removal of the protrusion of the dry weather flow connection into the regulator.	The protrusion was removed on October 1, 2020. The model was recalibrated with meter data collected following the removal of the protrusion.
Charlestown (BOS017)	Updated the model based on an investigation of the piping network associated with regulator RE017-3 and outfall BOS017 conducted by BWSC.	Model changes included: • Updated the configuration of siphon chambers at Sullivan Square to include the 36-inch connection from the 24x30-inch combined sewer to MWRA's Cambridge Branch Sewer and to adjust the fully opened siphon barrel to half open • Added connections on Middlesex Street and Tibbet's Town Way between Main Street and Rutherford Ave • Updated invert elevations on the Main Street Sewer • Added a subcatchment feeding stormwater into the BWSC combined sewer on Rutherford Avenue • Updated the configuration of the overflow structure and dry weather connection at regulator RE028-2
Cottage Farm	Incorporated the Cambridgeport partial sewer separation project into the model.	Additional information on the Cambridgeport partial sewer separation project is provided in Semiannual Report No. 6.
CAM005	Revised the modeled configuration of the weir at CAM005.	Removed a restriction over the top of the weir and adjusted the weir discharge coefficient based on review of field inspection data.
MWR018/ 019/020	Incorporated updates to regulator structures	Updates were made to regulators per January 2021 field inspections conducted by MWRA.
CAM017	Removed dry weather pipe from the model that the City of Cambridge indicated did not exist. The calibration was reviewed.	The City of Cambridge confirmed that a dry weather flow pipe that was included in the model did not exist in the field. The pipe was removed from the model.
Influent conduit to Prison Point downstream of Charles River siphon	Increased the diameter of a single 3-foot diameter pipe located on the influent conduit to Prison Point downstream of the Charles River siphon to match the downstream pipe diameter.	A pipe with a significantly smaller diameter than the upstream and downstream pipes was identified in the model. MWRA investigated and identified that the pipe has the same diameter as the downstream pipe.
Prison Point pumping configuration	Pump settings were adjusted to better correlate with observed flows following updates to regulators MWR018, 019, 020 and RE0017-3.	SCADA data provided by MWRA were used for pump adjustments.

Table 11-5. Changes made to the Mid-2020 system conditions model to create the Q3Q4-2020 System Conditions Model (Page 3 of 3)

Location	Summary of Change	Supporting Information
Somerville-Marginal CSO Facility/ Ten Hills Stormwater	Adjusted the model to match meter data collected from a stormwater area upstream of the Somerville-Marginal CSO Facility and incorporate information provided by the City of Somerville on highway drainage. The model calibration resulted in a significant decrease in the quantity of water from these stormwater areas, which in turn required adjustment of the runoff parameters in the combined sewer area upstream of the facility. Model adjustments also included more accurate representation of the dry weather flow connections at two upstream regulators.	Additional model information and meter data downstream of Ten Hills was used to calibrate the area. Additional information is provided in Semiannual Report No. 6.

11.6.2 Comparison of Metered and Modeled Results

Table 11-6 presents a comparison of the modeled and metered CSO discharges for the July 1, 2020 to December 31, 2020 period. As indicated in Table 11-6, the metered and modeled discharges were reasonably close at most locations where meter data were available. Locations where the differences were greater are discussed in Table 11-7.

Table 11-6. Summary of July 1-December 31, 2020 Modeled and Metered CSO Discharges (Page 1 of 3)

		July 1-December 31, 2020			
		Meter[1]		Model	
Outfall	Regulator	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Alewife Brook					
CAM001	RE-011	-	-	0	0.00
CAM002	RE-021	-	-	0	0.00
MWR003	RE-031	1	0.01	0	0.00
CAM401A	RE-401	-	-	2	0.10
CAM401B	RE-401B	-	-	1	0.04
SOM001A	RE-01A	-	-	1	0.00
Upper Mystic River					
SOM007A/MWR205A		4	10.99	2	5.61
Mystic/Chelsea Confluence					
MWR205 (Somerville-Marginal CSO Facility)		13	51.62	13	41.59
BOS013	RE013-1	-	-	5	0.08
BOS014	RE014-2	-	-	12	0.48
BOS017	RE017-3	-	-	1	0.03
CHE003	RE-031	-	-	0	0.00
CHE004	RE-041	-	-	2	0.64
CHE008	RE-081	-	-	11	0.58
Upper Inner Harbor					
BOS009	RE009-2	-	-	14	0.28
BOS010	RE010-2	-	-	4	0.17
BOS012	RE012-2	-	-	1	0.01
BOS019	RE019-2	2	1.07	0	0.00

Table 11-6. Summary of July 1-December 31, 2020 Modeled and Metered CSO Discharges (Page 2 of 3)

Outfall	Regulator	July 1-December 31, 2020			
		Meter[1]		Model	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
BOS057	RE057-6	-	-	2	0.02
BOS060	RE060-7	-	-	2	0.03
	RE060-20	-	-	1	0.08
MWR203 (Prison Point)		8	102.62	9	113.56
Lower Inner Harbor					
BOS003	RE003-2	-	-	1	0.02
	RE003-7	-	-	5	0.58
	RE003-12	-	-	5	1.45
BOS004	RE004-6	-	-	3	0.01
BOS005	RE005-1	-	-	0	0.00
Fort Point Channel					
BOS062	RE062-4	-	-	4	0.04
BOS064	RE064-4	-	-	0	0.00
	RE064-5	-	-	3	0.02
BOS065	RE065-2	-	-	3	0.11
BOS068	RE068-1A	-	-	0	0.00
BOS070/DBC	RE070/8-3	-	-	3	0.39
	RE070/8-6	-	-	0	0.00
	RE070/8-7	-	-	4	0.07
	RE070/8-8	-	-	0	0.00
	RE070/8-13	-	-	0	0.00
	RE070/8-15	-	-	0	0.00
	RE070/9-4	-	-	3	0.39
	RE070/10-5	-	-	0	0.00
	RE070/7-2	-	-	13	0.62
MWR215 (Union Park)		5	10.4	6	13.65
BOS070/RCC	RE070/5-3	-	-	0	0.00
BOS073	RE073-4	-	-	0	0.00
Reserved Channel					
BOS076	RE076/2-3	-	-	0	0.00
	RE076/4-3	-	-	1	0.00
BOS078	RE078-1, RE078-2	-	-	0	0.00
BOS079	RE079-3	-	-	0	0.00
BOS080	RE080-2B	-	-	0	0.00
Upper Charles					
CAM005	RE-051	-	-	4	0.09
CAM007	RE-071	-	-	0	0.00

Table 11-6. Summary of July 1-December 31, 2020 Modeled and Metered CSO Discharges (Page 3 of 3)

Outfall	Regulator	July 1-December 31, 2020			
		Meter(1)		Model	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Lower Charles					
CAM017	CAM017	-	-	0	0.00
MWR010	RE036-9	0	0	0	0.00
	RE037	0	0	0	0.00
MWR018		0	0.00	0	0.00
MWR019		0	0.00	0	0.00
MWR020		0	0.00	0	0.00
MWR201 (Cottage Farm)		2	2.04	1	2.73
MWR023	RE046-19	-	-	0	0.00
	RE046-30	-	-	0	0.00
	RE046-50	-	-	0	0.00
	RE046-54	-	-	0	0.00
	RE046-55	-	-	0	0.00
	RE046-62A	-	-	0	0.00
	RE046-90	-	-	0	0.00
	RE046-100	-	-	0	0.00
	RE046-105	-	-	0	0.00
	RE046-381	-	-	0	0.00
	RE046-192	-	-	0	0.00
Back Bay Fens					
BOS046(2)	Boston Gatehouse #1	-	-	0	0
	GRAND TOTAL		-	14 (max)	177.86

(1) Meter volume only reported for MWRA-metered outfalls.
(2) 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 model at BOS046 did not predict CSO discharging from Fens Gatehouse #1. For this period Boston Gatehouse 1 opened when the forecasted rainfall depth was greater than 1-inch.

Table 11-7. Notable Differences between Metered and Modeled CSO Discharges, July 1 - December 31, 2020

Location	Meter	Model	Comment
SOM007A/MWR205A	4 activations 10.99 MG	2 activations 5.61 MG	• The metered activations occurred on: 08/23/2020, 11/30/2020, 12/4/2020 and 12/25/2020. The model activated on 08/23/2020 and 12/5/2020. The 11/30/2020 storm had highly variable rainfall. • The model had less discharge volume mostly tied to missing the activation for the 11/30/2020 storm due to the highly variable rainfall. • The discharge volume at this location is tied to the discharge at the Somerville-Marginal CSO facility, the tide, and the stormwater coming in downstream of the facility. There is some uncertainty in the volume of stormwater entering downstream of the Somerville-Marginal CSO Facility.
Somerville Marginal CSO Facility	13 activations 51.62 MG	13 activations 41.59 MG	• The model had less discharge volume due to rainfall variability mostly tied to the 11/30/2020 storm event.
BOS019 Storage Facility	2 activations 1.07 MG	0 activation 0 MG	• The two metered activations occurred on 12/5/2020 and 12/25/2020. The rainfall on the 12/5/2020 storm was highly variable. • For both metered activations, the model predicted flow to enter the storage tanks, but not enough flow to cause an overflow.

11.7 Meter-Model Comparison: January 1 to June 30, 2021

The calibrated version of MWRA's model as of June 30, 2021 was used to simulate the storm events from January 1, 2021 to June 30, 2021.

11.7.1 Model Updates Incorporated

Table 11-8 describes updates to MWRA's Q3Q4-2020 system conditions model that were incorporated to create the "Q1Q2-2021" system conditions model. The model was then used to simulate the storm events from January 1, 2021 to June 30, 2021 with the measured rainfall.

Table 11-8. Model Changes from Q3Q4-2020 to Q1Q2-2021 System Conditions (Page 1 of 2)

Location	Summary of Change	Supporting Information
Full Model-CSO Facilities	Updated the Real Time Control (RTC) to include the storm-by-storm operation of the facilities based on facility operation data provided by MWRA.	The updated RTC was added for the January 1 – June 30, 2021 period based on MWRA-provided data.
BOS010	Raised the weir by 3 inches at RE010-2.	BWSC raised the weir 3 inches at RE010-2 in February 2021. Additional information is provided in Semiannual Report No. 6.
Charlestown (BOS017)	Removed leaky tide gate and removed 4 acres of stormwater upstream of BOS017.	Updated the model based on system changes provided by BWSC.
Somerville Marginal CSO Facility	Added 42-inch storm drain tributary to the 85" x 90" combined sewer upstream of Somerville Marginal CSO Facility and re-delineated its tributary area.	The stormwater areas tributary to the pipe were in the model but were redirected to the 42-inch drain as appropriate.

Table 11-8. Model Changes from Q3Q4-2020 to Q1Q2-2021 System Conditions (Page 2 of 2)

Location	Summary of Change	Supporting Information
Boston Marginal Conduit (BMC)	Revised the categorization of manholes along the BMC as sealed vs. unsealed.	Adjusted manhole configurations along the BMC based on recent field information.
	Updated the model to include DCR catch basins tributary to the BMC.	Catch basins were added based on review of DCR storm water drawings.
	Updated the model to include an interconnection between the Old Stony Brook Conduit (OSBC) and the Stony Brook Conduit (SBC).	Added an interconnection between the OSBC and the SBC based on field investigations conducted by BWSC.
	Made adjustments to headloss parameters at locations along the BMC.	Removed modeling losses at the manholes along the BMC identified during the alternative evaluation process to better reflect the structural configuration of the BMC and to improve the match between modeled and measured depths in the BMC.
BOS046, Boston Gate House #1	The model RTC was updated to reflect the actual gate conditions at Gate House #1 during the January 1, 2021 – June 30, 2021 period. The gate opening height was changed from 13 feet to 4 feet based on field information from BWSC.	BWSC opens the gates in Gate House #1 for each storm predicted to be 1 inch or greater over less than 24 hrs. Gate opening dates from Jan 1 to June 30, 2021 were provided by BWSC. The Typical Year version of the model will open the gates for rainfall events greater than 1-inch.
BOS046, Boston Gate House #2	Added overflow at Boston Gate House #2, at El. 13 BCB (El. 112.97 MDC)	This overflow location was added based on new field information provided by BWSC.
North Metropolitan Branch Sewer Downstream of Alewife Brook Pump Station	Made adjustments to headloss parameters at locations along the interceptor.	Updated headloss parameters in the North Metropolitan Branch sewer downstream of the Alewife Brook Pump Station based on a review of pipe configurations.
Cottage Farm/Willard Street	Updated the model to include local subcatchment areas and piping tributary to the MWRA interceptor at Willard Street.	Added 28 acres at 50% impervious and associated piping, based on information provided by the City of Cambridge.
Alewife/ CAM401A	Added 6 inches of sediment to the combined sewer downstream of the CAM401A regulator to reflect 6 inches of standing water observed during a field inspection.	The City of Cambridge reported observing 6 inches of water downstream of the CAM401A regulator as part of post cleaning measurements on April 13, 2021.
CHE004	Updated the weir elevation based on field investigations.	The weir in the Q1-2021 Conditions model was set at El. 109.83 to reflect the raising of this weir by the City of Chelsea in December 2020. Due to construction issues and based on field observations following December 2020, the weir elevation was reduced by 5 inches to El. 109.41.

11.7.2 Comparison of Metered and Modeled Results

Table 11-9 presents a comparison of the modeled and metered CSO discharges for the January 1, 2021 to June 30, 2021 period. As indicated in Table 11-9, the metered and modeled discharges were reasonably close at most locations where meter data were available. Locations where the differences were greater are discussed in Table 11-10.

Table 11-9. Summary of January 1- June 30, 2021 Modeled and Metered CSO Discharges (Page 1 of 3)

Outfall	Regulator	January 1- June 30, 2021			
		Meter[1]		Model	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Alewife Brook					
CAM001	RE-011	-	-	0	0.00
CAM002	RE-021	-	-	0	0.00
MWR003	RE-031	0	0.00	0	0.00
CAM401A	RE-401	-	-	0	0.00
CAM401B	RE-401B	-	-	0	0.00
SOM001A	RE-01A	-	-	0	0.00
Upper Mystic River					
SOM007A/MWR205A		3	7.47	1	6.68
Mystic/Chelsea Confluence					
MWR205 (Somerville-Marginal CSO Facility)		9	31.74	10	27.39
BOS013	RE013-1	-	-	1	0.07
BOS014	RE014-2	-	-	6	0.40
BOS017	RE017-3	-	-	1	0.06
CHE003	RE-031	-	-	0	0.00
CHE004	RE-041	-	-	1	0.29
CHE008	RE-081	-	-	4	0.88
Upper Inner Harbor					
BOS009	RE009-2	-	-	9	0.16
BOS010	RE010-2	-	-	1	0.11
BOS012	RE012-2	-	-	0	0.00
BOS019	RE019-2	1	0.09	0	0.00
BOS057	RE057-6	-	-	2	0.37
BOS060	RE060-7	-	-	1	0.18
	RE060-20	-	-	2	0.07
MWR203 (Prison Point)		4	74.1	5	95.46
Lower Inner Harbor					
BOS003	RE003-2	-	-	0	0.00
	RE003-7	-	-	3	0.67
	RE003-12	-	-	2	1.04
BOS004	RE004-6	-	-	1	0.03
BOS005	RE005-1	-	-	0	0.00
Fort Point Channel					
BOS062	RE062-4	-	-	1	0.62
BOS064	RE064-4	-	-	1	0.00
	RE064-5	-	-	1	0.01
BOS065	RE065-2	-	-	4	0.25
BOS068	RE068-1A	-	-	0	0.00
BOS070/DBC	RE070/8-3	-	-	1	0.07
	RE070/8-6	-	-	0	0.00
	RE070/8-7	-	-	0	0.00

Table 11-9. Summary of January 1- June 30, 2021 Modeled and Metered CSO Discharges (Page 2 of 3)

<table>
<tr><th rowspan="3">Outfall</th><th rowspan="3">Regulator</th><th colspan="4">January 1- June 30, 2021</th></tr>
<tr><th colspan="2">Meter[1]</th><th colspan="2">Model</th></tr>
<tr><th>Activation Frequency</th><th>Volume (MG)</th><th>Activation Frequency</th><th>Volume (MG)</th></tr>
<tr><td colspan="6">Fort Point Channel (cont.)</td></tr>
<tr><td rowspan="6">BOS070/DBC (cont.)</td><td>RE070/8-8</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>RE070/8-13</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>RE070/8-15</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>RE070/9-4</td><td>-</td><td>-</td><td>1</td><td>0.07</td></tr>
<tr><td>RE070/10-5</td><td>-</td><td>-</td><td>1</td><td>0.01</td></tr>
<tr><td>RE070/7-2</td><td>-</td><td>-</td><td>7</td><td>1.81</td></tr>
<tr><td colspan="2">MWR215 (Union Park)</td><td>4</td><td>11.45</td><td>5</td><td>18.26</td></tr>
<tr><td>BOS070/RCC</td><td>RE070/5-3</td><td>-</td><td>-</td><td>1</td><td>0.15</td></tr>
<tr><td>BOS073</td><td>RE073-4</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td colspan="6">Reserved Channel</td></tr>
<tr><td rowspan="2">BOS076</td><td>RE076/2-3</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>RE076/4-3</td><td>-</td><td>-</td><td>1</td><td>0.00</td></tr>
<tr><td>BOS078</td><td>RE078-1 RE078-2</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>BOS079</td><td>RE079-3</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>BOS080</td><td>RE080-2B</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td colspan="6">Upper Charles</td></tr>
<tr><td>CAM005</td><td>RE-051</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>CAM007</td><td>RE-071</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td colspan="6">Lower Charles</td></tr>
<tr><td>CAM017</td><td>CAM017</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td rowspan="2">MWR010</td><td>RE036-9</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td>RE037</td><td>-</td><td>-</td><td>0</td><td>0.00</td></tr>
<tr><td colspan="2">MWR018</td><td>1</td><td>0.46</td><td>1</td><td>0.71</td></tr>
<tr><td colspan="2">MWR019</td><td>1</td><td>0.18</td><td>1</td><td>0.44</td></tr>
<tr><td colspan="2">MWR020</td><td>1</td><td>0.16</td><td>1</td><td>0.74</td></tr>
<tr><td colspan="2">MWR201 (Cottage Farm)</td><td>0</td><td>0.00</td><td>0</td><td>0.00</td></tr>
<tr><td rowspan="11">MWR023</td><td>RE046-19</td><td rowspan="12">1</td><td rowspan="12">0.12</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-30</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-50</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-54</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-55</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-62A</td><td>0</td><td>0.00</td></tr>
<tr><td>RE046-90</td><td>1</td><td>0.00</td></tr>
<tr><td>RE046-100</td><td>1</td><td>0.11</td></tr>
<tr><td>RE046-105</td><td>1</td><td>0.07</td></tr>
<tr><td>RE046-381</td><td>1</td><td>0.19</td></tr>
<tr><td>RE046-192</td><td>0</td><td>0.00</td></tr>
<tr><td colspan="2">MWR023 Total[2]</td><td>1</td><td>0.09</td></tr>
</table>

Table 11-9. Summary of January 1- June 30, 2021 Modeled and Metered CSO Discharges (Page 3 of 3)

Outfall	Regulator	January 1- June 30, 2021			
		Meter(1)		Model	
		Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Back Bay Fens					
BOS046	Boston Gatehouse #1(2)	-	-	1	0.28
	Boston Gatehouse #2(3)	-	-	1	0.65
GRAND TOTAL			-	10 (max)	158.02

(1) Meter volume only reported for MWRA-metered outfalls.
(2) BOS046 (Gatehouse 1) is primarily a stormwater discharge but may discharge CSO if the upstream regulators overflow. The upstream regulators are monitored by BWSC. The gatehouse is normally closed but may be opened for flood mitigation. Flow can discharge at Gatehouse 1 if the gate is opened or if water overtops the closed gate. Based on model tracer studies, when a discharge occurs during model simulations at BOS046 and one or more of the upstream regulators in the Stony Brook system are predicted to activate, 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). Therefore, the reported CSO volumes for the model at MWR023 are based on 25% of the CSO volume from the upstream regulators and the CSO volumes at BOS046 are based on 75% of the predicted CSO volume from the upstream regulators. For Q1Q2-2021 BWSC opened the gates 6 times, however, upstream CSOs only occurred during one of those instances.
(3) BOS046(Gatehouse 2) contains a gate which may also be overtopped in larger storm events; this gate was added to the model after the Q1-2021 system conditions model run per new field information.

Table 11-10. Notable Differences between Metered and Modeled CSO Discharges, January 1- June 30, 2021

Location	Meter	Model	Comment
SOM007A/MWR205A	3 discharges 7.47 MG	1 discharge 6.68 MG	• The metered discharges occurred on 01/16/2021, 04/16/2021 and 05/28/2021. The model discharges only on the 05/28/2021 storm. • The 01/16/2021 storm volume was very small, only 0.02 MG. This storm occurred in the winter, when the model can be less accurate due to winter conditions. • For the 04/16/2021 storm, the model predicted that the water level rose to within 8 inches of the discharge elevation for SOM007A/MWR205A. Thus, the model reacted to the storm but it was not enough to cause an activation. The discharge volume at this location is influenced by the discharge at the Somerville-Marginal CSO facility, the tide, and the stormwater coming in downstream of the facility. There is some uncertainty in the volume of stormwater entering the outfall downstream of the Somerville-Marginal CSO Facility, which could contribute to differences in metered versus modeled conditions.
Prison Point CSO Facility	4 discharges 74.1 MG	5 discharges 95.46 MG	• The metered discharges occurred on 01/16/2021, 04/16/2021, 05/29/2021, and 06/22/2021. The model correctly simulated discharges on these dates, but also predicted a discharge of 1.93 MG on 04/01/2021. This discharge, as well as the differences in discharge volume, are likely attributed to spatial variation in rainfall. In particular, the 06/22/2021 storm was highly variable across the region.
BOS019	1 discharges 0.09 MG	0 discharges 0 MG	• The monitoring indicated there was one discharge at BOS019 (05/29/2021) while the model predicted zero. The model predicted that flow entered the storage tank for the 5/29/21 storm, but it was not enough to exceed the storage volume and discharge through BOS019.
Union Park Facility	4 discharges 11.45 MG	5 discharges 18.25 MG	• The metered discharges occurred on 01/16/2021, 04/16/2021, 05/29/2021, and 06/22/2021. The model correctly simulated discharges on these dates, but also predicted a discharge of 1.35 MG on 02/02/2021. This discharge may be due to the model being less accurate during winter conditions. The differences in discharge volume are likely due to spatial variation in rainfall. The 06/22/2021 storm had significant spatial variation, as evidenced by the differences in peak intensity measured at the rain gages.

12. Summary of Water Quality Model Development and Calibration

12.1 Chapter Synopsis

Hydrodynamic and water quality models of the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River were developed and calibrated to support the assessment of the performance of the current MWRA system in comparison to the goals identified in the Second Stipulation for the CSO variance waters. These models were intended to assess the benefits to bacterial water quality in these receiving waters resulting from the improvements made by implementing the MWRA CSO Long Term Control Plan over the last 30 years, as well as the remaining impacts of CSO and non-CSO bacteria sources. Specifically, these models were intended to:

- Assess the relative impact of remaining CSO on water quality in the Charles River and Alewife Brook/Mystic River;
- Provide information about impacts of stormwater and boundary conditions; and
- Predict resulting *E. coli* and *Enterococcus* counts during 3-month and 1-year storms as well as the Typical Year.

The various sources of flows and bacteria loads into the receiving waters represented in the models included the following:

- Stormwater;
- Untreated and treated CSO;
- Dry weather base flow (infiltration flow from storm drains or groundwater flow directly to a waterbody; could also include flow from illicit sanitary connections to storm drains); and
- Boundary conditions (flow into the study area from upstream).

The models were calibrated by comparing model-predicted *E. coli* and *Enterococcus* counts at specific locations in the receiving waters with concentrations measured at those locations during specific storm events and dry weather periods. For the two water quality models, MWRA's extensive in-stream water quality monitoring data were used as the basis for comparing to model results during the calibration process. These data included the results of water quality sampling and analysis at 17 stations in the Charles River and 17 stations in the Alewife Brook/Upper Mystic River. The *E. coli* and *Enterococcus* die-off rates and stormwater and CSO bacterial counts were adjusted within reasonable ranges to improve the match between the modeled and the measured values.

The models were run for dry weather periods as well as a series of storm events. Graphs were then prepared for each sampling station for each of the storm events comparing the measured and calculated *E. coli* counts. Overall there was a good correlation between the modeled and measured concentrations.

12.2 Introduction

This chapter presents a summary of the development and calibration of the water quality models to support the assessment of the performance of the MWRA system with respect to water quality impacts. This section is organized into the following major subsections:

- 12.3 - Overview of Water Quality Models. Presents a general overview of the modeling software used for the Charles River and Alewife Brook/Upper Mystic River models
- 12.4 - Data to Support Model Development. Presents the data collected to support model development, including CSO and stormwater sampling data, and development of boundary condition flows and concentrations.
- 12.5 - Model Calibration Data and Approach. Presents the data used to support the water quality model calibration, and the approach used to conduct the calibration.
- 12.6 - Charles River Model Calibration. Presents the results of the Charles River model calibration.

- 12.7 – Alewife Brook/Upper Mystic River Model Calibration. Presents the results of the Alewife Brook/Upper Mystic River model calibration.
- 12.8 – Sensitivity to Model Assumptions. Presents a discussion regarding the sensitivity of the model results to the assumptions used for the modeling.

Additional information on the model development and calibration can be found in *Task 5.2 Receiving Water Quality Model Development and Calibration* report (AECOM, 2020).

12.3 Overview of Water Quality Models

The water quality models of the Charles River and Alewife Brook/Upper Mystic River computed time-varying and spatially-varying concentrations of *E. coli* and *Enterococcus* in the rivers, taking into account the influence of river flow and geometry, and the impacts of dilution, dispersion, and die-off.

The Charles River model is a horizontally two-dimensional model based on the Delft3D software. The model includes a hydrodynamic part, which calculates water levels and depth-averaged velocities, and a water quality part, which calculates depth-averaged *E. coli* and *Enterococcus* counts. The model extends from the New Charles River Dam and locks to the Watertown Dam (Figure 12-1).

The Alewife Brook/Upper Mystic River model is a one-dimensional model based on the InfoWorks ICM software. The model includes a hydrodynamic part, which calculates water levels and cross-section-averaged velocities, and a water quality part, which calculates cross-section-averaged *E. coli* and *Enterococcus* counts. The model extends from the Amelia Earhart Dam to the Lower Mystic Lake and covers the Alewife Brook in its entirety (Figure 12-1).

The various sources of flows and bacteria loads into the receiving waters represented in the models included the following:

- Stormwater;
- Untreated and treated CSO;
- Dry weather base flow (infiltration flow from storm drains or groundwater flow directly to a waterbody; could also include flow from illicit sanitary connections to storm drains); and
- Boundary conditions.

The following sections present the basis for the modeled flows and loads from these sources.

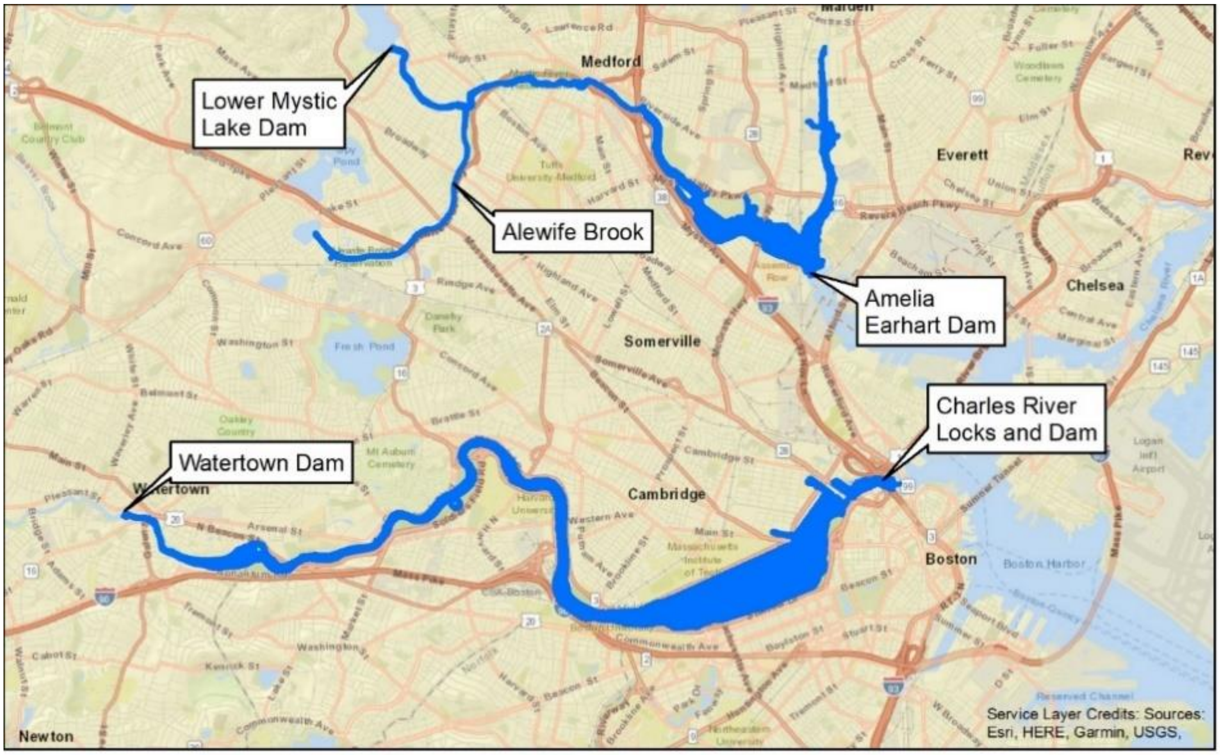


Figure 12-1. Extent of the Charles River and Alewife Brook/Upper Mystic River Models

12.4 Data to Support Model Development

The monitoring data that were used to support development of 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 are summarized in Table 12-1 on the following page and described in more detail in the subsections below.

12.4.1 Untreated CSOs

Untreated CSO sampling and analysis for *E. coli* and *Enterococcus* was conducted on influent flow to the Cottage Farm and Prison Point CSO Facilities, and at CSO outfalls CAM401A and SOM001A which discharge to Alewife Brook. The measured bacterial counts at Cottage Farm were substantially higher than the counts at the other locations. This difference was attributed to differences in the relative proportions of sanitary sewage and stormwater in the combined sewage. The combined sewage tributary to Cottage Farm had a much higher proportion of sanitary flow, due to the flows tributary to the facility from the upstream separately-sewered communities along the Charles River Valley Sewer and South Charles Relief Sewer. In contrast, the flow tributary to Prison Point, for example, was primarily separate stormwater from the Old Stony Brook system.

Table 12-1. Model Data Sources

Parameter	Charles River	Alewife Brook/Upper Mystic
Bathymetry	MIT surveys (2015-17)	FEMA measurements (2003)
Upstream Boundary Flow	Waltham USGS Gauge	InfoWorks ICM Mystic River Basin Model
Upstream Boundary Quality	Calibrated buildup/washoff model	MWRA receiving water quality monitoring (2017-2018)
CSO Flows	MWRA collection system hydraulic/hydrologic model (2019, and updated to Q1 2020)	
Untreated CSO Quality	Cottage Farm and Prison Point CSO Facility influent bacteria monitoring data (2017-19)	MWRA bacteria monitoring at outfalls CAM401A and SOM001A (2019)
Treated CSO Quality	Cottage Farm effluent bacteria monitoring data (2018 to 2019)	Somerville Marginal CSO Facility effluent bacteria monitoring data (2018)
Stormwater Flows	BWSC Drain model USGS Charles River Stormwater Model Cambridge Stormwater Model	InfoWorks ICM Mystic River Basin Model
Stormwater Quality	BWSC stormwater model (2012-16) USGS stormwater quality Monitoring Data (1999-2000)	MWRA stormwater monitoring in Medford and Arlington (2019) Cambridge and Somerville Monitoring (2019-2020)
Bacterial Die-off Rates	Literature and previous modeling	Literature and previous modeling

Therefore, instead of assigning a single, average value of bacteria count to untreated CSO, the modeling team used the collection system model to calculate time-varying CSO counts based on the relative fraction of stormwater and sanitary flow in the CSO and assigning different bacterial counts to the sanitary and stormwater fractions, the model could then compute the resulting concentration of the sanitary/stormwater mix, based on a mass-balance equation. The initial bacteria counts applied to the stormwater fractions were based on measured data, and the concentrations of the sanitary fractions were then adjusted based on trial-and-error until the computed CSO counts matched the measured counts in the sampled CSO. The resulting sanitary fraction counts were then checked for reasonableness against dry weather flow sampling data from the MWRA's North System at Deer Island.

Figure 12-2 presents a schematic of how this approach works, and Figure 12-3 shows an example of the measured versus predicted bacterial counts at the Cottage Farm and Prison Point influents using this approach. As indicated in Figure 12-3, this approach reproduced the observed variations in bacterial counts at the two facilities.

The sanitary and stormwater bacteria counts estimated from sampling data were then adjusted within reasonable bounds to better match measured in-stream counts as part of the calibration process as described in the *Task 5.2 Receiving Water Quality Model Development and Calibration* report (AECOM, 2020).

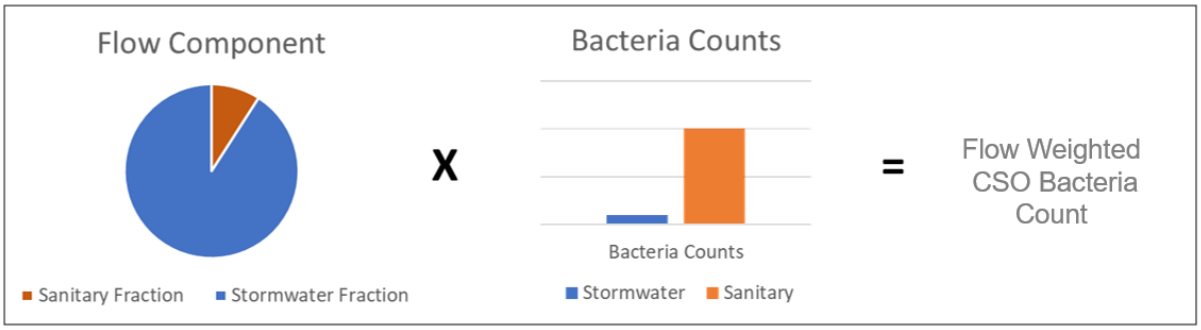


Figure 12-2. Sanitary Fraction Approach to Computing CSO Bacteria Counts

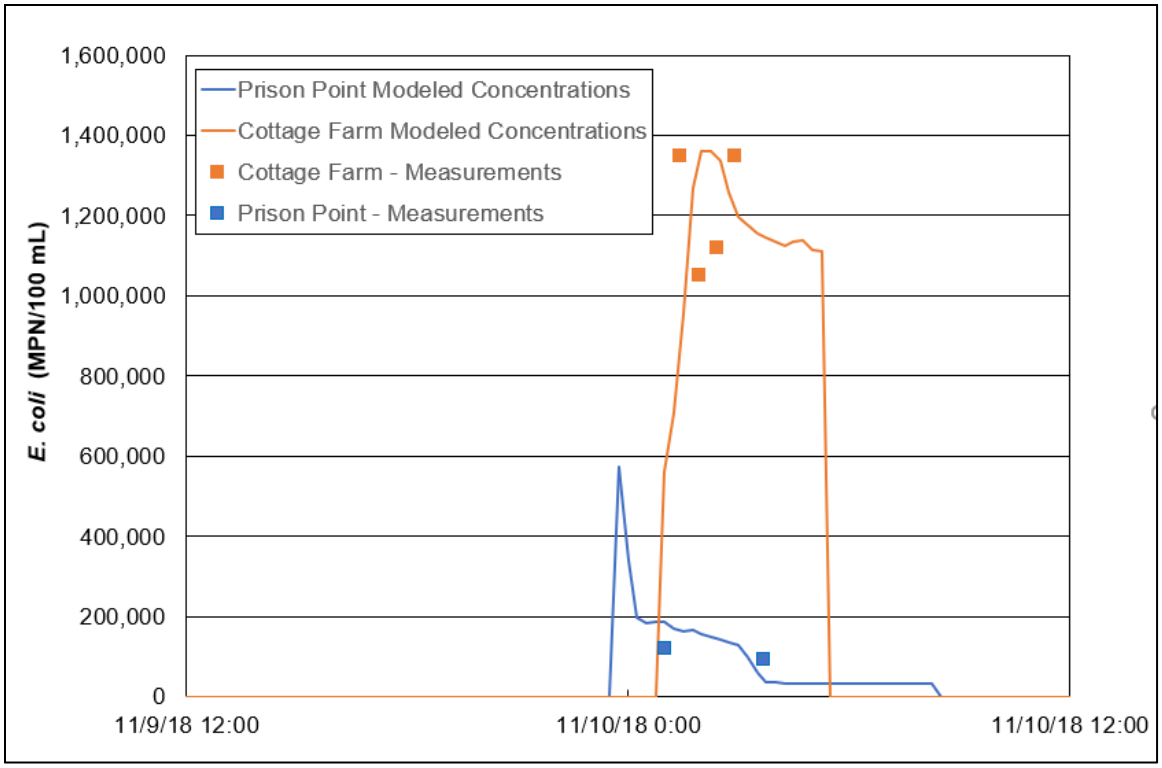


Figure 12-3. Measured and Calculated *E. coli* Counts at Cottage Farm and Prison Point

12.4.2 Treated CSOs

For treated CSOs from the Cottage Farm and Somerville Marginal CSO Facilities, average bacterial counts from sampling of the treated effluent from those facilities were calculated and applied to the water quality models.

12.4.3 Stormwater

Stormwater bacterial counts were assessed through sampling conducted in 2019 and 2020 in Cambridge (4 locations), Medford (3 locations), Arlington (2 locations) and Somerville (5 locations). Details on the sampling locations and results are provided in the *Task 5.2 Receiving Water Quality Model Development and Calibration* report (AECOM, 2020). These locations are shown in Figure 12-4 and Figure 12-5 on the following page. The results of the sampling are shown in Table 12-2.

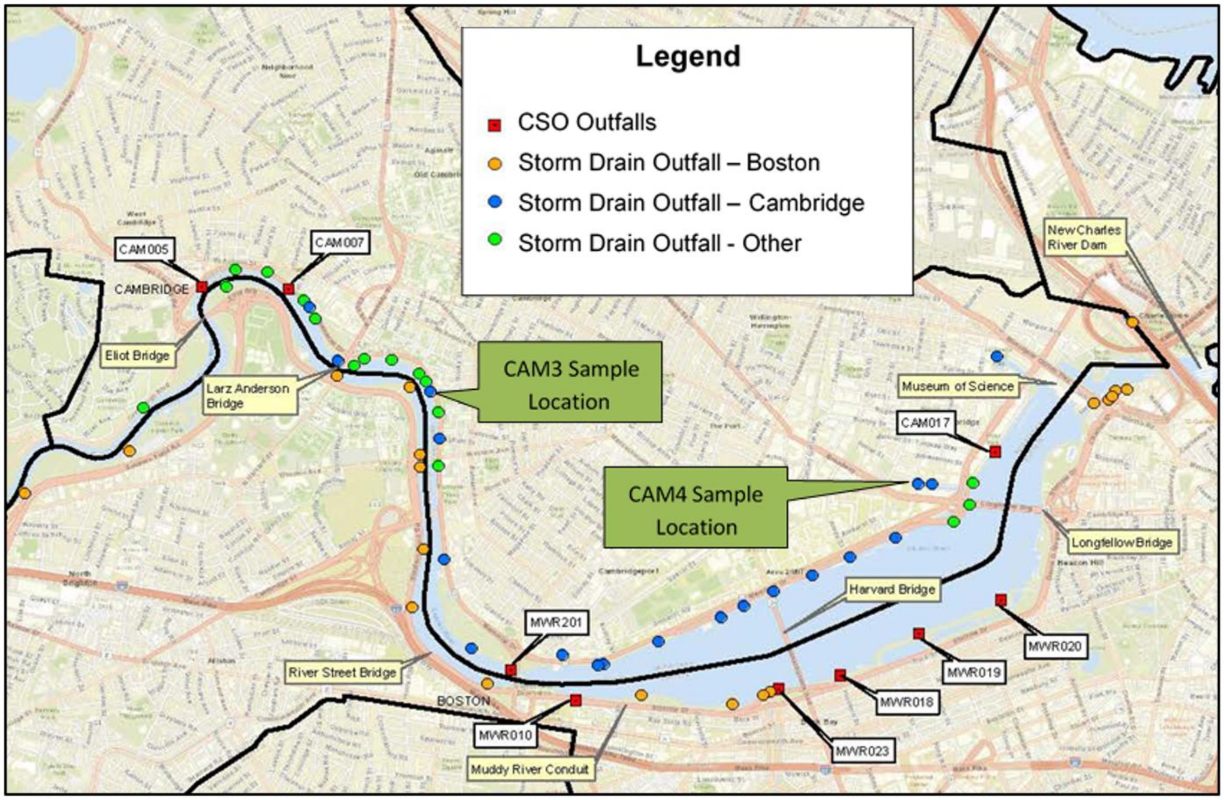


Figure 12-4. Stormwater Monitoring Stations for the Charles River

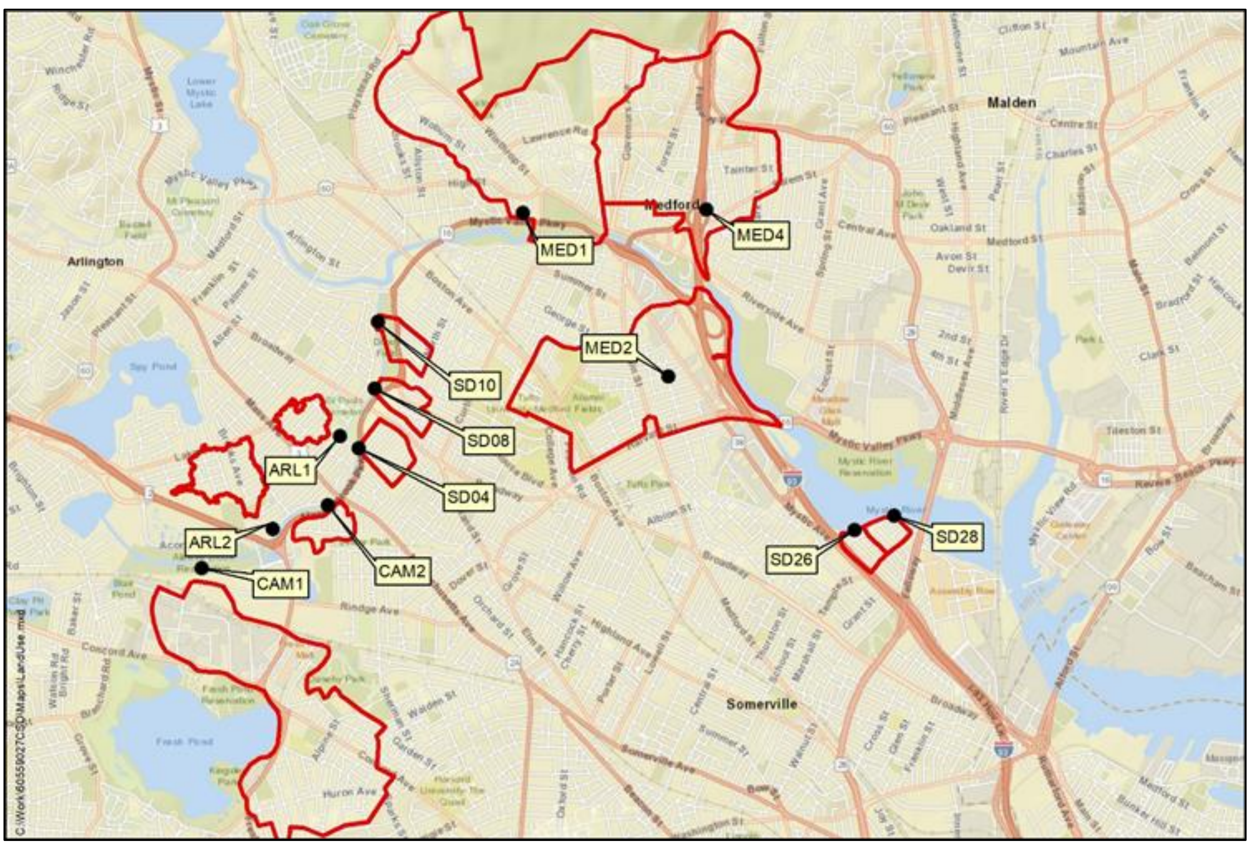


Figure 12-5. Stormwater Monitoring Stations for Alewife Brook/Upper Mystic River

Table 12-2. 2019-2020 Stormwater Sampling Bacterial Results (Page 1 of 2)

Date	10/7/2019	10/27/2019	11/18/2019	11/24/2019	12/13/2019	5/8/2020						
Depth (in)(1)	0.16	1.43	0.24	1.51	1.41	0.41						
Duration (hr)	2.5	10.5	6	17	17.25	14.25						
Peak 15-minute Intensity (in/hr)	0.16	0.56	0.12	0.6	0.24	0.07						
Prior Dry Days	2	3	5	1	2.2	7						
E. coli (MPN/100 mL)												
	Average by Storm(2)						By Station(3)		By Town(4)		All Data(5)	
							Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
ARL1	14,030	28,895	8,015	2,910			11,258	14,964	19,358	32,994	13,395	29,046
ARL2	2,670	4,600		74,980			29,666	45,966				
CAM1	1,760	24,940		5,640	504		8,211	26,515	11,361	31,953		
CAM2	402	175		700	512		441	393				
CAM3	46,200	3,610		4,480	15,580		17,468	18,511				
CAM4	640	2,750		9,346	64,560		19,324	54,383				
MED1	3,800	3,148	10,578	625			4,456	7,187	14,625	23,995		
MED2	8,210	6,928	9,848	2,000			6,655	6,573				
MED4	27,518	27,915	49,454	22,114			32,198	34,230				
SD04						2,650	2,650	551	10,687	23,942		
SD08						358	358	246				
SD10						47,200	47,200	34,388				
SD26						100	100	0				
SD28						1,110	1,110	658				

Table 12-2. 2019-2020 Stormwater Sampling Bacterial Results (Page 2 of 2)

Date	10/7/2019	10/27/2019	11/18/2019	11/24/2019	12/13/2019	5/8/2020						
Depth (in)(1)	0.16	1.43	0.24	1.51	1.41	0.41						
Duration (hr)	2.5	10.5	6	17	17.25	14.25						
Peak 15-minute Intensity (in/hr)	0.16	0.56	0.12	0.6	0.24	0.07						
Prior Dry Days	2	3	5	1	2.2	7						
***Enterococcus* (MPN/100 mL)**												
	Average by Storm(2)						**By Station(3)**		**By Town(4)**		**All Data(5)**	
							Average	**Standard Deviation**	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
ARL1	9,195	25,150	4,723	10,605			10,599	9,790	8,406	8,020	5,477	20,933
ARL2	3,723	4,423		8,223			5,614	3,805				
CAM1	918	960		4,678	1,130		1,922	1,817	2,832	2,887		
CAM2	1,154	370		4,412	990		1,716	2,354				
CAM3	7,116	2,938		4,772	9,180		6,002	3,259				
CAM4	1,508	1,364		1,656	2,232		1,690	1,034				
MED1	7,135	4,418	1,200	1,030			3,503	3,398	9,762	31,221		
MED2	4,125	4,375	3,556	2,080			3,454	2,415				
MED4	78,250	4,468	9,574	3,380			21,980	63,429				
SD04						1,265	1,265	239	811	694		
SD08						360	360	202				
SD10						1,768	1,768	498				
SD26						100	100	0				
SD28						660	660	383				

Notes:
(1) From Somerville Marginal rain gauge.
(2) Average of individual wet weather samples taken during the storm.
(3) Average and standard deviation of all wet weather samples taken for each station for all storms sampled.
(4) Average and standard deviation of all wet weather samples taken at all stations in the community for all storms sampled.
(5) Average and standard deviation of all wet weather samples taken.

Potential correlations of the stormwater bacterial counts with storm characteristics and catchment land use were explored, to see whether it would be appropriate to apply different stormwater counts to different land use characteristics or storm characteristics. Correlations evaluated included storm depth, number of prior dry days, catchment area, percent undeveloped land, undeveloped area, percent residential, and residential area. No correlations were observed and there was no consistent pattern of higher counts early in a storm ("first flush"). Therefore, average values were used, with the potential for adjustments during the calibration process.

12.5 Model Calibration Data and Approach

The calibration process involved comparing model-predicted *E. coli* and *Enterococcus* counts at specific locations in the receiving waters with concentrations measured at those locations during specific storm events and dry weather periods. Certain model parameters could then be adjusted within reasonable ranges to improve the match between the modeled and the measured values. This section provides an overview of the in-stream sampling data used to compare against model predictions, the specific model parameters that could be adjusted during calibration, and the metrics used to assess how well the model was calibrated. More detail on model calibration is given in the *Task 5.2 Receiving Water Quality Model Development and Calibration* report (AECOM, 2020).

12.5.1 Calibration Data

For the two water quality models, MWRA's extensive in-stream water quality monitoring data were used as the basis for comparing to model results during the calibration process. These data included the results of water quality sampling and analysis at 17 stations in the Charles River and 17 stations in the Alewife Brook/Upper Mystic River.

During the period used for calibration, MWRA sampled the receiving water segments in two-week rotating blocks (sampling rounds). Weekend sampling during and after storm events was added for the Charles River and Alewife Brook/Upper Mystic River in 2017 to support the modeling effort. At each station, near-surface water samples were collected and for deeper stations near-bottom samples were also collected. The samples were tested for several water quality parameters including *E. coli* and *Enterococcus*.

Model calibration was conducted with in-stream monitoring data collected in 2018 during 14 rounds of wet weather sampling in the Charles River, and 10 rounds of sampling in the Alewife Brook/Upper Mystic River for totals of 1,082 samples in the Charles River and 1,057 samples in the Alewife Brook/Upper Mystic River. The 2018 sampling data provided a sufficient range of data to conduct the calibration.

12.5.2 Calibration Parameters

The model parameters that were considered for adjustment during the calibration process were:

- *E. coli* and *Enterococcus* die-off rates; and
- Stormwater and CSO bacterial counts.

While these parameters were subject to adjustments during calibration, the adjustments were strongly constrained by literature values (for the die-off rates) and monitoring data (for the stormwater and CSO bacterial counts). Most of the data input to the models were either measured data or data resulting from other models, such as the MWRA collection system model, that were separately calibrated.

12.5.3 Calibration Metrics

The calibration fit was initially visual, by assessing graphical comparisons of model predictions with measurements. This Weight-of-Evidence approach compares the general shape of the bacterial count versus time curves, including peaks and lows. Since measurements were available only at discrete monitoring stations and only once on each sampling day, they did not provide a complete depiction of the bacterial count variations with time, which can change rapidly during and after a storm. Therefore, it was important to calibrate over a number of storms so that the general comparison of the model versus measured values could be assessed.

Quantitative measures of model to measurement comparison are generally desirable to impartially establish that one set of calibration parameters is better than another. The quantitative metric selected was the Wilmott "Index of Agreement" (IA) (Willmott, 1981) which calculates the difference between predicted and observed time series as an index that varies between 0 and 1, with 1 showing perfect agreement between the model output and the observed time series. Overall values of IA were computed from model output at all stations from each calibration run.

12.6 Charles River Model Calibration

This section presents the approach and results of the Charles River model calibration.

12.6.1 Hydrologic Model

Calibrated stormwater models developed by the USGS, BWSC, and Cambridge were used to develop stormwater flows as a function of time and rainfall for input into the Charles River model, and the MWRA collection system model was used to develop CSO flows as a function of time and rainfall.

12.6.2 Boundary Conditions

The Charles River model had two external boundaries: one at the upstream end at the Watertown Dam, and one at the downstream end at the New Charles River Locks and Dam. The modeled representation of the conditions at these boundaries are described below.

Upstream Boundary. At the upstream end of the model (the Watertown Dam), stream flow and water quality needed to be specified as a function of time. During wet weather events, flows and pollutant concentrations at the Watertown Dam increased due to upstream runoff and non-point sources. As documented in previous studies and in the MWRA in-stream monitoring, the increases in flow and pollutant concentration were substantial, and had considerable impact on water quality downstream of the dam. Therefore, the accuracy of the upstream boundary condition was important.

Flows at the Watertown Dam were estimated from measurements at the USGS gauge in Waltham located upstream of the dam, with adjustments based on the distance between the gauge and the dam (USGS, 2002b). Available bacterial data were not sufficiently frequent to be used for the model boundary condition. Therefore, a model based on the buildup/washoff formulation was used to estimate the bacterial counts at the Watertown Dam based on measured flows in the river at the USGS gauge.

Downstream Boundary. Water level versus time needed to be specified at the downstream end of the model. At the New Charles River Locks and Dam, water is discharged at low tide and pumped out of the basin in anticipation of wet weather events, with the goal of maintaining a stable water level. For the model, the water levels measured at the New Charles River Dam USGS gauge were specified as the downstream boundary condition. The model indicated that the water level fluctuations at the dam, however small, propagated up to the Watertown Dam, with some attenuation.

12.6.3 Dry Weather Calibration

The in-stream monitoring showed elevated bacterial counts in the Charles River during dry weather. Previous modeling indicated that some of the dry weather bacterial counts were due to the effects of previous discharges, which could last for several days. Dry weather sources, for example illicit sanitary connections to storm drains, could also contribute to dry weather bacterial counts in the river. The stormwater models used to specify stormwater inflows to the river included dry weather flows, and bacterial counts were assigned to those dry weather flows to simulate dry weather bacterial loading sources. Through a process of trial-and-error, assigning counts of 134 MPN/100 mL for *E. coli* and 45 MPN/100 mL for *Enterococcus* to the dry weather flows were found to result in satisfactory match of the predicted in-river counts to the measured counts in dry weather.

12.6.4 Wet Weather Calibration

The wet weather calibration was primarily conducted for *Enterococcus*, with corresponding parameter values applied to *E. coli*. Many different model simulations were conducted with different combinations of parameters including primarily the bacterial counts in stormwater and die-off rates. The parameters that were found to yield in-stream bacterial counts close to the measurements are summarized in Table 12-3. The model-computed sanitary fractions, and the flow-weighted *E. coli* and *Enterococcus* counts in the CSOs discharging to the Charles River for the calibration period varied depending on the outfall. An example of a model-to-measurement comparison plot is shown in Figure 12-6. The 2020 *Task 5.2 Receiving Water Quality Model Development and Calibration* report (AECOM, 2020) contains many more similar figures.

Table 12-3. Selected Charles River Model Parameters

	Stormwater Count (MPN/100 mL)	Base Flow Count (MPN/100 mL)	CSO Sanitary Fraction Count (MPN/100 mL)	CSO non-Sanitary Fraction Count (MPN/100 mL)	Die-off Rate (Day^{-1})
E. coli	14,000	134	7,000,000	14,000	0.8
Enterococcus	10,000	45	1,000,000	6,700	0.8

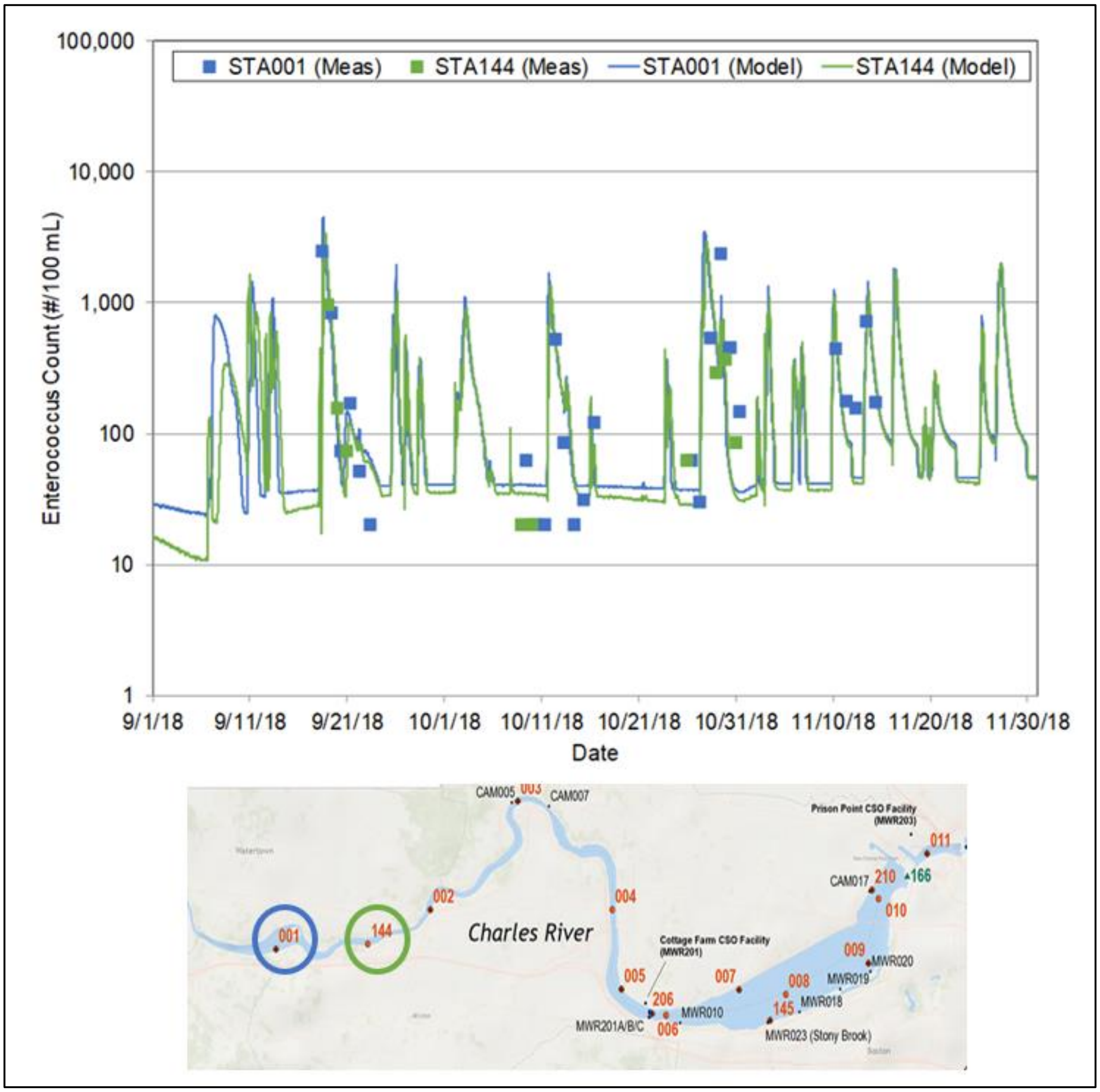


Figure 12-6. Graph with Measured and Calculated *Enterococcus* Counts at Stations 001 and 144 for September through November 2018 with die off rate of 0.8 day^{-1} and Map with Locations of Sampling Sites

12.7 Alewife Brook/Upper Mystic River Model Calibration

12.7.1 Hydrologic Model

The Alewife Brook/Upper Mystic River model was based on a model developed for FEMA and converted to InfoWorks by the City of Cambridge. To better simulate rainfall and groundwater influences throughout the year the model hydrology was replaced by the SWMM RUNOFF hydrology, with groundwater routines that simulated the infiltration of stormwater into the ground and the groundwater discharge to the stream. The parameters governing runoff and groundwater infiltration and discharge were calibrated to flows measured at the USGS Alewife Brook Gauge. An example of measured to model flows in Alewife Brook at the USGS Alewife Brook Gauge is shown in Figure 12-7.

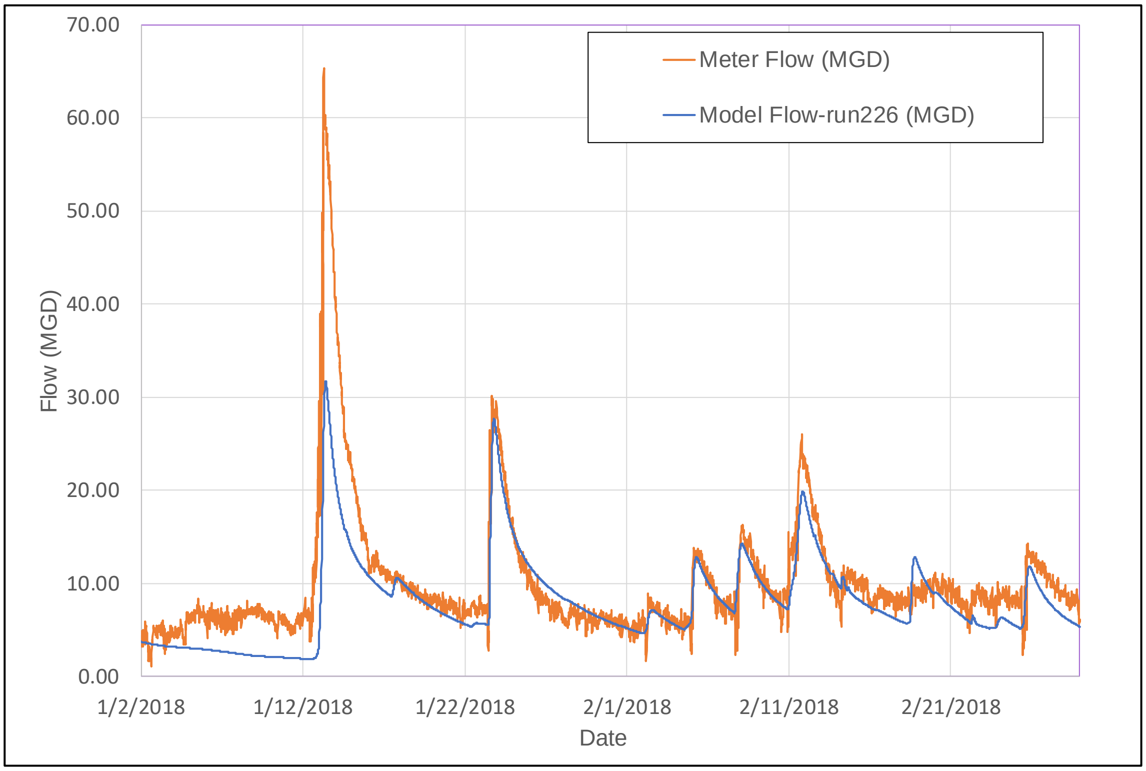


Figure 12-7. Measured and Calculated Flows at the Alewife Brook River Gauge for Jan-Feb, 2018

12.7.2 Boundary Conditions

The Alewife Brook/Upper Mystic River model had three upstream boundaries and one downstream boundary. The upstream boundaries were at the upstream ends of Alewife Brook and the Malden River, and at the outlet of the Lower Mystic Lake into the Mystic River. The downstream boundary was at the Amelia Earhart Dam. The modeled representation of the conditions at these boundaries are described below.

Upstream Boundaries. Stream flow at the boundary at the outlet of the Lower Mystic Lake was specified based on the original version of the watershed model, which covered the entire watershed extending beyond the Upper and Lower Mystic Lakes. Water quality was simulated by specifying base flow and stormwater flow bacterial counts in the sub-catchments just downstream of the lake.

The flows at the boundaries at the upstream ends of Alewife Brook and the Malden River were generated directly from the tributary sub-catchments in the InfoWorks model, with bacteria counts assigned to baseflow (dry weather) and runoff flows during wet weather.

Downstream Boundary. Measured water levels at the USGS gauge just upstream of the Amelia Earhart Dam were specified for the downstream boundary.

12.7.3 Dry Weather Calibration

Bacterial counts were specified in the groundwater discharge to the stream. Following an iterative process, values corresponding to dry weather counts of 134 MPN/100 mL for *E. coli* and 45 MPN/100 mL for *Enterococcus* were found to closely replicate measured counts in the receiving waters.

12.7.4 Wet Weather Calibration

The values of the parameters that were used for calibration are listed in Table 12-4. The model-computed sanitary fractions, and the flow-weighted *E. coli* and *Enterococcus* counts in the CSOs discharging to the Alewife Brook for the calibration period varied depending on the outfall. The only CSO to the Upper Mystic River is the relief outfall for the Somerville Marginal CSO facility, for which the bacterial counts did not vary by storm but were set to the average values of measured counts sampled from the treatment facility effluent in 2018. An example of model-to-measurement comparison is shown in Figure 12-8.

Table 12-4. Selected Alewife Brook/Upper Mystic River Model Parameters

	Stormwater Count (MPN/100 mL)	Soil Store Inflow Count (MPN/100 mL)	CSO Sanitary Fraction Count (MPN/100 mL)	CSO non-Sanitary Fraction Count (MPN/100 mL)	Die-off Rate (Day^{-1})
Enterococcus	6,700	45	1,000,000	6,700	0.8
E. coli	25,000	134	2,500,000	14,000	0.8

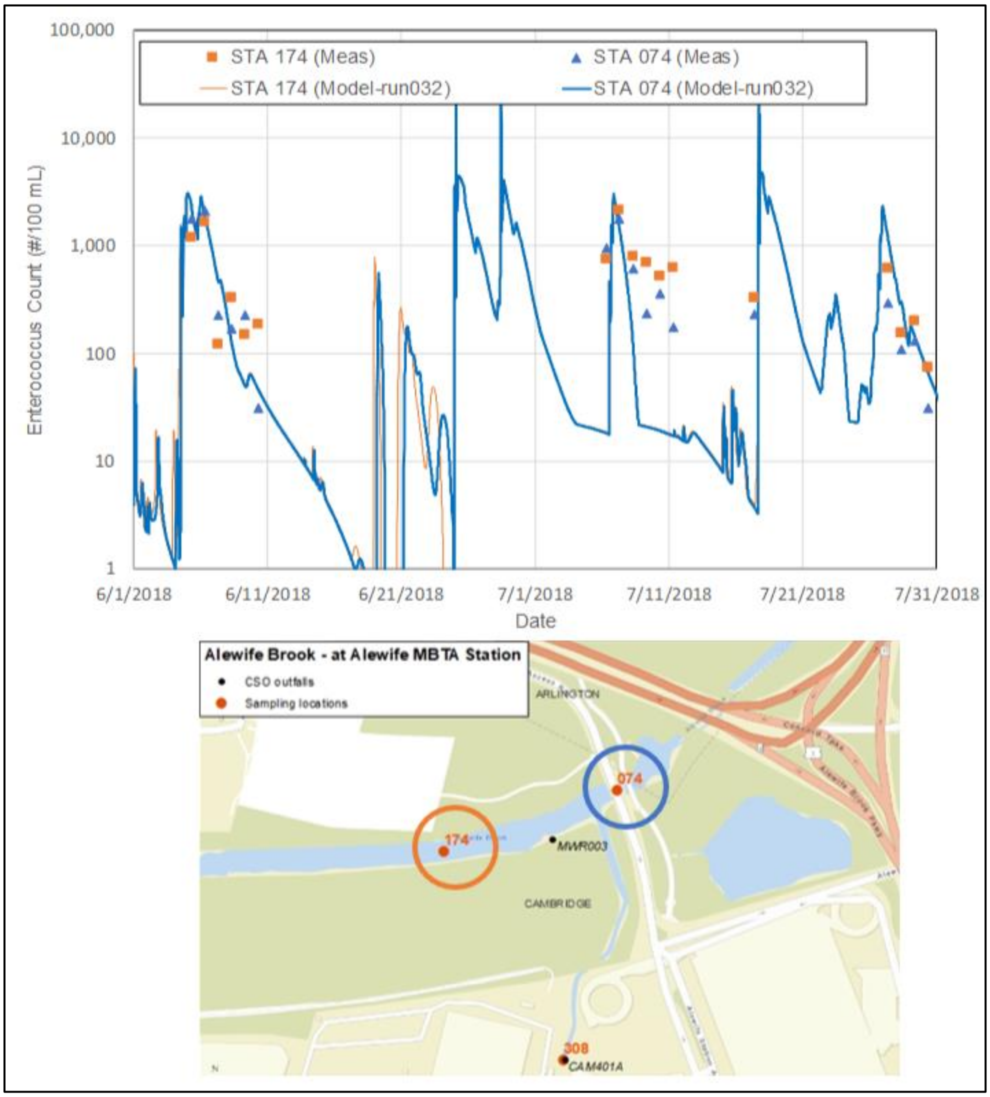


Figure 12-8. Graph with Measured and Calculated *Enterococcus* Counts at Stations 074 and 174 for June and July 2018 with die off rate of 0.8 day^{-1} and Map with Locations of Sampling Sites

12.8 Sensitivity to Model Assumptions

The receiving water models were constructed using well-documented hydrodynamic and water quality models, with input from the newly-calibrated hydraulic collection system model described elsewhere as well as a validated buildup/washoff model for the Charles watershed. The calibration process made use of MWRA's long-term receiving water monitoring in the Charles and Alewife/Mystic, with expanded wet weather sampling, and other reliable data sources such as USGS stream gauges and CSO facility influent and effluent bacteria measurements. Stormwater and untreated CSO data were collected to provide recent, relevant data on sources. The stormwater data collected showed no clear patterns of variation spatially or over time, so the assumption of constant values is defensible. Stormwater and the upstream boundary contribute the majority of the bacterial loads, but this is realistic given the (measured) quality of urban stormwater and the much greater volume of these inputs compared to the CSOs that remain in the Charles River and Alewife Brook/Upper Mystic River. These calibrated models were used to perform water quality assessments in the Charles, Alewife and Upper Mystic as described in Chapter 3. As part of those evaluations, the sensitivity of model results to variations in the modeled bacterial counts in CSO and stormwater were assessed.

13. References

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