CSO Annual Report April 29, 2022:
CSO Discharge Estimates and Rainfall Analyses for Calendar Year 2021

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1. Introduction

On December 30, 2021 MWRA submitted the *Task 6 Post Construction Monitoring Program and Performance Assessment Report* to the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MassDEP) documenting the results of the four-year study to measure the performance of its Long Term Control Plan (LTCP). This was the final court scheduled milestone 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 the performance assessment report, all of the original court imposed deadlines were met. MWRA's obligations for CSO control under the Court Order are defined in the March 15, 2006, *Second Stipulation of the United States and the Massachusetts Water Resources Authority on Responsibility and Legal Liability for Combined Sewer Overflow Control*, as amended on April 30, 2008 (the "Second Stipulation"). For more information about MWRA's federal court obligations for CSO control, including the LTCP levels of control, see Section 1.3.5 in Semiannual CSO Discharge Report No. 2, May 3, 2019.

This report is the first of three Annual Reports as required by the United States' Response to the Supplemental Report submitted by MWRA on September 30, 2021 which allows the Court Order to be extended until December 2024 to complete identified projects and further evaluate alternatives to further reduce CSOs at the sixteen outfalls that did not meet the LTCP goals by December 31, 2021. As part of this extension MWRA is required to provide documentation of the Massachusetts Water Resources Authority's (MWRA) estimates of combined sewer overflow (CSO) discharges in its service area during calendar year 2021. These annual estimates of CSO discharges, overlap with reporting requirements in the Variance Extensions for the Alewife/Upper Mystic River and the Lower Charles River/Charles Basin, issued by MassDEP in 2019 pursuant to the Massachusetts Surface Water Quality Standards at 314 CMR 4.00. The Variances authorize limited CSO discharges to the Alewife Brook/Upper Mystic River and the Lower Charles River/Charles Basin in conjunction with National Pollution Discharge Elimination System (NPDES) permits MA0103284, MA0101982 and MA0101974 issued to MWRA, the City of Cambridge and the City of Somerville, respectively.

MWRA reports herewith its estimates using hydraulic modeling of calendar year 2021 CSO activation frequency and total discharge volume from each of the CSO outfalls addressed in MWRA's approved LTCP, including but not limited to the outfalls discharging to the Alewife Brook/Upper Mystic River and the Lower Charles River/Charles Basin. In addition, MWRA also provides estimates of CSO activation frequency and volume at each of the outfalls calculated using meter data. MWRA has also provided this information to its member communities with CSOs, including Boston Water and Sewer Commission (BSWC) and the cities of Cambridge, Chelsea and Somerville.

This report is organized into the following chapters:

Chapter 1: Introduction

Chapter 2: Summary of 2021 Meter[1] Data and Comparison to Model Results presents the following information related to 2021 system performance:

- a summary of the model changes incorporated into the 2021 system conditions model

[1] Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.

- a summary analysis of the 2021 rainfall in comparison to the Typical Year[2]
- a table has been provided with the metered CSO activation frequency, duration, and volume for each of the MWRA outfalls tributary to the variance waters for 2021 to meet the reporting requirement as described in section D.4.b.iv of the 2019 Alewife Brook Variance and as described in section D.3.b.iv of the 2019 Charles River Variance
- the estimated CSO activations and discharge volume during calendar year 2021 using the MWRA collection system model, configured to represent system conditions in 2021
- the estimated CSO activations and discharge volumes calculated from monitoring data from MWRA and the CSO community meters.

Chapter 3: Updated System Performance Assessment and Comparison with LTCP Levels of Control. Presents the following:

- A comparison of the CSO activations and discharge volumes for the Typical Year for Q4-2021 (end of 2021) system conditions to the activation frequency and volume goals established for each outfall under the Second Stipulation. Also presented are previously-modeled Typical Year CSO activations and volumes for 1992 system conditions
- A summary of the status of further evaluations of outfalls that did not meet the LTCP goals for activation frequency and/or volume as of the end of 2021.

Appendix A: Rainfall Data Collection and Analyses January 1, 2021- December 31, 2021. Provides a summary of the rainfall data collected for 2021, characterizes the return period for each storm, and provides a comparison to the Typical Year rainfall.

2. Summary of 2021 Model Results and Comparison to Meter[3] Data

MWRA developed estimated CSO activation frequency and discharge volume at each CSO outfall during calendar year 2021 using the MWRA's ICM collection system model. The model simulated each of the rainfall events in 2021 with system conditions existing at the time of each storm. In support of these simulations, MWRA updated the model to account for new information and known changes to the system, including system improvements that were completed during the year, new meter data, and results of field inspections. Each system change was incorporated into the 2021 Typical Year simulation, which represents end-of-year conditions. The model updates for 2021 are summarized in section 2.1 and the rainfall analysis is summarized in section 2.2. Section 2.3 presents the meter estimates of MWRA CSO discharges to the variance waters for 2021 and Section 2.4 presents the comparison of meter and modeled estimates of all CSO discharges for the January 1, 2021 – December 31, 2021 period.

2.1 Hydraulic Model Updates

Updates to MWRA's hydraulic model are necessary to estimate CSO discharges as improvements are made to the MWRA and community sewer systems; to compare model predictions against meter data; and to update Typical Year CSO performance for comparison with the LTCP activation and volume goals. The MWRA's Q4-2020 model was updated with the changes listed in Table 1 below. The table provides the **Location** of the part of the model that was modified. The **Summary of Change** provides information

[2] 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.

[3] Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.

on what was changed in the model. **Supporting Information** provides additional context on the justification/source of information about the modification that was made to the model. These changes with the exception of the last three listed in the table were documented in Semiannual Report No. 7 which covered the period of January 1, 2021 through June 30, 2021. The version of the model developed in Semiannual Report No. 7 reflected the Q1Q2-2021 conditions. The Q1Q2-2021 conditions model was used to predict CSO discharges during the storms that occurred in the period January 1, 2021 through June 30, 2021. The Q4-2021 model is based on the Q1Q2-2021 model 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. The Q4-2021 system conditions model was used to predict CSO discharges during the storms that occurred in the period of July 1, 2021 through December 31, 2021 and to assess the Typical Year CSO performance for current system conditions.

Table 1. Model Changes from Q4-2020 System Conditions

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 – December 31, 2021 period based on MWRA-provided data.
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 85x90-inch 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.
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 Boston Marginal Conduit (BMC).	Catch basins were added based on review of DCR storm drain 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 – December 31, 2021 period (the Typical Year version of the model will open the gates for rainfall events greater than 1-inch). The model configuration was further updated to represent 2 gates that can open independent of each other. 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 generate 1 inch or more of rainfall within a 24-hr period. Gate opening dates from January 1 to December 31, 2021 were provided by BWSC.

Table 1. Model Changes from Q4-2020 System Conditions

Location	Summary of Change	Supporting Information
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 the field inspection.	The City of Cambridge reported observing 6 inches of standing water downstream of the CAM401A regulator as part of post cleaning measurements on April 13, 2021.
CHE004	Updated the weir elevation.	The weir was raised in the field to El. 109.83 in August 2021
East Boston	Incorporated Contract 2 of East Boston sewer separation. Contract 2 separates approximately 31.5 acres tributary to outfalls BOS010 and BOS005. BWSC estimates that the sewer separation will reduce inflow into the sewer system from these areas by up to 85%.	Contract 2 of the BWSC's East Boston Sewer Separation project was substantially completed in November 2021.

2.2 Rainfall Analyses

Rainfall is a driving factor in the analysis of CSOs, as the occurrence of overflows within the MWRA sewer system is dependent on rainfall intensity and/or depth. The rainfall for the period of January 1 to December, 31, 2021 was analyzed to help support the understanding of the modeled performance for 2021 conditions with respect to the measured activations and volumes at each outfall for the 2021 period, and with respect to the LTCP targets for performance for the Typical Year. The rainfall analyses presented in previous Semiannual Reports were based on Technical Paper 40 (TP-40)[4] which was originally published in 1961 and reissued in 1963. TP-40 continued to be used through submission of the Final Post Construction Monitoring Report to be consistent with the work done for the Long Term Control Plan. For this report and for analyses going forward the methodology for characterizing the recurrence intervals of rainfall events was updated to NOAA Atlas 14, Volume 10 originally published in 2015 and updated in 2019[5]. Atlas 14 includes analysis of more recent historical rainfall data for the Northeastern United States. In addition, this change is responsive to language provided by MassDEP in a response to comments document on the 2019 Charles River Variance. In the response it was noted that "MassDEP expects that when MWRA and Cambridge and Somerville do future CSO planning, they will utilize the NOAA 14 Atlas for precipitation data, which is the most current compilation of area rainfall data." MassDEP went on further to state that "While storm recurrence frequencies have changed, especially for larger events, MassDEP does not expect the benefits of MWRA's CSO control plan to be compromised significantly for the events occurring in the 'typical year' used to evaluate the effectiveness of CSO controls."

[4] TP 40: https://reduceflooding.com/wp-content/uploads/2018/09/TechnicalPaper_No40.pdf
[5] Atlas 14 Volume 10 report : https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

When comparing the recurrence intervals for NOAA Atlas 14 and TP-40 it was observed that in general for NOAA Atlas 14, smaller storms (like those in a Typical Year) tended to occur less frequently, while larger storms (not in a Typical Year) tended to occur more frequently. Using NOAA Atlas 14 to perform the rainfall analysis on the 2021 rainfall does not change the conclusions regarding past completed CSO projects, nor efforts currently underway to achieve the LTCP goals for the 16 remaining outfalls. Values for Atlas 14 for Boston were extracted from NOAA's data server[6] on April 12, 2022. The Atlas 14 partial duration curves were used to assign the recurrence intervals. The smallest storm the partial duration curves addresses is the 1-year storm, so the partial duration intensity-duration- frequency (IDF) curves for the 3-month and 6-month frequencies were extrapolated. All of the storm recurrence intervals identified in the text and sections below and in Appendix A are based on the 2019 edition of Atlas 14 referenced above.

Appendix A includes the following tables that were prepared in support of this analysis:

- Table A-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2021
- Table A-5. Frequency of Events within Selected Ranges of Total Rainfall for January 1 to December 31, 2021
- Table A-6. Comparison of Storms Between January 1 and December 31, 2021 and Typical Year with Greater Than 2 Inches of Total Rainfall
- Table A-7. Comparison of Storms Between January 1 and December 31, 2021 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour

The findings from those tables are summarized below.

In 2021, Metropolitan Boston experienced significantly greater volume of rain, back to back large storms, and many storms with relatively high peak intensity. The impact of these many large storms (in terms of total rainfall, as well as peak intensity), is evident in the 2021 vs. Typical Year rainfall comparisons in the rainfall summary tables, and in comparing the metered and modeled CSO discharge estimates.

In terms of comparing the metered estimates versus modeled CSO activation frequencies and volumes, a key finding was that during the period of July through mid-September 2021, 24.75 inches of rain fell at the Ward Street Headworks rain gauge, with 12.74 inches in July alone. The rainfall in that two-and-a-half month period equaled approximately half of the total annual rainfall in the Typical Year. Storms during this period varied from short duration, high intensity events to longer duration, lower intensity events. The Northeast Regional Climate Center (NRCC)[7] declared July 2021 the wettest July on record in Massachusetts with a state-wide rainfall average of 10.38 inches, which was 6.55 inches above the normal average for July. The implications of this extreme rainfall period are discussed further below.

In terms of comparing the 2021 rainfall to the Typical Year, the following observations are noted:

- 2021 averaged 95 storm events with an average annual rainfall depth of 58.10 inches, compared to 93 storm events with an average annual rainfall depth of 46.80 inches for the Typical Year (Table A-5).
- In general, the breakdown of numbers of storms by rainfall depth categories for 2021 were relatively close to the values for the Typical Year, except for storms in the 1-2 inch category, where 2021 averaged twelve versus eight for the Typical Year (Table A-5).
- In terms of larger storms, while the average number of storms with greater than 2 inches of total rainfall across all gauges in 2021 matched the Typical Year (six storms), each of the gauges listed in Table A-6 had two storms with total rainfall greater than the largest storm in the Typical Year. The largest storm in 2021 for the rain gauges presented in Table A-6 had a 10-year storm

[6] NOAA's Data server for MA: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ma
[7] NRCC: http://www.nrcc.cornell.edu/regional/tables/tables.html

recurrence interval for 24-hour duration (5.15 inches of rainfall in 17.25 hours at Columbus Park rain gauge), while the largest storm in the Typical Year has a 1 to 2-year, 24-hour recurrence interval (3.89 inches of rainfall in 50 hours).

- For the four gauges shown in Table A-7, the number of storms with peak intensities greater than 0.40 inches per hour ranged from eleven to fourteen, compared to nine for the Typical Year. The evaluated gauges had between two and four storms with peak intensity greater than 1.0 inches per hour, with peaks as high as 1.66 inches per hour. In comparison, the Typical Year peak had one storm with intensity of 1.08 inches per hour with the remaining eight storms having peak intensities between 0.75 and 0.42 inches per hour.

Three storm events during the monitoring period (on 7/1/2021, 7/8/2021, and 9/1/2021) had rainfall characteristics that were substantially different from the rainfall in the Typical Year. Table 2 presents the rainfall characteristics and recurrence intervals based on NOAA Atlas 14, Volume 10 for these three storms for the Ward Street, Columbus Park, Chelsea Creek and USGS Fresh Pond rain gauges. The largest storms in the Typical Year are generally on the order of a 1 to 2-year, 24-hour recurrence interval. As indicated in Table 2, most of the recurrence intervals computed for the 7/1/2021 and 9/1/2021 storms for the four gauges listed were on the order of 3 years or greater. Recurrence intervals of 10 years or greater are highlighted in bold in Table 2. The 9/1/2021 storm had 6-hour and 12-hour recurrence intervals of greater than 20 years at the Columbus Park gauge, and the 7/1/2021 storm had 6-hour and 12-hour recurrence intervals of 10 and 15 years, respectively, at the Chelsea Creek gauge. The third storm, on 7/8/2021, had recurrence intervals consistent with the larger storms from the Typical Year period, but its proximity to the preceding extreme event on 7/1/2021 appears to have influenced its effect on CSO volume. The influence was likely due to a high groundwater state caused by the heavy rain from the 7/1/2021 storm resulting in increased runoff from pervious areas. In the comparison of metered versus modeled CSO activations and volumes presented in the section below, these three storm events have been classified as extreme events which resulted in unusually large metered CSO overflow volumes.

Appendix A presents the rainfall data measured during the period of January 1, 2021 through December 31, 2021. It also describes the analysis of the rainfall data used to characterize the return period of each storm event and a comparison of measured rainfall for the 2021 period to the rainfall included in the Typical Year. Further detail regarding the rainfall data collection and processing can be found in Chapter 9 of the *Task 6 Final CSO Post Construction Monitoring Program and Performance Assessment Report.*

Table 2. Extreme Storm Event Return Intervals (Atlas 14)

Rain Gauge	Date	Duration (hr)	Total Rainfall (in)	Peak 1-hour Intensity (in/hr)	Storm Recurrence Interval (1-hr)	Storm Recurrence Interval (6-hr)	Storm Recurrence Interval (12-hr)	Storm Recurrence Interval (24-hr)
Ward Street	7/1/2021	78.5	5.69	1.23	4y	7y	5y	3y
	7/8/2021	32.75	3.03	0.91	1y-2y	4y	3m-6m	1y-2y
	9/1/2021	17.25	4.62	1.25	4y	**14y**	**14y**	6y
Columbus Park	7/1/2021	77.5	5.83	0.87	1y	4y	3y	1y-2y
	7/8/2021	33	2.55	0.76	6m-1y	2y	1y	1y
	9/1/2021	17.25	5.15	1.41	5y	**23y**	**23y**	**10y**
Chelsea Creek	7/1/2021	17.25	3.96	1.66	**10y**	**15y**	8y	4y
	7/8/2021	30.5	2.49	0.71	6m-1y	1y-2y	1y	1y
	9/1/2021	17.75	4.7	1.24	4y	**13y**	**16y**	7y
Fresh Pond (USGS)	7/1/2021	58	5.16	1.55	8y	7y	4y	2y
	7/8/2021	30.25	2.77	0.68	6m-1y	3y	1y-2y	1y
	9/1/2021	16.75	4.25	0.99	1y-2y	6y	10y	5y

2.3 Meter Estimates of CSO Discharges to Variance Waters for 2021

Under the CSO Variances for the Alewife/Upper Mystic River and the Lower Charles River/Charles Basin, MWRA, Cambridge, and Somerville must provide public notification of CSO activations within four hours and estimate volumes within five business days. In addition, the variances require MWRA, Cambridge and Somerville to report the annual CSO volumes and overflow durations no later than April 30th of each year. MWRA and the CSO communities have been collecting meter data used to report the CSO discharges at each of the outfalls tributary to the variance waters as part of the CSO Notification Program.

Table 3 presents the estimated activation frequency, duration, and volume to the variance waters for MWRA owned outfalls based on meter data. The data were collected by MWRA, except for MWR023 for which BWSC monitoring of regulators tributary to both MWR023 and BOS046 was used. As described above and in Appendix A, 2021 contained a number of extreme events that resulted in a disproportionate amount of overflow volume. In a few cases the metered discharge volumes in Table 3 below have been updated from the values originally reported as part of the CSO Notification Program based on further analysis or additional data and may differ from those volume estimates provided soon after storm events and posted on the city/MWRA web sites. Locations where the originally-posted MWRA meter data have been revised or are currently under review are indicated with footnotes in Table 3, and are described further below. Refer to the Cambridge and Somerville annual reports for additional discussion regarding community metering data.

Table 3. 2021 MWRA Metered(1) CSO Discharges to Variance Waters(2)

Outfall/Waterbody	MWRA Metered CSO Discharge Estimates		
	Activation Frequency	Volume (MG)	Duration (hr)
Alewife Brook			
MWR003	5	6.77(3)	10.50(3)
Upper Mystic			
SOM007A/MWR205A(4)	17	67.57	37.02
Lower Charles			
MWR010	0	0	
MWR018	4	2.98(3)	8.00(3)
MWR019	4	1.26(3)	5.25(3)
MWR020	4	1.21(3)	4.75(3)
MWR201 (Cottage Farm) (treated)	5	88.1	21.73
MWR023(5)	4	1.75(6)	10.07

(1) Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.
(2) Metered volume reported is from MWRA meters except for MWR023, which is calculated by MWRA from BWSC meter data.
(3) The originally-posted value has been revised based on further review of the original meter data volume computations. The value shown is the revised value.
(4) MWRA is currently reviewing the facility meter data to assess inconsistencies in observed flow and water levels.
(5) MWRA is currently reviewing the overflow volume calculation methodology at BOS046/MWR023 and coordinating with BWSC.
(6) The originally-posted value has been revised based on review of data about Gatehouse 1 operation (outfall BOS046).

2.4 Meter and Modeled Estimates of 2021 System Wide CSO Discharges

The Q1Q2-2021 system conditions model was used to simulate the storm events from January 1, 2021 to June 30, 2021, and the Q4-2021 system conditions model was used to simulate the storm events from July 1, 2021 to December 31, 2021. MWRA and the CSO communities have been collecting meter data at each of the outfalls listed in the LTCP as part of the CSO Notification Program. These meter data were used to tabulate the CSO activation frequency and volume for the January 1, 2021 to December 31, 2021 period.

The estimations of CSO activations and volumes based on meter data for non-MWRA-owned outfalls are made available from Boston, Cambridge, Chelsea and Somerville. Each of the communities utilizes a professional metering firm for the installation and maintenance of flow metering equipment and the assessment of CSO activations, volumes and durations based on the meter data. MWRA has not reviewed the meter configurations or the methodologies for computing the CSO activations and volumes based on meter data at these locations. Calculating CSO discharges from meter data for the purpose of developing volume estimates, whether by MWRA or by the communities, is inherently difficult and can be inaccurate given complex hydraulics, difficultly in proper calibration given normal dry conditions, etc.

MWRA has reviewed its metered CSO estimates and determined that prior CSO estimates for the following locations as reported through the notification system require adjustment given the complex hydraulics of these locations that can influence CSO discharges. Below is a table which presents a comparison of the original MWRA metered CSO discharge estimates as posted on the MWRA web site as part of the CSO notification program to the updated metered CSO discharge estimates. The MWRA metered locations that are not listed in the table did not require updating. Refer to the community annual reports for updates to the previously reported values from the communities.

Table 4. Comparison of 2021 Original to Updated MWRA Metered[(1)] CSO Discharge Estimates

Outfall	Original MWRA Metered CSO Discharge Estimates Posted on MWRA CSO Notification Web Site[(2)]			Updated MWRA Metered CSO Discharge Estimates After Review of Original Estimates[(2)]			Reason for Update
	Act Freq	Volume (MG)	Duration (hr)	Act Freq	Volume (MG)	Duration (hr)	
Alewife Brook							
MWR003	5	21.1	10.73	5	6.77	10.50	Original method of calculating flow did not account for downstream water levels or headlosses through the structure during high flow conditions.
Lower Charles							
MWR018	4	6.84	7.84	4	2.98	8.00	Original method of calculating flow did not account for outfall capacity restrictions given the limited opening downstream of the weir.
MWR019	4	2.73	7.13	4	1.26	5.25	Original method of calculating flow did not account for outfall capacity restrictions given the limited opening downstream of the weir.
MWR020	4	1.94	6.25	4	1.21	4.75	Original method of calculating flow did not account for headlosses through the structure.
MWR023[(3)]	4	6.99	10.07	4	1.75	10.07	The originally reported volume is the sum of the volumes at the BOS046 regulators that discharge to the Stony Brook Conduit, as computed from the meter data. Model studies show that when Boston Gatehouse 1 is open, as it was for all four activations, 75% of the CSO volume would discharge at outfall BOS046.

(1) Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.

(2) Meter volume reported is from MWRA meters except for MWR023, which is calculated by MWRA from BWSC meter data.

The following presents a summary of the data review process and the reason for the adjustment to each reported CSO discharge volume listed above in Table 4. As noted above, as part of the Annual Report submittal, MWRA updates the collection system model as described in Sections 2.1 and 2.2, runs the model for the annual period and prepares a table comparing the meter and model results. The initial results showed significant deviations between the model and original metered CSO volume estimates which had been reported within 5 days of the activation. These differences warranted further investigation which resulted in adjustments, as explained below.

MWR003

MWR003 is part of the Alewife Brook System as shown in Figure 1 below. This outfall provides relief to the Alewife Brook Conduit (ABC) and discharges to the Little River.

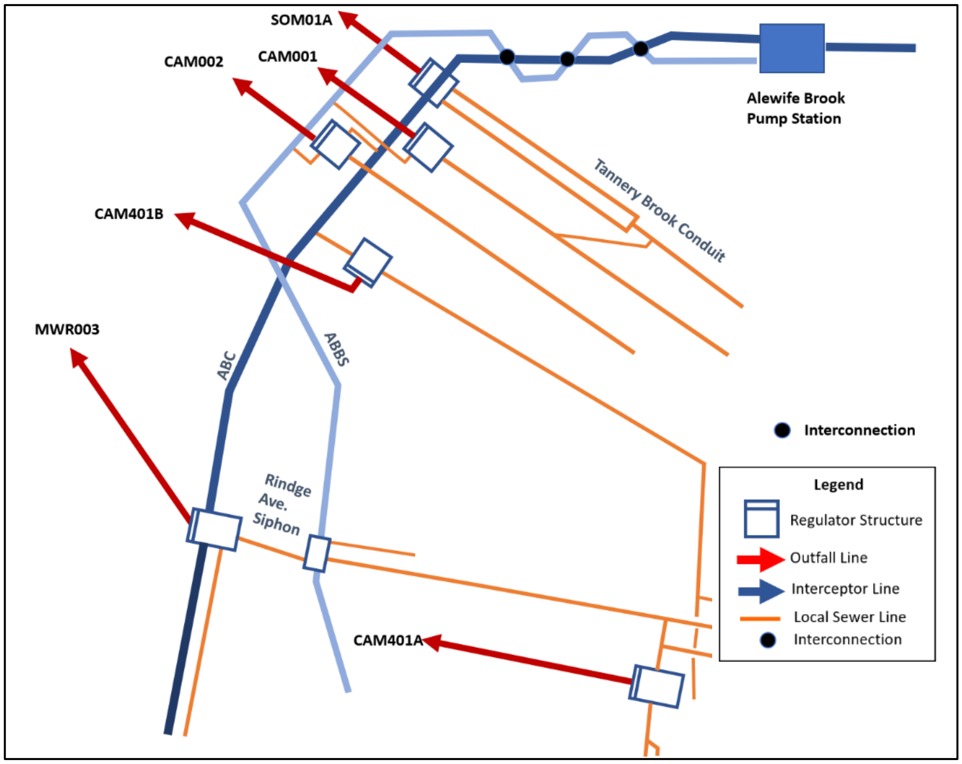

Figure 1. Schematic of Alewife Sub-System

At this location the metered and modeled activation frequency were the same, however, the volume originally reported by MWRA based on metering data was much higher than the volume calculated by the model. The volume originally reported based on the meter data was more than double the CSO volume predicted by the model for the 07/02/2021 and 09/02/2021 storm events. The extreme events of 2021 were some of the first events resulting in the regulator structure level being high enough to trigger the relief gate to drop as designed to protect the upstream system. CSO volume discharge estimates were initially based on a weir equation with the depth over the weir determined by the upstream regulator depth measurement. However, this calculation did not consider the impacts of headlosses in the regulator structure which would cause the actual water level at the weir to be lower than the level where the depth was measured. The calculation also did not consider the impacts of backwater from the Little River, which could affect the flow over the weir during periods when the weir gate was lowered.

In a first attempt to improve metered discharge estimates, a submerged weir equation was used during periods where the weir gate was lowered. The submerged weir equation incorporated depth measurement downstream of the tide gate in the outfall pipe and was applicable when the downstream water level was above the elevation of the weir. However, this method still likely overestimated the discharge volume because it did not take into consideration the headloss (i.e. energy loss) in the flow as it passed under the baffle, through the chamber downstream of the weir gate, and through the tide gate. Ultimately, a computer program was used to calculate the discharge volume based on the time-varying measured upstream and downstream water levels and accounting for sources of headloss between the two measured points based on established equations for headloss and flow. This program was also applied at other locations as described below.

MWR018, MWR019 and MWR020

Outfalls MWR018, MWR019 and MWR020 are located along the Boston Marginal Conduit (BMC) upstream of the Prison Point CSO Facility (Figure 2). These outfalls overflow to the Charles River when the hydraulic grade line in the BMC exceeds the controlling weir elevations at each structure.

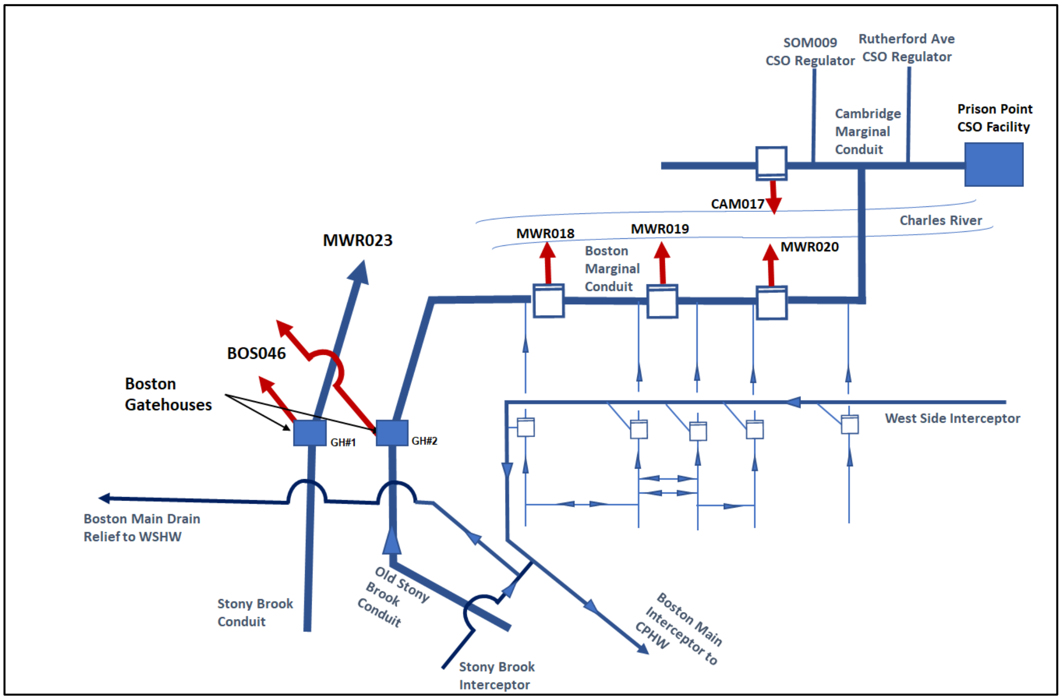

Figure 2. MWR018, MWR019, MWR020 System Schematic

The MWRA maintains depth meters at two locations along the BMC, one upstream of the connection to outfall MWR018, and one downstream of the connection to MWR020. To compute the discharge volumes originally reported, the depth in the BMC at the connections to the overflow structures at MWR018, MWR019 and MWR020 were first estimated by interpolating between the two measured depths along the BMC. These interpolated levels were then used with a weir equation to compute the estimated discharge at each outfall based on the height and width of the stop log weirs at each outfall. Upon further investigation, this approach did not appear to account for the additional headlosses in the overflow structures between the BMC and the stop log weirs. In addition, at MWR018 and MWR019, the limited opening between the stop log weir and the concrete roof slab in the weir structure can cause the weir to function as an orifice under certain high flow conditions. Taking these additional factors into account would have the effect of lowering the computed discharge volume from these outfalls based on the meter data. As was done for MWR003, a computer program was used to recompute the discharge volumes based on the time-varying depths in the BMC and established equations for headloss and flow, resulting in the lower volumes shown in Table 4.

MWR023

MWR023 and BOS046 are primarily stormwater discharges but may discharge CSO if the upstream CSO regulators overflow. The upstream regulators are monitored by BWSC. Combined sewage may discharge from outfall BOS046 as well as MWR023 during large storms, depending on the status of Gatehouse 1. The gatehouse is normally closed but may be opened by BWSC 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 at BOS046 and one or more of the upstream regulators in the Stony Brook system has activated, approximately 25% of the CSO from the upstream regulators discharges at the MWR023 outfall (Charles River) and 75% discharges at BOS046 (Back Bay Fens). Therefore, because the gate was open during all four activations in 2021, the total reported CSO volume at MWR023 have been adjusted to include 25% of the CSO volume from the upstream regulators; the remaining 75% will have discharged from outfall BOS046.

MWRA is currently reviewing the overflow volume calculation methodology at BOS046/MWR023 in coordination with BWSC.

Summary of 2021 Modeled and Metered CSO Discharges

The comparison of metered estimates and modeled CSO discharges from January 1, 2021 to December 31, 2021 has been summarized in two tables. CSO activations and volumes for 2021 are summarized in Table 5. CSO activations and volumes for the three storms identified in Table 2 above as extreme events that were responsible for a disproportionate amount of overflow volume are summarized in Table 7.

The model was able to replicate the storm responses for the majority of storm events in the 2021 period. However, it is not possible to match all of the modeled and metered activations for every meter and storm event. These differences may be attributed to various condition or combination of conditions, including rainfall data quality and rainfall spatial variation, unknown transient conditions in the collection system, and the accuracy of overflow metering data (see Section 4.2 of Semiannual Report No. 5 *Model Calibration and Factors Affecting Model Results*).

Table 6 provides a list of the locations with notable differences between metered and modeled CSO discharges for the January 1 – December 31, 2021 period.

Table 5. Summary of 2021 Modeled and Metered CSO Discharges

Outfall	January 1 – Dec 31, 2021			
	Meter(1) (2)		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Alewife Brook				
CAM001	5	0.20	4	0.17
CAM002	0	0	2	0.06
MWR003	5	6.77	5	7.49
CAM401A	18	21.7	10	4.24
CAM401B	7	4.09	5	2.29
SOM001A	8	17.98	8	10.98
TOTAL	**18**	**50.74**	**10**	**25.23**
Upper Mystic River				
SOM007A/MWR205A(3)	17	67.57	12	41.79
Mystic/Chelsea Confluence				
MWR205 (Somerville Marginal Facility) (3)	28	211.27	32	143.75
BOS013	15	0.09	13	0.79
BOS014	15	0.17	17	4.72
BOS017	6	2.76	10	2.58
CHE003	0	0	1	0.00
CHE004	5	0.92	6	1.38
CHE008	16	5.41	16	7.39
TOTAL	**28**	**220.62**	**32**	**160.61**

Table 5. Summary of 2021 Modeled and Metered CSO Discharges

Outfall	January 1 – Dec 31, 2021			
	Meter[(1) (2)]		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Upper Inner Harbor				
BOS009	21	2.45	23	1.98
BOS010	11	0.22	8	1.03
BOS012	7	0.19	0	0.00
BOS019	5	2.60	3	3.33
BOS057	7	15.51	8	8.97
BOS060	9	1.47	22	5.58
MWR203 (Prison Point)	19	444.14	21	474.36
TOTAL	**21**	**466.58**	**23**	**495.25**
Lower Inner Harbor				
BOS003	16	18.08	15	18.74
BOS004	6	0.26	4	0.15
BOS005	0	0	0	0
TOTAL	**16**	**18.34**	**15**	**18.89**
Fort Point Channel				
BOS062	6	0.47	9	6.38
BOS064	9	7.05	5	0.48
BOS065	3	2.84	8	7.24
BOS068	3	0.90	2	0.24
BOS070/DBC	11	39.99	20	44.45
MWR215 (Union Park)	15	71.77	15	85.66
BOS070/RCC	1	0.65	4	1.57
BOS073	2	0.37	3	0.12
TOTAL	**15**	**124.04**	**20**	**146.14**
Reserved Channel				
BOS076	4	0.51	5	3.70
BOS078	3	0.53	2	0.37
BOS079	0	0	0	0.00
BOS080	2	0.08	2	0.11
TOTAL	**4**	**1.12**	**5**	**4.18**
Upper Charles				
CAM005	11	4.97	12	2.20
CAM007	4	6.15	6	7.80
TOTAL	**11**	**11.12**	**12**	**10.00**

Table 5. Summary of 2021 Modeled and Metered CSO Discharges

Outfall	January 1 – Dec 31, 2021			
	Meter[1] [2]		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Lower Charles				
CAM017	6	13.00	3	5.15
MWR010	0	0	1	0.11
MWR018	4	2.98	4	6.60
MWR019	4	1.26	4	4.51
MWR020	4	1.21	4	12.40
MWR201	5	88.10	4	72.73
MWR023[4][6]	4	1.75	4	0.53
TOTAL	**6**	**108.30**	**4**	**102.03**
Back Bay Fens				
BOS046[4][5]	4	5.24	4	1.59
TOTAL	**4**	**5.24**	**4**	**1.59**
TOTAL UNTREATED		**190.82**		**187.42**
TOTAL TREATED		**815.28**		**776.5**
GRAND TOTAL		**1,006.10**		**963.92**

(1) Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.
(2) Meter volume reported is calculated from MWRA, Cambridge, Somerville, Chelsea, and BWSC community meters.
(3) MWRA is currently reviewing the facility meter data to assess inconsistencies in observed flow and water levels.
(4) 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, because the gate was open during all four activations in 2021, 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 CSO volume from the upstream regulators.
(5) 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. Meter activations and volume were not available for Boston Gatehouse 2 during 2021.
(6) MWRA is currently reviewing the overflow volume calculation methodology at these locations and coordinating with BWSC.

Table 6. Notable Differences Between Metered and Modeled CSO Discharges, January 1 – December 31, 2021

Location	Meter	Model	Comment
CAM401A	18 discharges 21.7 MG	10discharges 4.24 MG	• Reported CSO volumes and activations from these locations are inconsistent with the detailed metering program performed by MWRA in 2018-2019 in support of model calibration. MWRA and the CSO communities are working together to resolve and further understand observed differences.
SOM007A/MWR205A	17 discharges 67.57 MG	12 discharges 41.79 MG	• MWRA is currently reviewing the facility meter data to assess inconsistencies in observed flow and water levels.
Somerville Marginal CSO Facility MWR205	28 discharges 211.27 MG	32 discharges 143.75 MG	• MWRA is currently reviewing the facility meter data to assess inconsistencies in observed flow and water levels.
BOS012	7 discharges 0.19 MG	0 discharges 0 MG	• Reported CSO volumes and activations from these locations are inconsistent with the detailed metering program performed by MWRA in 2018-2019 in support of model calibration. MWRA and the CSO communities are working together to resolve and further understand observed differences.
BOS070, regulator RE070/8-15	11 discharges 16.49 MG	2 discharges 0.32 MG	
BOS070, regulator RE070/7-2	6 discharges 12.63 MG	20 discharges 28.72 MG	
CAM017	6 discharges 13.00 MG	3 discharge 5.15 MG	
MWR018/019/020	4 discharges 5.45 MG (total)	4 discharges 23.5 MG	• The water level in the BMC was overpredicted by the model during the 07/02/2021, 07/08/2021 and 09/02/2021 storm events. Model versus meter comparisons from recent years have demonstrated that the model does a much better job of predicting the level in the BMC and CSO volumes at MWR018, MWR019 and MWR020 during less-extreme storm events. MWRA is continuing to investigate the overprediction of the level in the BMC during the large events.

As noted above, three storm events during the monitoring period (on 7/1/2021, 7/8/2021, and 9/1/2021) had rainfall characteristics that were substantially different from the rainfall events in the Typical Year. These storm events have been classified as extreme events which resulted in unusually large metered CSO overflow volumes at several locations. The metered versus modeled overflow activation frequency and volume for these three storms are summarized in Table 7.

Table 7. Summary of Modeled and Metered CSO Discharges for Extreme Storm Events (July 1, 2021, July 8, 2021 and September 1, 2021)

Outfall	Extreme Events			
	Meter(1)(2)		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Alewife Brook				
CAM001	3	0.10	3	0.12
CAM002	0	0	1	0.06
MWR003	3	5.09	3	5.83
CAM401A	3	11.78	3	3.05
CAM401B	3	3.14	3	1.68
SOM001A	3	12.15	3	6.99
TOTAL	**3**	**32.26**	**3**	**17.73**

Table 7. Summary of Modeled and Metered CSO Discharges for Extreme Storm Events (July 1, 2021, July 8, 2021 and September 1, 2021)

Outfall	Extreme Events			
	Meter(1)(2)		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Upper Mystic River				
SOM007A/MWR205A(3)	3	32.63	3	14.84
Mystic/Chelsea Confluence				
MWR205 (Somerville Marginal Facility) (3)	3	91.67	3	52.46
BOS013	3	0.06	3	0.45
BOS014	3	0.06	3	2.94
BOS017	3	2.22	3	2.06
CHE003	0	0.00	1	0.00
CHE004	2	0.75	3	0.94
CHE008	3	3.65	3	5.32
TOTAL	**3**	**98.41**	**3**	**64.17**
Upper Inner Harbor				
BOS009	2	0.60	3	1.21
BOS010	2	0.12	3	0.85
BOS012	1	0.01	0	0.00
BOS019	3	2.50	3	3.33
BOS057	3	14.65	3	8.34
BOS060	3	0.77	3	5.18
MWR203 (Prison Point)	3	211.39	3	207.39
TOTAL	**3**	**230.04**	**3**	**226.3**
Lower Inner Harbor				
BOS003	3	12.43	3	12.19
BOS004	3	0.11	3	0.12
BOS005	0	0.00	0	0
TOTAL	**3**	**12.54**	**3**	**12.31**
Fort Point Channel				
BOS062	2	0.16	3	5.46
BOS064	3	6.88	3	0.46
BOS065	2	2.56	3	6.98
BOS068	3	0.90	2	0.24
BOS070/DBC	3	27.56	3	40.07
MWR215 (Union Park)	3	45.53	3	46.79
BOS070/RCC	1	0.65	3	1.42
BOS073	2	0.37	3	0.12
TOTAL	**3**	**84.61**	**3**	**101.54**

Table 7. Summary of Modeled and Metered CSO Discharges for Extreme Storm Events (July 1, 2021, July 8, 2021 and September 1, 2021)

Outfall	Extreme Events			
	Meter(1)(2)		Model	
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)
Reserved Channel				
BOS076	3	0.41	3	3.59
BOS078	3	0.53	2	0.35
BOS079	0	0.00	0	0.00
BOS080	1	0.07	1	0.11
TOTAL	**3**	**1.01**	**3**	**4.07**
Upper Charles				
CAM005	3	4.34	3	1.53
CAM007	3	5.49	3	6.12
TOTAL	**3**	**9.83**	**3**	**7.65**
Lower Charles				
CAM017	3	9.71	2	5.05
MWR010	0	0.00	1	0.11
MWR018	3	2.66	3	5.89
MWR019	3	1.1	3	4.07
MWR020	3	1.06	3	11.70
MWR201	3	78.83	3	64.56
MWR023(4)(6)	3	1.72	3	0.44
TOTAL	**3**	**95.08**	**3**	**91.82**
Back Bay Fens				
BOS046(4)(5)	3	5.15	3	1.31
TOTAL	**3**	**5.15**	**3**	**1.31**
TOTAL TREATED		**427.42**		**371.2**
TOTAL UNTREATED		**141.51**		**155.7**
GRAND TOTAL		**568.93**		**526.90**

(1) Metered data are estimates of outfall discharge calculated using data from sensors, taking into account physical configurations and constraints.
(2) Meter volume reported for metered outfalls is from MWRA, Cambridge, Somerville, and BWSC community meters.
(3) MWRA is currently reviewing the facility meter data to assess inconsistencies in observed flow and water levels
(4) 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, because the gate was open during all three storms, 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 CSO volume from the upstream regulators.
(5) 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. Meter activations and volume were not available for Boston Gatehouse 2 during monitoring period.
(6) MWRA is currently reviewing the overflow volume calculation methodology at these locations and coordinating with BWSC.

3. Updated System Performance Assessment and Comparison with LTCP Levels of Control

3.1 Performance Assessment

Hydraulic modeling has historically served as the basis for evaluating performance of the MWRA's CSO system. This section summarizes the system performance under Typical Year rainfall based on the Q4-2021 system conditions model, representing conditions as of the end of 2021. Table 8 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 8 also presents previously-modeled CSO discharge levels for 1992 system conditions for the Typical Year, and the LTCP goals for Typical Year levels of control as defined in the Second Stipulation. In Table 8, Q4-2021 System Conditions activations or volumes that are greater than (i.e. do not achieve) the LTCP goals are shaded in grey, and 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 which are particularly challenging with no clear plan established to achieve the LTCP goals.

Table 8. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals

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(9)	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 8. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals

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]			7	6.18	3	2.19
MWR215 (Union Park Facility)	4	281.62	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[10]	N/A	0 / 25 year[10]	N/A
BOS082	28	3.75	0 / 25 year[10]	N/A	0 / 25 year[10]	N/A
BOS083	14	1.05	Closed	N/A	0 / 25 year[10]	N/A
BOS084	15	3.22	0 / 25 year[10]	N/A	0 / 25 year[10]	N/A
BOS085	12	1.31	0 / 25 year[10]	N/A	0 / 25 year[10]	N/A
BOS086	80	3.31	0 / 25 year[10]	N/A	0 / 25 year[10]	N/A
BOS087	9	1.27	Closed	N/A	0 / 25 year[10]	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[9]	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 8. Typical Year Performance: Baseline 1992, Q4-2021 Conditions and LTCP Goals

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(9)	2	3.18	2	1.11	0	0.00
MWR019(9)	2	1.32	2	0.47	0	0.00
MWR020(9)	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(9) (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**

Notes:

* 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 9 below for outfalls forecast to attain LTCP goals by 2024.
(8) See Table 10 below for site-specific investigations underway where modeled concepts predicted to attain LTCP goals are moving into design.
(9) See Table 11 below for site-specific investigations underway where no additional system improvement has yet been recommended to attain LTCP goals.
(10) The outfalls do not discharge in a 25-year storm as defined at the time the LTCP was approved.

As indicated in Table 8, 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 have projects to meet the LTCP goals that are in design or construction and are expected to be completed by 2024. Conceptual plans have been established for four outfalls which will be brought into design and possibly construction, should detailed design provide consistent findings to the modeled concept developed. The six outfalls that remain are particularly challenging and no clear alternatives commensurate to receiving water benefits have been identified. Investigations continue for these six challenging outfalls.

3.2 Outfalls Forecast to Attain LTCP Activation and Volume Goals by December 2024

Table 9 presents the six outfalls that are forecast to meet the LTCP goals by December 2024. These outfalls were originally presented in Table 2-3 of the December 30, 2021 *Task 6 Final CSO Post Construction Monitoring Program and Performance Assessment Report* ("the Task 6 Report"). Table 9 presents the same information from Table 2-3 with updated information provided in bold text. For each outfall, Table 9 presents a description and updated status of the system improvement(s) intended to result in attainment of the LTCP goals by 2024, as well as the entity implementing the work and the tentative schedule for completion.

Table 9. Outfalls Forecast to Attain LTCP Goals by 2024

<table>
<tr><th>OUTFALL</th><th>LOCATION</th><th>SYSTEM IMPROVEMENT(S)*</th><th>TO BE IMPLEMENTED BY</th><th>TENTATIVE SCHEDULED COMPLETION</th></tr>
<tr><td>MWR205</td><td rowspan="2">Somerville Marginal CSO Facility</td><td rowspan="2">Construct new connection from the facility influent conduit to the interceptor and replace tide gate. Project is currently in the design phase. Survey has been conducted and borings needed to design the connecting structure and gate chamber are being coordinated with MassDOT and are expected this spring. Project is scheduled to bid in Spring 2023, completed in Spring 2024.</td><td rowspan="2">MWRA</td><td rowspan="2">2024</td></tr>
<tr><td>SOM007A/ MWR205A</td></tr>
<tr><td>BOS003</td><td rowspan="3">East Boston</td><td rowspan="2">Complete BWSC Sewer Separation Contract 3, including upgrade of interceptor connection at regulator RE003-12. Construction began in August 2021 and is ongoing. Separation is complete for approximately 10% of the area to be separated. Additional work has been completed to facilitate future separation.</td><td rowspan="3">BWSC</td><td rowspan="3">2023</td></tr>
<tr><td>BOS009</td></tr>
<tr><td>BOS014</td><td>Construct new interceptor connection as part of BWSC Sewer Separation Contract 3. New connection has been completed and was brought online January 24, 2022.</td></tr>
<tr><td>CHE008</td><td>Chelsea Creek</td><td>Replace/upgrade interceptor connection. Final design is almost complete and the project is anticipated to be advertised in May 2022 and the award issued in August 2022.</td><td>MWRA</td><td>2023</td></tr>
</table>

*__Bold__ text indicates update to the table since it was originally presented in the *Task 6 Report*.

3.3 Outfalls Where Modeled Concepts are Moving into Design

Table 10 presents four of the remaining locations where Typical Year CSO activation and/or volume exceed the LTCP goals. At these locations 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. MWRA is continuing to work with BWSC to further develop designs which are predicted to meet LTCP goals when they are implemented. MWRA is working with BWSC to evaluate the constructability and cost for these projects. Information on these outfalls was original presented in Table 2-4 of the *Task 6 Report*. Similar to the table above, updates to the previous information provided are shown in bold.

Table 10. Outfalls with Modeled Concept Designs Predicted to Attain LTCP Goals

OUTFALL	Q4-2021 SYSTEM CONDITIONS MODEL		LONG TERM CONTROL PLAN		FUTURE CONDITION		OUTFALLS WITH MODELED CONCEPT DESIGNS PREDICTED TO ATTAIN LTCP GOALS*
	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	Activation Frequency	Volume (MG)	
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. • **MWRA continues to work with BWSC to evaluate constructability and cost for this project**
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. • **MWRA continues to work with BWSC to evaluate constructability and cost for this project**
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. • **MWRA continues to work with BWSC to evaluate constructability and cost for this project**
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. • **MWRA continues to work with BWSC to evaluate constructability and cost for this project. BWSC will be installing level sensors in Spring 2022 that will be used to assess the water level in the interceptors near RE070/7-2.**

*__Bold__ text indicates update to the table since it was originally presented in the *Task 6 Report*.

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

Table 11 presents the six remaining locations where Typical Year CSO activation and/or volume exceed the LTCP goals and no additional system improvement has yet been recommended. MWRA has continued to track CSO performance at these locations and assess the causes of higher overflow activity. In Table 2-4 of the *Task 6 Report*, MWRA 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 11 presents the same list of outfall locations where site specific investigations continue. For the remaining six outfalls that present significant challenges, evaluations will continue.

Table 11. Outfalls Presenting Significant Challenges

OUTFALL	Q4-2021 SYSTEM CONDITIONS MODEL		LONG TERM CONTROL PLAN		FUTURE CONDITION		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*	• 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.
CHARLES RIVER							
MWR201 (Cottage Farm)	2	9.10	2	6.30	TBD*	TBD*	• 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.
CAM005	8	0.74	3	0.84	TBD*	TBD*	• 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.
MWR018	2	1.12	0	0.00	TBD*	TBD*	• 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.
MWR019	2	0.48	0	0.00	TBD*	TBD*	
MWR020	2	0.48	0	0.00	TBD*	TBD*	

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

3.5 Summary

With the completion of the Post Construction Monitoring Program and Performance Assessment, MWRA has demonstrated that 70 of the 86 outfalls listed in Exhibit B of the Second Stipulation have achieved or materially achieved LTCP goals by the end of 2021. As noted in the introduction, the United States' Response to the Supplemental Report submitted by MWRA on September 30, 2021 allowed the Court Order to be extended until December 2024 to complete identified projects and further evaluate alternatives to further reduce CSOs at the sixteen outfalls that did not meet the LTCP goals by December 31, 2021. The next phase of this project will therefore to be to focus on the 16 additional outfalls not yet forecasted to meet LTCP goals. As described above, 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 have projects to meet the LTCP goals that are in design or construction and are expected to be completed by 2024. Conceptual plans have been established for four outfalls which will be brought into design and possibly construction, should constructability be confirmed and detailed design provide consistent findings to the modeled concept developed. The six outfalls that remain are particularly challenging and no clear alternatives commensurate to the minimal receiving water quality benefits have been identified. Investigations continue for these six challenging outfalls.

Appendix A Rainfall Processing and Analyses January 1, 2021 – December 31, 2021

A.1 Rainfall Analyses

This section presents the rainfall data measured from 20 gauges within the MWRA wastewater service area during the period of January 1, 2021 through December 31, 2021. It also describes the analysis of the rainfall data used to characterize the return period of each storm event and a comparison of measured rainfall for the 2021 period to the rainfall included in the Typical Year[8]. Previous rainfall analyses were based on Technical Paper 40 (TP-40)[9] which was originally published in 1961 and reissued in 1963. TP-40 continued to be used through submission of the Final Post Construction Monitoring Report to be consistent with the work done for the Long Term Control Plan. For this report and for analyses going forward the methodology for characterizing the recurrence intervals of rainfall events was updated to NOAA Atlas 14, Volume 10 originally published in in 2015 and updated in 2019[10]. Atlas 14 includes analysis of more recent historical rainfall data for the Northeastern United States. In addition, this change is responsive to language provided by MassDEP in a response to comments document on the 2019 Charles River Variance. In the response it was noted that "MassDEP expects that when MWRA and Cambridge and Somerville do future CSO planning, they will utilize the NOAA 14 Atlas for precipitation data, which is the most current compilation of area rainfall data." MassDEP went on further to state that "While storm recurrence frequencies have changed, especially for larger events, MassDEP does not expect the benefits of MWRA's CSO control plan to be compromised significantly for the events occurring in the 'typical year' used to evaluate the effectiveness of CSO controls."

When comparing the recurrence intervals for NOAA Atlas 14 and TP-40 it was observed that in general for NOAA Atlas 14, smaller storms (like those in a Typical Year) tended to occur less frequently, while larger storms (not in a Typical Year) tended to occur more frequently. Using NOAA Atlas14 does not affect the conclusions regarding compliance of past completed CSO control projects nor efforts currently underway to achieve the LTCP goals for the 16 Remaining Outfalls.

Values for Atlas 14 for Boston were extracted from NOAA's data server[11] on April 12, 2022. The Atlas 14 partial duration curves were used to assign the recurrence intervals. The smallest storm the partial duration curves address is the 1-year storm so the partial duration IDF curves for the 3-month and 6-month frequencies were extrapolated. All of the storm recurrence intervals identified in the text and sections below are based on the 2019 edition of Atlas 14 referenced above.

A.1.1 Rainfall Data Collection and Processing

Rainfall was quantified for this analysis using 15-minute rainfall data collected at rain gauges distributed over the MWRA system. The rain gauges are listed in Table A-1 and the locations are shown in Figure A-1.

[8] 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.

[9] TP 40: https://reduceflooding.com/wp-content/uploads/2018/09/TechnicalPaper_No40.pdf

[10] Atlas 14 Volume 10 report : https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

[11] NOAA's Data server for MA: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ma

Table A-1. Rain Gauges

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

(1) Project gauges were removed as of July 1, 2020. Project gauge data has been replaced with the nearest rain gauge, following the QA/QC procedures and closest rain gauges substitution table.

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.

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 A-2 identifies the two closest rain gauges to each of the rain gauges. Replacement of suspect data was recorded in Table A-3.

Additional information on the methodologies for rainfall data collection and processing can be found in Semiannual Reports 1 and 2.

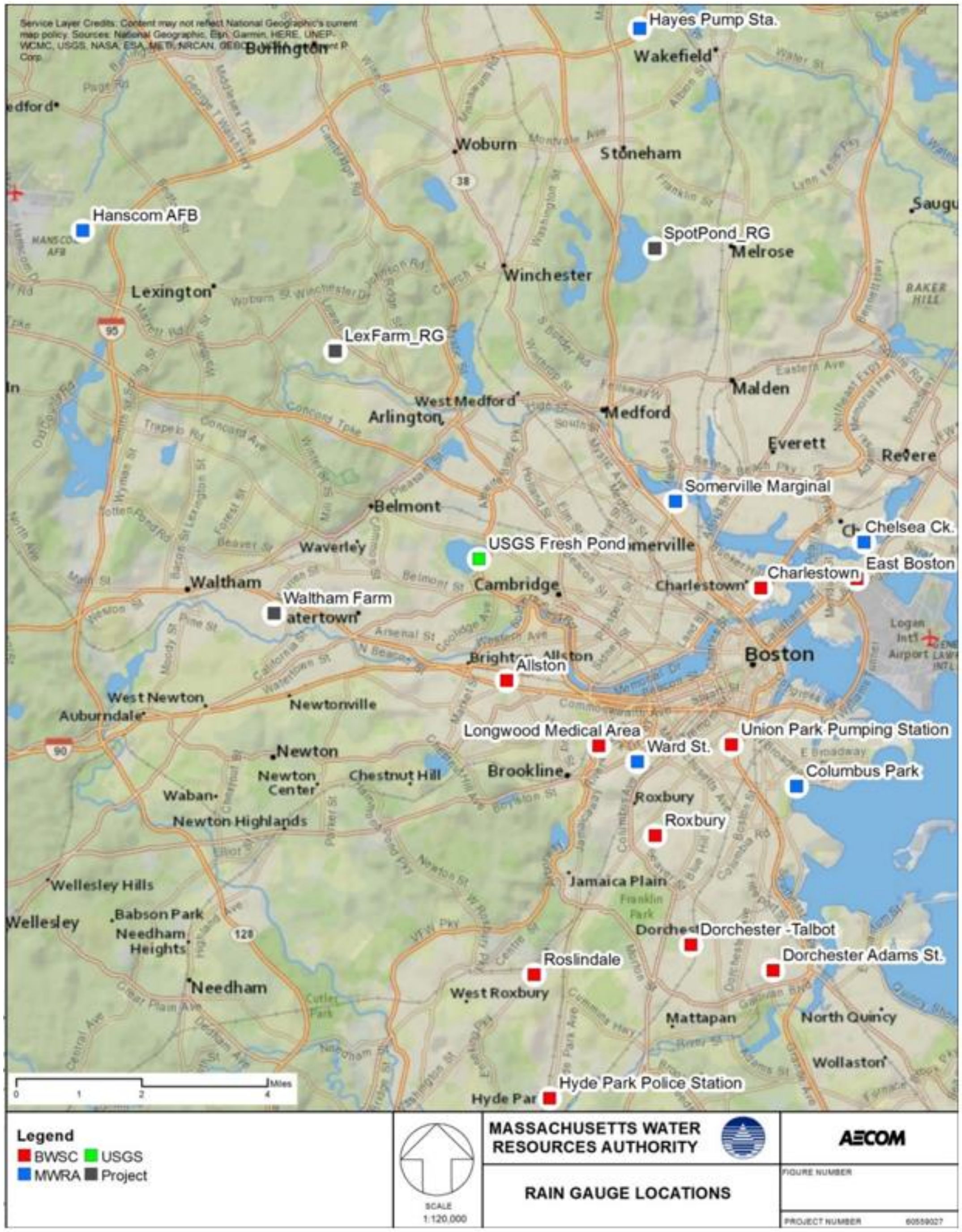

Figure A-3. Rain Gauge Location Plan

Table A-2. Closest Rain Gauges for Data Substitution

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

Table A-3. Summary of Rainfall Data Replacement, January - December 2021

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 (BWSC001)	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)

Table A-3. Summary of Rainfall Data Replacement, January - December 2021 (Continued)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
Roslindale (BWSC002)	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. (BWSC003)	01/01/2021 0:00	01/03/2021 0:00	Roxbury (ROX)
	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 (BWSC006)
	04/30/2021 6:00	06/30/2021 23:45	Roslindale (BWSC002)
	07/1/2021 0:00	07/31/2021 23:45	Dorchester Talbot (BWSC006)
	08/1/2021 0:00	08/22/2021 23:45	Roslindale (BWSC002)
	08/23/2021 0:00	12/31/2021 23:45	Dorchester Talbot (BWSC006)
Allston (BWSC004)	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 (BWSC005)	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)
Dorchester -Talbot (BWSC006)	01/01/2021 0:00	01/03/2021 0:00	Roxbury (ROX)
	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 (BWSC002)
	08/1/2021 0:00	08/22/2021 23:45	Roslindale (BWSC002)
Charlestown (BWSC007)	01/01/2021 0:00	12/31/2021 23:45	East Boston (EB)
Longwood Medical Area (BWSC008)	01/01/2021 0:00	12/31/2021 23:45	Ward Street (BO-DI-1)
Chelsea Creek (CH-BO-1)	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)
	12/17/2021 9:00	12/17/2021 9:15	Somerville (SOM)
East Boston (EB)	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)
	12/1/2021 0:00	12/31/2021 23:45	Chelsea Creek (CH-BO-1)
USGS Fresh Pond (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 (SOM)
	07/1/2021 0:00	08/27/2021 12:45	Allston (BWSC004)
	09/18/2021 0:00*	09/18/2021 0:45	Allston (BWSC004)
	09/28/2021 0:00*	09/28/2021 0:45	Allston (BWSC004)

Table A-3. Summary of Rainfall Data Replacement, January - December 2021 (Continued)

Rain Gauge	Replacement Data Start Time	Replacement Data End Time	Replacement Rain Gauge
USGS Fresh Pond (FRESH_POND)	10/30/2021 2:30	10/31/2021 5:30	Allston (BWSC004)
	11/3/2021 0:00*	11/3/2021 0:45	Allston (BWSC004)
	11/12/2021 0:00*	11/12/2021 0:45	Allston (BWSC004)
	11/27/2021 0:00*	11/27/2021 0:45	Allston (BWSC004)
	12/11/2021 0:00*	12/11/2021 0:45	Allston (BWSC004)
	12/16/2021 23:00*	12/16/2021 23:45	Allston (BWSC004)
	12/24/2021 23:00*	12/24/2021 23:45	Allston (BWSC004)
	12/27/2021 23:00*	12/27/2021 23:45	Allston (BWSC004)
	12/28/2021 23:00*	12/28/2021 23:45	Allston (BWSC004)
Hanscom AFB (HF-1C)	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond (FRESH_POND)
	7/1/2021 0:00	8/27/2021 12:45	Allston (BWSC004)
	8/27/2021 13:00	12/31/2021 23:45	Fresh Pond (FRESH_POND)
Lexington Farm (Lex)	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond (FRESH_POND)
	07/1/2021 0:00	08/27/2021 12:45	Allston (BWSC004)
	08/27/2021 13:00	12/31/2021 23:45	Fresh Pond (FRESH_POND)
Hayes Pump Sta. (RG-WF-1)	01/26/2021 18:45	01/27/2021 18:00	Fresh Pond (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 (FRESH_POND)
	11/24/2021 11:30	11/29/2021 12:45	Somerville (SOM)
Roxbury (ROX)	01/03/2021 0:30	12/31/2021 23:45	Ward Street (BO-DI-1)
Somerville (SOM)	01/16/2021 20:00	01/27/2021 18:00	Chelsea Creek (CH-BO-1)
	02/18/2021 16:30	02/21/2021 16:30	Ward Street (BO-DI-1)
Spot Pond (SP)	01/01/2021 0:00	12/31/2021 23:45	Somerville (SOM)
Waltham Farm (WF)	01/01/2021 0:00	06/30/2021 23:45	Fresh Pond (FRESH_POND)
	07/1/2021 0:00	08/27/2021 12:45	Allston (BWSC004)
	08/27/2021 13:00	12/31/2021 23:45	Fresh Pond (FRESH_POND)

*Replacing missing timestep from USGS Fresh Pond with nearest active gauge

A.1.2 Monitored Storms and Comparison with Typical Year

For the period of January 1 to December 31, 2021, 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, 1-2 year, or the nearest year for recurrence intervals greater than 2 year, based on comparison to the IDF values from Atlas 14. Table A-4 presents the summary of storm events for Ward Street Headworks for the period of January to

December 2021. These data show that 100 storm events occurred in the year long 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.

During the period of July through mid-September 2021, 24.75 inches of rain fell at the Ward Street Headworks rain gauge with 12.74 inches in July alone. The rainfall in that two-and-a-half month period equaled approximately half of the total annual rainfall in the Typical Year. Storms during this period varied from short duration and high intensity events to longer duration, lower intensity events. The Northeast Regional Climate Center (NRCC)[12] declared July 2021 the wettest July on record in Massachusetts with a state-wide rainfall average of 10.38 inches, which was 6.55 inches above the normal average.

Table A-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2021

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
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	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	0.10	0.04	0.05	0.00	N/A	<3m	<3m	N/A

[12] NRCC: http://www.nrcc.cornell.edu/regional/tables/tables.html

Table A-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2021 (Continued)

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
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	0.60	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-1y	N/A
38	5/30/2021 8:45	23	1.00	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	4yr	3m-6m	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	0.40	0.09	0.24	0.02	N/A	<3m	<3m	N/A
46	7/1/2021 19:00	78.5	5.69	0.07	1.23	0.14	0.10	4y	3y	4y
47	7/6/2021 3:00	16	0.15	0.01	0.10	0.01	N/A	<3m	<3m	N/A
48	7/7/2021 18:15	10.25	0.50	0.04	0.35	0.02	N/A	<3m	<3m	N/A
49	7/8/2021 18:45	32.75	3.03	0.09	0.91	0.12	0.07	1y-2y	1y-2y	1y-2y
50	7/11/2021 17:45	16	1.54	0.10	0.56	0.06	N/A	3m-6m	<3m	N/A
51	7/13/2021 4:30	0.25	0.01	0.00	0.01	0.03	N/A	<3m	<3m	N/A
52	7/16/2021 14:45	0.5	0.23	0.46	0.23	0.01	N/A	<3m	<3m	N/A
53	7/17/2021 9:00	31	0.60	0.02	0.12	0.02	0.02	<3m	<3m	<3m
54	7/19/2021 8:30	0.25	0.01	0.00	0.01	0.01	N/A	<3m	<3m	N/A
55	7/21/2021 0:15	0.25	0.04	0.00	0.04	0.00	N/A	<3m	<3m	N/A
56	7/22/2021 19:30	0.75	0.20	0.27	0.20	0.01	N/A	<3m	<3m	N/A
57	7/25/2021 8:15	3	0.19	0.06	0.18	0.01	N/A	<3m	<3m	N/A
58	7/27/2021 18:30	14	0.37	0.03	0.34	0.02	N/A	<3m	<3m	N/A

Table A-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2021 (Continued)

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
59	7/29/2021 22:00	3.25	0.18	0.06	0.15	0.01	N/A	<3m	<3m	N/A
60	8/4/2021 18:45	21	1.56	0.07	0.4	0.07	N/A	3m	3m-6m	N/A
61	8/6/2021 6:45	0.25	0.01	0.00	0.01	0.02	N/A	<3m	<3m	N/A
62	8/9/2021 18:00	16.75	0.6	0.04	0.34	0.03	N/A	<3m	<3m	N/A
63	8/19/2021 6:45	5.25	1.31	0.25	0.57	0.05	N/A	6m	3m	N/A
64	8/20/2021 6:15	0.5	0.02	0.04	0.02	0.06	N/A	<3m	<3m	N/A
65	8/22/2021 2:30	16.75	0.83	0.05	0.57	0.03	N/A	6m	<3m	N/A
66	8/23/2021 16:15	8.5	1.53	0.18	0.51	0.06	N/A	3m-6m	<3m	N/A
67	8/28/2021 19:30	4.5	0.16	0.04	0.12	0.01	N/A	<3m	<3m	N/A
68	8/30/2021 21:45	0.25	0.03	0.00	0.03	0.00	N/A	<3m	<3m	N/A
69	9/1/2021 12:00	17.25	4.62	0.27	1.25	0.19	N/A	4y	6y	N/A
70	9/5/2021 22:00	1.5	0.03	0.02	0.02	0.00	N/A	<3m	<3m	N/A
71	9/9/2021 4:30	33	1.31	0.04	0.47	0.05	N/A	3m	3m	N/A
72	9/13/2021 4:45	1.5	0.07	0.05	0.04	0.00	N/A	<3m	<3m	N/A
73	9/16/2021 4:45	3	0.43	0.14	0.39	0.02	N/A	<3m	<3m	N/A
74	9/18/2021 21:45	5	0.37	0.07	0.2	0.02	N/A	<3m	<3m	N/A
75	9/23/2021 11:15	0.5	0.02	0.04	0.02	0.00	N/A	<3m	<3m	N/A
76	9/24/2021 5:30	0.25	0.01	0.00	0.01	0.00	N/A	<3m	<3m	N/A
77	9/25/2021 21:15	7.75	0.48	0.06	0.3	0.02	N/A	<3m	<3m	N/A
78	9/28/2021 8:45	11	0.82	0.07	0.28	0.03	N/A	<3m	<3m	N/A
79	10/3/2021 22:45	35.5	1.69	0.05	0.26	0.06	0.04	<3m	<3m	6m
80	10/11/2021 9:15	0.25	0.01	0.00	0.01	0.00	N/A	<3m	<3m	N/A
81	10/16/2021 20:45	6.75	0.32	0.05	0.12	0.01	N/A	<3m	<3m	N/A
82	10/25/2021 0:00	64.25	2.80	0.04	0.37	0.08	0.05	<3m	6m	6m-1y
83	10/30/2021 2:00	28	1.63	0.06	0.55	0.07	0.03	3m-6m	3m-6m	3m-6m
84	11/12/2021 8:30	8.25	0.79	0.10	0.27	0.03	N/A	<3m	<3m	N/A
85	11/13/2021 17:30	1.25	0.16	0.13	0.15	0.01	N/A	<3m	<3m	N/A
86	11/14/2021 23:45	4	0.14	0.04	0.06	0.01	N/A	<3m	<3m	N/A
87	11/19/2021 0:45	3.5	0.26	0.07	0.11	0.01	N/A	<3m	<3m	N/A
88	11/22/2021 2:00	7.25	0.3	0.04	0.22	0.01	N/A	<3m	<3m	N/A
89	11/26/2021 11:00	21.75	0.07	0.01	0.02	0.00	N/A	<3m	<3m	N/A
90	12/2/2021 22:00	1.25	0.04	0.03	0.03	0.00	N/A	<3m	<3m	N/A

Table A-4. Summary of Storm Events at Ward Street Headworks Rain Gauge (BO-DI-1) for January to December 2021 (Continued)

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
91	12/6/2021 6:15	1	0.11	0.11	0.11	0.00	N/A	<3m	<3m	N/A
92	12/6/2021 20:45	2	0.24	0.12	0.17	0.01	N/A	<3m	<3m	N/A
93	12/9/2021 9:00	0.5	0.02	0.04	0.02	0.00	N/A	<3m	<3m	N/A
94	12/11/2021 7:30	17	0.3	0.02	0.15	0.01	N/A	<3m	<3m	N/A
95	12/15/2021 21:30	9.75	0.2	0.02	0.07	0.01	N/A	<3m	<3m	N/A
96	12/18/2021 14:15	17.5	1.05	0.06	0.12	0.04	N/A	<3m	<3m	N/A
97	12/22/2021 11:15	6.25	0.12	0.02	0.1	0.01	N/A	<3m	<3m	N/A
98	12/25/2021 8:30	20.25	0.63	0.03	0.12	0.03	N/A	<3m	<3m	N/A
99	12/28/2021 4:00	6.25	0.05	0.01	0.01	0.00	N/A	<3m	<3m	N/A
100	12/30/2021 11:45	10.5	0.06	0.01	0.02	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-1y), 1 year (1y), 1 to 2 year (1y-2y) or the nearest year for recurrence intervals >2 year, based on Atlas 14.

The characteristics of the rain events that occurred in the January 1 through December 31, 2021 monitoring period were compared to rainfall characteristics from the Typical Year to help interpret the measured CSO activations and volumes in comparison to Typical Year performance.

The total rainfall and number of storms at each rain gauge were identified for the period of January 1 through December 31, 2021, and the number of storms by depth. These values were then compared to the values from the Typical Year. Table A-5 presents this comparison. As indicated in Table A-5, during 2021 the rain gauges measured an average total rainfall volume of 58.10 inches, compared with 46.8 inches in the Typical Year, an 11.3-inch increase in precipitation over the Typical Year. The number of storms within the depth categories in Table A-5 were generally similar, except for the 1.0 to 2.0-inch range, where the gauges averaged 12 events, compared to eight for the Typical Year. It is important to note that most of the larger events in 2021, and a substantial portion of the total annual rainfall (e.g. 40 percent of the rainfall at the Ward Street gauge), occurred within the 2.5-month period of July through mid-September noted above.

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 A-6). Experience has shown that large storms often account for a disproportionate volume of CSO. While the average number of storms with greater than 2 inches of total rainfall across all gauges in 2021 matched the Typical Year (6 storms), each of the gauges listed in Table A-6 had two storms with total rainfall greater than the largest storm in the Typical Year (3.89 inches). Also, within the Typical Year, the storms with greater than 2 inches of rainfall were separated from each other by a period of at least one month. In 2021, some of the gauges (e.g., Chelsea Creek) had as many as five storms with greater than 2 inches of total rainfall within a period of two months. The concentration of multiple large storm events within a relatively short period of time can influence CSO volumes as saturated soils would generate more runoff.

Table A-5. Frequency of Events within Selected Ranges of Total Rainfall for January 1 to December 31, 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
Typical Year	46.8	93	49	14	16	8	6
January - December 2021 Metering Data							
Average of Rain Gauges							
Average	58.10	95	46	14	17	12	6
MWRA Rain Gauges							
Ward Street	60.03	100	50	15	16	13	6
Columbus Park	62.28	99	47	16	16	12	8
Chelsea Creek	58.57	96	46	11	18	15	6
Hanscom AFB	54.13	88	39	16	16	11	6
Hayes PS	56.6	88	38	11	20	12	7
BWSC Rain Gauges							
Allston	57.26	99	51	12	20	9	7
Charlestown	58.24	92	44	10	16	16	6
Dorchester-Adams	60.77	97	48	13	18	11	7
Dorchester-Talbot	60.76	97	48	13	18	11	7
Hyde Park	60.03	105	55	18	16	9	7
East Boston	58.24	92	44	10	16	16	6
Longwood	60.03	100	50	15	16	13	6
Roslindale	61.45	104	56	15	15	12	6
Roxbury	59.98	99	49	15	16	13	6
Union Park	59.64	104	53	17	16	12	6
USGS Rain Gauge							
Fresh Pond	54.13	88	39	16	16	11	6
MWRA Rain Gauges							
Lexington Farm	54.13	88	39	16	16	11	6
Spot Pond	55.79	91	41	15	19	10	6
Somerville	55.79	91	41	15	19	10	6
Waltham Farm	54.13	88	39	16	16	11	6

Table A-6. Comparison of Storms Between January 1 and December 31, 2021 and Typical Year with Greater Than 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)(1)
Typical Year	12/11/1992	50	3.89	0.08	0.20	1y-2y
	8/15/1992	72	2.91	0.04	0.66	6m
	9/22/1992	23	2.76	0.12	0.65	1y-2y
	11/21/1992	84	2.39	0.03	0.31	6m
	5/31/1992	30	2.24	0.07	0.37	6m-1y
	10/9/1992	65	2.04	0.03	0.42	<3m
January-December 2021 Rain Gauge Data						
Ward Street	4/15/2021	41.5	2.74	0.07	0.24	1y
	5/28/2021	20	2.38	0.12	0.29	6m-1y
	7/1/2021	78.5	5.69	0.07	1.23	3y
	7/8/2021	32.75	3.03	0.09	0.91	1y-2y
	9/1/2021	17.25	4.62	0.27	1.25	6y
	10/25/2021	64.25	2.80	0.04	0.37	6m
Columbus Park	4/15/2021	39	2.29	0.06	0.27	6m-1y
	5/28/2021	19.25	2.55	0.13	0.31	1y
	7/1/2021	77.5	5.83	0.08	0.87	1y-2y
	7/8/2021	33	2.55	0.08	0.76	1y
	8/4/2021	24	2.30	0.10	0.45	6m-1y
	8/23/2021	11.75	2.03	0.17	1.04	6m-1y
	9/1/2021	17.25	5.15	0.30	1.41	10y
	10/25/2021	64.75	3.91	0.06	0.57	1y
Chelsea Creek	4/15/2021	39.5	2.20	0.06	0.24	6m-1y
	5/28/2021	19.25	2.28	0.12	0.28	6m-1y
	7/1/2021	17.25	3.96	0.23	1.66	4y
	7/8/2021	30.5	2.49	0.08	0.71	1y
	9/1/2021	17.75	4.70	0.26	1.24	7y
	10/25/2021	70.25	2.22	0.03	0.27	<3m
Fresh Pond (USGS)	4/15/2021	23.5	2.35	0.10	0.22	6m-1y
	7/1/2021	58	5.16	0.09	1.55	2y
	7/8/2021	30.25	2.77	0.09	0.68	1y
	8/19/2021	5.5	2.12	0.39	1.02	1y-2y
	9/1/2021	16.75	4.25	0.25	0.99	5y
	10/26/2021	32.5	2.31	0.07	0.45	6m-1y

Notes:

(1) Recurrence intervals based on Atlas 14.

Table A-6 also indicates that multiple storm events had 24-hour recurrence intervals of greater than 1 year. The largest storm event of the period was recorded at Columbus Park Headworks on September 1, 2021, with 5.15 inches of rainfall over 17.25 hours, which equates to a 10-year 24-hour recurrence interval. All gauges recorded over a 5-year 24-hour recurrence interval for this storm suggesting its distribution was relatively uniform across the watershed.

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 A-7). Storms with intensities greater than 0.40 in/hr are of importance because higher intensity storms have been found to produce more CSO activations and volumes than lower intensity storms. The full Typical Year has nine storm events with intensities greater than 0.40 inches per hour. For the four gauges shown in Table A-7, the number of storms with peak intensities greater than 0.40 inches per hour ranged from 11 to 14, with some of the gauges having more than one storm exceeding the Typical Year peak intensity of 1.08 inches per hour. When these storms occur during the summer months, often as thunderstorms, spatial variability of the rainfall becomes a factor. This spatial variability can have an impact on predicting CSO events compared to metered activations at regulators and CSO facilities.

Table A-7. Comparison of Storms Between January 1 and December 31, 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)(1)
Typical Year	10/23/1992	4	1.18	0.29	1.08	2y
	8/11/1992	11	0.87	0.08	0.75	6m-1y
	8/15/1992	72	2.91	0.04	0.66	6m-1y
	9/22/1992	23	2.76	0.12	0.65	6m-1y
	5/2/1992	7	1.14	0.16	0.63	6m
	9/9/1992	1	0.57	0.57	0.57	6m
	9/3/1992	13	1.19	0.09	0.51	3m-6m
	6/5/1992	18	1.34	0.07	0.44	3m
	10/9/1992	65	2.04	0.03	0.42	3m
January-December 2021 Rain Gauge Data						
Ward Street Headworks (BO-DI-1)	6/22/2021	8.25	1.75	0.21	1.23	4y
	7/1/2021	78.5	5.69	0.07	1.23	4y
	7/8/2021	32.75	3.03	0.09	0.91	1y-2y
	7/11/2021	16	1.54	0.10	0.56	3m-6m
	8/4/2021	21	1.56	0.07	0.40	3m
	8/19/2021	5.25	1.31	0.25	0.57	6m
	8/22/2021	16.75	0.83	0.05	0.57	6m
	8/23/2021	8.5	1.53	0.18	0.51	3m-6m
	9/1/2021	17.25	4.62	0.27	1.25	4y
	9/9/2021	33	1.31	0.04	0.47	3m
	10/30/2021	28	1.63	0.06	0.55	3m-6m
Columbus Park Headworks (BO-DI-2)	6/22/2021	6.25	1.09	0.17	0.46	3m
	7/1/2021	77.5	5.83	0.08	0.87	1y
	7/8/2021	33	2.55	0.08	0.76	6m-1y
	7/11/2021	15.5	1.32	0.09	0.61	6m
	8/4/2021	24	2.30	0.10	0.45	3m
	8/9/2021	12	1.03	0.09	0.63	6m
	8/19/2021	5	0.93	0.19	0.42	3m
	8/22/2021	8	0.98	0.12	0.76	6m-1y

Table A-7. Comparison of Storms Between January 1 and December 31, 2021 and the Typical Year with Peak Intensities Greater than 0.40 inches/hour (Continued)

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Hourly Intensity (inch/hour)	Storm Recurrence Interval (1-hour) (1)
Columbus Park Headworks (BO-DI-2)	8/23/2021	11.75	2.03	0.17	1.04	2y
	9/1/2021	17.25	5.15	0.30	1.41	5y
	10/25/2021	64.75	3.91	0.06	0.57	6m
	10/30/2021	27.25	1.54	0.06	0.65	6m-1y
Chelsea Creek Headworks (CH-BO-1)	6/22/2021	6.5	1.70	0.26	1.02	1y-2y
	7/1/2021	17.25	3.96	0.23	1.66	10y
	7/7/2021	10.5	0.58	0.06	0.49	3m-6m
	7/8/2021	30.5	2.49	0.08	0.71	6m-1y
	7/11/2021	17	1.41	0.08	0.58	6m
	8/9/2021	8	1.19	0.15	0.60	6m
	8/19/2021	5	1.56	0.31	0.97	1y-2y
	8/22/2021	8	0.8	0.10	0.59	6m
	8/23/2021	9.25	1.69	0.18	1.01	1y-2y
	9/1/2021	17.75	4.70	0.26	1.24	4y
	9/9/2021	20.75	1.31	0.06	0.56	3m-6m
	9/16/2021	2.75	0.47	0.17	0.40	3m
	10/30/2021	36.75	1.74	0.05	0.64	6m
Fresh Pond (USGS)	7/1/2021	58	5.16	0.09	1.55	8y
	7/8/2021	30.25	2.77	0.09	0.68	6m-1y
	7/11/2021	16	1.05	0.07	0.46	3m
	7/17/2021	25	1.01	0.04	0.49	3m-6m
	7/27/2021	2.75	0.54	0.20	0.49	3m
	8/9/2021	11.5	0.72	0.06	0.41	3m
	8/19/2021	5.5	2.12	0.39	1.02	1y-2y
	8/22/2021	12.75	0.96	0.08	0.59	6m
	8/23/2021	15.25	1.05	0.07	0.45	3m
	9/1/2021	16.75	4.25	0.25	0.99	1y-2y
	9/28/2021	10.75	1.60	0.15	0.48	3m-6m
	10/26/2021	32.5	2.31	0.07	0.45	3m
	10/30/2021	27.5	1.62	0.06	0.67	6m-1y
	11/12/2021	9.25	1.07	0.12	0.48	3m-6m

Notes:

(1) Recurrence intervals based on Atlas 14.

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 show the 15-minute rainfall intensities and show the distribution of rainfall during the storm. Rainfall distribution during a storm can impact the behavior of system hydraulics due to soil saturation.

For example, a storm where the peak rainfall occurs towards the end of the event will generally create more CSO than a storm with similar total rainfall and peak intensity, where the peak occurs at the beginning of the storm. An example hyetograph for the September 1, 2021 at the Ward Street gauge is shown in Figure A-2. This hyetograph is a clear example of the peak of the storm occurring towards the end of the event, which could compound the impact of this major event (4.62 inches total rainfall at the Ward Street gauge) on CSO volumes.

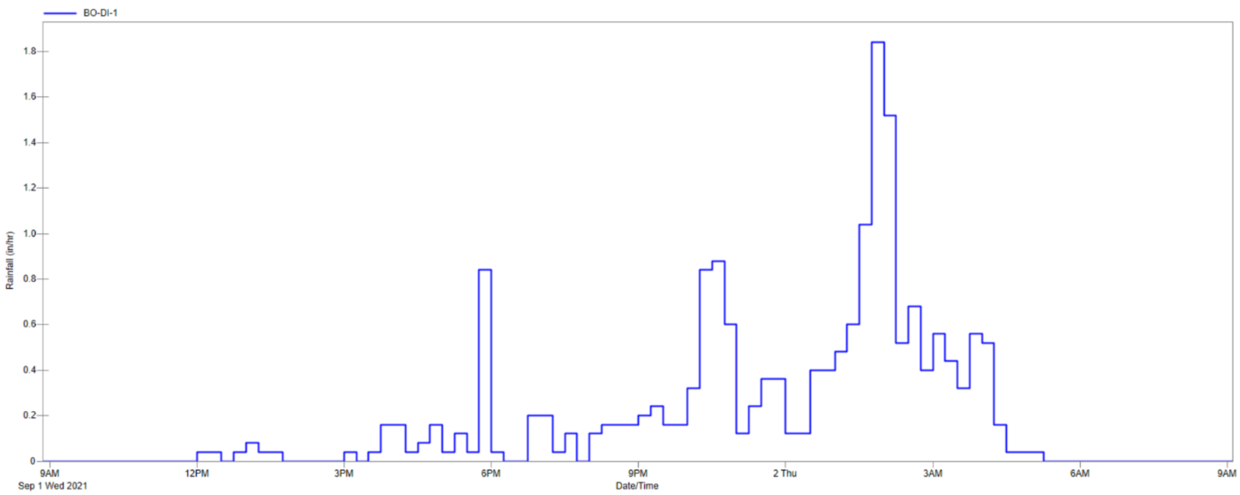

Figure A-4. Hyetograph from the Ward Street Headworks Gauge for September 1, 2021

The following is a summary of the rainfall comparison of January to December 2021 to the Typical Year:

- 2021 averaged 95 storm events with an average annual rainfall depth of 58.10 inches, compared to 93 storm events with an average annual rainfall depth of 46.80 inches for the Typical Year (Table A-5).
- In general, the breakdown of numbers of storms by rainfall depth categories for 2021 were relatively close to the values for the Typical Year, except for storms in the 1-2 inch category, where 2021 averaged 12 versus eight for the Typical Year (Table A-5).
- In terms of larger storms, while the average number of storms with greater than 2 inches of total rainfall across all gauges in 2021 matched the Typical Year (6 storms), each of the gauges listed in Table A-6 had two storms with total rainfall greater than the largest storm in the Typical Year. The largest storm in 2021 for the rain gauges presented in Table A-6 had a 10-year storm recurrence interval for 24-hour duration (5.15 inches of rainfall in 17.25 hours at Columbus Park rain gauge), while the largest storm in the Typical Year had a 1 to 2-year, 24-hour recurrence interval (3.89 inches of rainfall in 50 hours).For the four gauges shown in Table A-7, the number of storms with peak intensities greater than 0.40 inches per hour ranged from eleven to fourteen, compared to nine for the Typical Year. The evaluated gauges had between two and four storms with peak intensity greater than 1.0 inches per hour, with peaks as high as 1.66 inches per hour. In comparison, the Typical Year peak had one storm with intensity of 1.08 inches per hour with the remaining 8 storms having peak intensities between 0.75 and 0.42 inches per hour.

The temporal distribution of the rainfall in 2021 is likely to be an important factor in assessing the impact of rainfall on CSO volumes. The 2.5-month period from July through the middle of September 2021 experienced a high concentration of total rainfall as well as larger individual rainfall events. For example, 24.75 inches of rain fell at the Ward Street Headworks rain gauge in that period, equating to half of the Typical Year total rainfall, and some of the gauges (e.g., Chelsea Creek) had as many as five storms with greater than 2 inches of total rainfall in that period. Statewide, the NRCC declared July 2021 the wettest July on record in Massachusetts with a state-wide rainfall average 6.55 inches above the normal average. The temporal distribution of rainfall within some of the individual large events in 2021 may also be a factor in the resulting CSO volumes. The hyetograph for the September 1, 2021 storm which produced 4.62 inches of total rainfall at the Ward Street gauge shows the peak of the storm occurring towards the end of the event. This timing could compound the impact of this major event on CSO volumes due to the soil becoming saturated immediately prior to the peak of the storm.

In 2021, Metropolitan Boston experienced significantly greater volume of rain, back-to-back large storms, and many storms with relatively high peak intensity. The impact of these many large storms (in terms of total rainfall, as well as peak intensity), is evident in the 2021 vs. Typical Year rainfall comparisons in the rainfall summary tables, and in CSO comparison tables presented in section 2.