MASSACHUSETTS WATER RESOURCES AUTHORITY

Charlestown Navy Yard
100 First Avenue, Building 39
Boston, MA 02129

Frederick A. Laskey
Executive Director

Telephone: (617) 242-6000
Fax: (617) 788-4899
TTY: (617) 788-4971

April 30, 2017

Kevin Brander, P.E.
Section Chief, Municipal Services Section
DEP Northeast Region Office
205B Lowell Street
Wilmington, MA 01887

Todd J. Borci
Office of Environmental Stewardship
US EPA New England
5 Post Office Square
Suite 100 (OES 04-4)
Boston, MA 02109-3912

Subject: CSO Discharge Estimates and Rainfall Analyses for Calendar Year 2016

Dear Mr. Brander and Mr. Borci:

Enclosed please find documentation of the Massachusetts Water Resources Authority's (MWRA) estimates of combined sewer overflow (CSO) discharges in its service area during calendar year 2016. MWRA is required to submit estimates of CSO activations and volumes for the previous calendar year for the Alewife Brook/Upper Mystic River and the Lower Charles River/Charles Basin in accordance with conditions in the Variance Extensions for CSO Discharges to these waters, issued by the Massachusetts Department of Environmental Protection in 2016 pursuant to the Massachusetts Surface Water Quality Standards at 314 CMR 4.00. The Variance Extensions 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 of calendar year 2016 CSO activation frequency, total discharge duration and total discharge volume from the CSO outfalls within its service area addressed in MWRA's approved CSO Long-Term Control Plan (LTCP), including but not limited to the outfalls discharging to the Alewife Brook/Upper Mystic River and the Lower Charles River/ Charles Basin. MWRA has also provided this information to its member communities with CSOs, including BWSC and the cities of Cambridge, Chelsea and Somerville.

Table 10: Summary of 2016 and Typical Year Model Simulation Results and Comparison to Typical Year LTCP

Table 10, attached, presents estimated CSO activations, discharge duration and discharge volume at each CSO outfall during calendar year 2016. For most outfalls, the estimates were developed using the MWRA InfoWorks sewer system model by simulating each of the rainfall events in 2016 with system conditions existing at the time of each storm and with storm-specific system operations. 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 the results of field inspections. Each system change was incorporated into the 2016 rainfall simulations for subsequently occurring storms, and all of the changes were incorporated into the 2016 Typical Year simulation, which represents end-of-year conditions. The most significant model updates for 2016 reflect the following new information. These and other model updates are also briefly listed at the bottom of Table 10.

- BWSC informed MWRA that it permanently closed the overflow at the sole regulator of Outfall BOS072 at Fort Point Channel. Outfall BOS072 is no longer an active CSO.

- MWRA has incorporated the City of Cambridge's updated and calibrated submodel of the (former outfall) CAM004 system, which accurately reflects post Alewife Brook sewer separation conditions, as well as extensive meter data collected by the City in 2016. The model changes result in lower predictions of CSO discharge at certain Alewife Brook outfalls, including outfalls CAM401B and MWR003.

- MWRA continues to work with the City of Chelsea on comparison of the CSO activation data from Chelsea's overflow meters with the CSO discharge predictions of MWRA's hydraulic model, for outfalls CHE004 and CHE008. In early 2016, MWRA installed temporary meters at and upstream of the regulator structures of these two outfalls. Due to lower than normal 2016 rainfall, the amount of MWRA temporary meter data was limited. MWRA data results continue to be different from Chelsea meter results. MWRA continues to questions whether the Chelsea meter data discharges correlate reasonably to rainfall. The CHE008 temporary meter data were available last year to adjust parameters for the CHE008 regulator and its upstream drainage area in the 2015 model, which resulted in the higher Typical Year discharge predictions that were presented in last year's (April 2016) report. The CHE008 data were also used to make adjustments to certain model parameters for CHE004, to the extent that the CHE008 and CHE004 structures and drainage areas have similarities. The 2016 temporary meter data for CHE004 later became available, and further adjustments to the CHE004 model parameters have been made in updating the model to 2016 conditions. These adjustments result in lower Typical Year discharge predictions at CHE004, from 4 activations/0.54 million gallons (MG) predicted by the 2015 model to 1 activation/0.10 MG predicted by the current 2016 model.

Table 5 compares the measured CSO discharges from the City's meter data to MWRA's model predictions at CHE004 and CHE008 for storms in 2016. Among other findings, the measured activations that are not predicted by the model have very small activation durations and discharge volumes.

- For the Cottage Farm CSO facility, the model's influent water level set point that closes the three influent gates as rainfall subsides was raised 1 foot from elevation 94.0 MWRA to elevation 95.0. This is consistent with latest operating protocol. The change results in lowering the volume of overflow that enters the facility, lowering the frequency that the inflows exceed the facility's basin storage volume, and treated discharge volume to the Charles River Basin.

- The model was adjusted in the Outfall BOS003 (East Boston) area based on new information from BWSC. The model's top of weir elevation at regulator RE003-7 was adjusted to match recent field measurement, other physical condition adjustments were made based on field inspections, and the model was recalibrated using meter data collected by BWSC at regulator RE003-12 during late 2015. These changes have the net result of higher model predicted Typical Year overflows at Outfall BOS003.

- The 2016 model incorporates sewer separation completed by BWSC in the Outfall BOS068 area. The work should improve upon already low CSO activations and discharges at the BWSC outfalls along the western edge of Fort Point Channel.

- The 2016 model incorporates additional sewer separation completed by BWSC in areas tributary to outfall BOS004 and BOS005 in East Boston.

At the outfalls associated with MWRA's four CSO treatment facilities, the discharge estimates (activation frequency, duration and volume) presented in Table 10 for calendar year 2016 storms are from recorded measurements at the facilities, not model predictions. These outfalls are MWR201 (Cottage Farm), MWR203 (Prison Point), MWR205 (Somerville-Marginal), and MWR215 (Union Park). The activation frequencies and durations in Table 10 for outfalls SOM007A/MWR205A (Somerville-Marginal high tide relief) and BOS019 are from data generated by MWRA depth sensors at the overflow weirs, but the estimated annual volumes at these two outfalls are from model predictions. The following table compares the recorded CSO measurements to the model predictions for these facilities for the storms in 2016 and for Typical Year rainfall under 2016 system conditions and the approved LTCP.

Comparison of MWRA CSO Discharge Measurements to Model Predictions

Facility	Measured in 2016		Model Predicted					
			2016 Storms		Typical Year/2016		Typical Year/LTCP	
	#	Volume	#	Volume	#	Volume	#	Volume
Cottage Farm	1	13.31	1	9.96	3	10.49	2	6.30
Prison Point	15	147.20	14	178.41	18	286.29	17	243.00
Somerville Marginal*	21	50.99	20	48.62	22	71.68	39	60.58
Union Park	3	8.16	11	17.27	11	32.72	17	71.37
SOM007A/SOM205A	6	NM	5	1.28	3	1.99	3	3.48
BOS019	0	NM	1	0.05	2	0.30	2	0.58

Notes: Volumes are in million gallons. NM = not measured. Typical Year simulations utilize standard operating procedures and do not incorporate earlier opening of influent gates on thunderstorm forecasts.
* All flow through CSO facility to both outfalls MWR205 and SOM007A/MWR205A

Table 10 compares the results of the Typical Year simulation using end-of-year 2016 system conditions to the activation frequencies and annual volumes in the approved Long-Term Control Plan as defined in Exhibit B to the Second Stipulation of the United States and the Massachusetts Water Resources Authority on Responsibility and Legal Liability for Combined Sewer Overflow Control in the Federal District Court Order in the Boston Harbor Case (as amended in May 2008). This comparison allows a tracking of progress towards meeting the long-term control levels.

Rainfall Summary Tables and Rainfall Intensity Comparison Graph

Table 1: Comparison of Frequency of Rain Events within Selected Ranges of Total Rainfall, Typical Year Versus 2016

Table 2: Comparison of Storms with Greater than 2 Inches of Total Rainfall, Typical Year Versus 2016

Table 3: Comparison of Storms with Peak Intensities Greater than 0.40 Inch/Hour, Typical Year Versus 2016

Table 4: Top Ten Storms Contributing the Most CSO (Comparison of Model Predicted CSO Volumes for Storms in 2016 to Storms in the Typical Year)

Figure 1: Rainfall Intensity Comparison: 2016 vs. Typical Year

These rainfall comparisons were developed to be able to explain the magnitude of the estimated CSO discharges caused by 2016 rainfall relative to the model predicted discharges for the Typical Year with 2016 system conditions. These comparisons help to confirm that actual CSO discharges (and their associated impacts) are in line with the predictions that supported regulatory approvals of MWRA's LTCP. They also help to verify progress toward the approved long-term levels of control.

Year 2016 was reported by all sources as a "drought year," characterized by very little rainfall and contributing to moderate to severe drought conditions in Eastern Massachusetts. Table 1 shows that while there were more measured rainfall events in the Boston area in 2016 (approximately 99, varying by gauge location) than in the Typical Year (93), a significantly higher proportions of the rainfall events in 2016 had very low rainfall volumes (<0.25 inch) or low to moderate rainfall volumes (0.25 to 0.50 inch). Table 1 and Table 2 also show significantly fewer large volume rains (>2.0 inches) in 2016 than in the Typical Year. Figure 1 shows that 2016 had fewer high intensity (>0.40 inch/hr) rainfall events than the Typical Year. Among the >0.40 inch/hr storms, presented in Table 3, rainfall durations and peak intensities were generally less in 2016 than in the Typical Year. Table 4 shows that the top ten storms by CSO discharge volume generated far less CSO in 2016 (206.49 million gallons (MG)) than in the Typical Year (357.84 MG).

From these comparisons, 2016 rainfall would be expected to produce significantly lower CSO discharge frequency and volume compared to the Typical Year at all or most outfalls. This is the case, as shown in Table 10. MWRA's estimate of total CSO discharge volume in 2016, 240 MG, is 44 percent less than the total Typical Year CSO discharge volume of 432 MG for the same (2016) system conditions. Both treated and untreated discharge volumes were significantly less through the storms of 2016.

Long-Term Levels of CSO Control

All 35 projects in MWRA's approved LTCP were complete and operational by December 2015. Other, continuing wastewater system improvements by MWRA and the CSO communities have the added benefit of improving upon the level of CSO control. Some of these efforts are mentioned in the bullets describing model changes, on pages 2 and 3, above, including most notably the closing of Outfall BOS072 (Fort Point Channel) by BWSC. All four CSO communities (BWSC, Cambridge, Chelsea and Somerville) continue to complete or pursue sewer separation in combined sewer areas and/or stormwater source controls that lower stormwater inflow to the sewer system. MWRA will continue to update its hydraulic model to reflect the completion of these continuing efforts.

Alewife Brook: As mentioned earlier, MWRA recently updated its sewer system submodel for the CAM004 (Alewife Brook) area, including confirmation of the as-built CAM004 sewer separation improvements and a calibration upgrade using data from the post-construction flow metering conducted by the City of Cambridge. Verification of the post-construction system performance allows MWRA to investigate increasing the hydraulic capacity of the upgraded connection of Somerville's Tannery Brook Conduit to MWRA's Alewife Brook Conduit at Outfall SOM01A, to attempt to lower CSO discharges at this outfall, and making other potential system adjustments. MWRA plans to conduct the investigation and make recommendations this year.

Charles River/Cottage Farm: The City of Cambridge's ongoing, long-term sewer separation work tributary to MWRA's North Charles Met and North Charles Relief sewers is predicted to reduce CSO discharges at outfalls CAM005 and CAM007 and at the Cottage Farm facility.

East Boston: The 2016 Typical Year discharge predictions are higher than LTCP levels at a few of the East Boston outfalls, particularly BOS003 and BOS014. BWSC plans to perform additional sewer separation in East Boston in the coming years. MWRA continues to coordinate with BWSC in investigating the system conditions and potential localized system problems, in part using data from overflow related meters BWSC has installed in parts of the East Boston system.

Prison Point Facility: CSO discharge volume remains higher than the LTCP level at this facility. Overflows to the Prison Point facility are higher since the City of Somerville lowered the weir elevation at the SOM009 regulator following the extreme storm of July 10, 2010 that had caused serious flooding in Union Square. MWRA is coordinating with the City of Somerville on the City's stormwater control studies and evaluations toward long-term recommendations for the configuration of the SOM009 regulator.

Reserved Channel: BWSC attained substantial completion of the Reserved Channel Sewer Separation project in December 2015, in compliance with Schedule Seven. With the removal of large quantities of stormwater from the tributary sewer system now complete, BWSC is evaluating overflow weir adjustments to minimize CSO to the Reserved Channel while protecting upstream systems. In April 2017, BWSC raised the overflow weir in the sole remaining regulator associated with Outfall BOS080. MWRA has incorporated the new weir elevation into its hydraulic model, for future simulations.

Should you have questions about MWRA's CSO discharge estimates for 2016 and Typical Year comparisons, please feel free to contact me, at 617-788-4359.

Very truly yours,

Michael J. Hornbrook
Chief Operating Officer

Attachments: Table 10: Summary of 2016 and Typical Year Model Simulations Results and Comparison to Typical Year Long Term CSPO Control Plan
Table 5: Reported 2016 CSO Activations by City of Chelsea vs. Model Predictions
Table 1: Comparison of Frequency of Rain Events within Selected Ranges of Total Rainfall, Typical Year Versus 2016
Table 2: Comparison of Storms with Greater than 2 Inches of Total Rainfall, Typical Year Versus 2016
Table 3: Comparison of Storms with Peak Intensities Greater than 0.40 Inch/Hour, Typical Year Versus 2016
Table 4: Top Ten Storms Contributing the Most CSO (Comparison of Model Predicted CSO Volumes for Storms in 2016 to Storms in the Typical Year)
Figure 1: Rainfall Intensity Comparison: 2016 vs. Typical Year

CSO File: 1000.21

TABLE 10. SUMMARY OF 2016 AND TYPICAL YEAR MODEL SIMULATION RESULTS, AND COMPARISON TO TYPICAL YEAR LONG TERM CSO CONTROL PLAN

	2016 RAINFALL UNDER 2016 SYSTEM CONDITIONS			TYPICAL-YEAR RAINFALL UNDER 2016 SYSTEM CONDITIONS		TYPICAL-YEAR RAINFALL W/ LONG TERM CSO CONTROL PLAN	
Outfall	**Activation Frequency**	**Duration (hrs)**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**
ALEWIFE BROOK							
CAM001	0	0.00	0.00	1	0.03	5	0.19
CAM002	1	0.71	0.03	1	0.22	4	0.69
MWR003	1	0.96	0.06	2	0.48	5	0.98
CAM004	Closed	N/A	N/A	Closed	N/A	Closed	N/A
CAM400	Closed	N/A	N/A	Closed	N/A	Closed	N/A
CAM401A	1	0.97	0.08	2	0.49	5	1.61
CAM401B	1	0.96	0.05	2	0.21	7	2.15
SOM001A	1	1.49	1.08	5	4.00	3	1.67
SOM001	Closed	N/A	N/A	Closed	N/A	Closed	N/A
SOM002A	Closed	N/A	N/A	Closed	N/A	Closed	N/A
SOM003	Closed	N/A	N/A	Closed	N/A	Closed	N/A
SOM004	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**5.09**	**1.30**		**5.43**		**7.29**
UPPER MYSTIC RIVER							
SOM007A/MWR205A [1]	6	6.03	1.28	3	1.99	3	3.48
SOM007	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**6.03**	**1.28**		**1.99**		**3.48**
MYSTIC/CHELSEA CONFLUENCE							
MWR205 (Somerville Marginal Facility) [2]	21	58.75	50.99	22	71.68	39	60.58
BOS013	2	1.88	0.07	4	0.13	4	0.54
BOS014	2	2.17	0.34	4	0.45	0	0.00
BOS015	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS017	1	0.67	0.02	0	0.00	1	0.02
CHE002	0	0.00	0.00	0	0.00	4	0.22
CHE003	0	0.00	0.00	0	0.00	3	0.04
CHE004	2	1.60	0.09	1	0.10	3	0.32
CHE008	6	9.45	1.22	7	1.83	0	0.00
TOTAL		**74.51**	**52.74**		**74.19**		**61.72**
UPPER INNER HARBOR							
BOS009	1	1.39	0.10	3	0.10	5	0.59
BOS010	1	1.71	0.19	6	0.46	4	0.72
BOS012	2	2.39	0.22	7	0.55	5	0.72
BOS019 [3]	0	0.00	0.00	2	0.30	2	0.58
BOS050	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS052	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS057	1	1.24	0.83	2	0.57	1	0.43
BOS058	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS060	1	0.71	0.03	1	0.02	0	0.00
MWR203 (Prison Point) [4]	15	48.80	147.20	18	286.29	17	243.00
TOTAL		**56.25**	**148.57**		**288.27**		**246.04**
LOWER INNER HARBOR							
BOS003	16	27.37	7.23	18	11.80	4	2.87
BOS004	1	1.94	0.15	5	0.28	5	1.84
BOS005	0	0.00	0.00	0	0.00	1	0.01
BOS006 [5]	Closed	N/A	N/A	Closed	N/A	4	0.24
BOS007 [5]	Closed	N/A	N/A	Closed	N/A	6	1.05
TOTAL		**29.30**	**7.38**		**12.08**		**6.01**

TABLE 10. SUMMARY OF 2016 AND TYPICAL YEAR MODEL SIMULATION RESULTS, AND COMPARISON TO TYPICAL YEAR LONG TERM CSO CONTROL PLAN

	2016 RAINFALL UNDER 2016 SYSTEM CONDITIONS			TYPICAL-YEAR RAINFALL UNDER 2016 SYSTEM CONDITIONS		TYPICAL-YEAR RAINFALL W/ LONG TERM CSO CONTROL PLAN	
Outfall	**Activation Frequency**	**Duration (hrs)**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**
CONSTITUTION BEACH							
MWR207	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**N/A**	**N/A**		**N/A**		**N/A**
FORT POINT CHANNEL							
BOS062	0	0.00	0.00	0	0.00	1	0.01
BOS064	0	0.00	0.00	0	0.00	0	0.00
BOS065	1	0.75	0.12	1	0.52	1	0.06
BOS068	0	0.00	0.00	0	0.00	0	0.00
BOS070							
BOS070/DBC	1	0.73	0.15	4	2.99	3	2.19
MWR215 (Union Park) [4]	3	7.97	8.16	11	32.72	17	71.37
BOS070/RCC	2	2.22	0.40	6	0.87	2	0.26
BOS072	Closed	N/A	N/A	Closed	N/A	0	0.00
BOS073	0	0.00	0.00	0	0.00	0	0.00
TOTAL		**11.67**	**8.82**		**37.10**		**73.89**
RESERVED CHANNEL							
BOS076	2	1.26	0.07	6	1.16	3	0.91
BOS078	0	0.00	0.00	0	0.00	3	0.28
BOS079	0	0.00	0.00	0	0.00	1	0.04
BOS080	2	1.70	0.02	7	0.24	3	0.25
TOTAL		**2.96**	**0.09**		**1.41**		**1.48**
NORTHERN DORCHESTER BAY							
BOS081	0	0.00	0.00	0	0.00	0 / 25 year	N/A
BOS082	0	0.00	0.00	0	0.00	0 / 25 year	N/A
BOS083 [6]	Closed	N/A	N/A	Closed	N/A	0 / 25 year	N/A
BOS084	0	0.00	0.00	0	0.00	0 / 25 year	N/A
BOS085	0	0.00	0.00	0	0.00	0 / 25 year	N/A
BOS086	0	0.00	0.00	0	0.00	0 / 25 year	N/A
BOS087	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**0.00**	**0.00**		**0.00**		**0.00**
SOUTHERN DORCHESTER BAY							
BOS088/BOS089 (Fox Point)	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS090 (Commercial Point)	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**N/A**	**N/A**		**N/A**		**N/A**
UPPER CHARLES							
BOS032	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS033	Closed	N/A	N/A	Closed	N/A	Closed	N/A
CAM005	1	1.25	0.54	3	1.36	3	0.84
CAM007	1	1.23	0.34	2	0.26	1	0.03
CAM009 [7]	Closed	N/A	N/A	Closed	N/A	2	0.01
CAM011 [7]	Closed	N/A	N/A	Closed	N/A	0	0.00
TOTAL		**2.47**	**0.88**		**1.62**		**0.88**

TABLE 10. SUMMARY OF 2016 AND TYPICAL YEAR MODEL SIMULATION RESULTS, AND COMPARISON TO TYPICAL YEAR LONG TERM CSO CONTROL PLAN

	2016 RAINFALL UNDER 2016 SYSTEM CONDITIONS			TYPICAL-YEAR RAINFALL UNDER 2016 SYSTEM CONDITIONS		TYPICAL-YEAR RAINFALL W/ LONG TERM CSO CONTROL PLAN	
Outfall	**Activation Frequency**	**Duration (hrs)**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**	**Activation Frequency**	**Volume (MG)**
LOWER CHARLES							
BOS028	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS042	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS049	Closed	N/A	N/A	Closed	N/A	Closed	N/A
CAM017	1	1.25	3.44	1	1.32	1	0.45
MWR010	0	0.00	0.00	0	0.00	0	0.00
MWR018	1	1.99	2.80	0	0.00	0	0.00
MWR019	1	0.99	0.29	0	0.00	0	0.00
MWR020	1	0.47	0.02	0	0.00	0	0.00
MWR021	Closed	N/A	N/A	Closed	N/A	Closed	N/A
MWR022	Closed	N/A	N/A	Closed	N/A	Closed	N/A
MWR201 (Cottage Farm) [4]	1	2.58	13.31	3	10.49	2	6.30
MWR023	1	5.22	0.53	1	0.02	2	0.13
SOM010	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**12.50**	**20.38**		**11.82**		**6.88**
NEPONSET RIVER							
BOS093	Closed	N/A	N/A	Closed	N/A	Closed	N/A
BOS095	Closed	N/A	N/A	Closed	N/A	Closed	N/A
TOTAL		**N/A**	**N/A**		**N/A**		**N/A**
BACK BAY FENS							
BOS046 [8]	1	5.61	21.48	1	1.56	2	5.38
TOTAL		**5.61**	**21.48**		**1.56**		**5.38**
Total Treated			**220**		**401**		**381**
Total Untreated			**21**		**31**		**23**
GRAND TOTAL			**240**		**432**		**404**

(1) Includes portion of flow treated at Somerville Marginal facility and separate stormwater entering the Somerville Marginal Conduit (outfall) downstream of the facility. Activation frequency and volume for 2015 rainfall are from MWRA depth sensor measurements and MWRA model results, respectively.

(2) Volume represents all flow through the CSO treatment facility. Activation frequency and volume for 2015 rainfall are from MWRA facility records (measurements).

(3) Activation frequency and volume for 2015 rainfall are from MWRA depth sensor measurements and MWRA model results, respectively.

(4) Activation frequency and volume for 2015 rainfall are from MWRA facility records (measurements).

(5) BWSC has permanently closed outfalls BOS006 and BOS007 in East Boston as part of sewer separation and development plans in the tributary areas, although the outfalls were assumed to remain active in the long-term CSO control plan.

(6) CSO discharge at Outfall BOS083 was redirected to Outfall BOS084 as part of the construction of the North Dorchester Bay Storage Tunnel.

(7) The City of Cambridge closed outfalls CAM009 and CAM011 in November 2007, and continues to monitor upstream hydraulic effects.

(8) Volumes represent model predicted total discharge at outfall BOS046, including Stony Brook Conduit stormwater and CSO contributions.

Key 2016 Model Updates

Incorporated Cambridge's calibrated CAM004 submodel. The CAM004 tributary area was calibrated using Cambridge CAM004 post-sewer separation flow monitoring data.

Incorporated BWSC BOS068 sewer separation.

Incorporated BWSC BOS072 CSO regulator closure.

Calibrated BWSC BOS003, regulator RE003-12 tributary area and dry weather flow connection friction loss coefficient using BWSC metering data.

Adjusted weir elevation using BWSC field measurements at outfall BOS003, regulator RE003-7.

Calibrated Chelsea CHE004 tributary area and regulator structure minor loss coefficient using Chelsea's temporary metering data.

Table 5: Reported 2016 CSO Activations by City of Chelsea vs. Model Predictions

Date	MWRA CCHW Rain Gauge				Reported CSO Activation @Outfall CHE004		Model Predicted CSO Activation @Outfall CHE004		Reported CSO Activation @Outfall CHE008		Model Predicted CSO Activation @Outfall CHE008	
	Rainfall (inches)	Duration (hr)	Average Intensity (inches.hr)	Peak Intensity (inches/hr)	Discharge Volume (MG)	Activation Duration (hrs)	Discharge Volume (MG)	Activation Duration (hrs)	Discharge Volume (MG)	Activation Duration (hrs)	Discharge Volume (MG)	Activation Duration (hrs)
2/24/2016	1.22	43.00	0.03	0.42	0.067	0.25			0.073	0.75		
4/7/2016	0.95	8.75	0.11	0.26					0.002	0.17		
4/14/2016	0.78	0.25	3.12	0.78			0.01	0.45			0.16	1.22
5/24/2016	0.53	4.00	0.13	0.44	0.006	0.08						
5/30/2016	1.28	10.25	0.12	0.55					0.049	1.42	0.06	1.13
6/5/2016	0.92	12.50	0.07	0.28					0.026	0.42		
7/9/2016	0.43	7.25	0.06	0.36	0.010	0.08			0.082	0.33		
8/13/2016	0.50	10.50	0.05	0.39	0.004	0.08			0.075	0.25		
8/22/2016	1.00	4.00	0.25	0.43					0.005	0.08	0.08	1.19
9/23/2016	0.46	1.50	0.31	0.43					0.004	0.08		
10/20/2016	1.73	43.25	0.04	1.08	0.620	1.00	0.08	1.15	0.598	1.33	0.72	2.41
11/15/2016	1.27	14.00	0.09	0.41					0.003	0.08	0.14	2.41
12/29/2016	1.10	7.75	0.14	0.41					0.125	0.58	0.05	1.09
Total Volume (MG)					**0.71**	**1.50**	**0.09**	**1.60**	**1.04**	**5.50**	**1.21**	**9.45**
# of Activations					**5**		**2**		**11**		**6**	
# of Activations with volume less than 0.1 MG					**4**		**2**		**9**		**3**	
# of Activations with volume greater than 0.1 MG					**1**		**0**		**2**		**3**	

RAINFALL CHARACTERISTICS

TABLE 1. COMPARISON OF FREQUENCY OF RAIN EVENTS WITHIN SELECTED RANGES OF TOTAL RAINFALL, TYPICAL YEAR VERSUS 2016

Conditions	Total Rainfall (inches)	Total Number of Storms	Number of Storms by Volume				
			Volume < 0.25 inches	Volume 0.25 to 0.5 inches	Volume 0.5 to 1.0 inches	Volume 1.0 to 2.0 inches	Volume >= 2.0 inches
Typical Year	46.8	93	49	14	16	8	6
MWRA Rain Gauges							
Ward Street	37.42	99	59	16	11	12	1
Columbus Park	35.67	102	60	21	9	11	1
Chelsea Creek	36.97	104	63	16	13	12	0
HF-1C	36.14	102	63	14	13	11	1
RG-WF-1	31.46	101	64	18	9	10	0
BWSC Rain Gauges							
Allston	32.86	91	54	15	10	12	0
Dorchester - Adam Street	32.67	96	58	18	8	12	0
Charlestown	33.24	95	54	21	8	12	0
Roslindale	36.24	96	53	19	12	11	1
Union Park	33.81	95	56	21	6	12	0
USGS Rain Gauge							
Fresh Pond	31.64	105	66	17	13	9	0

TABLE 2. COMPARISON OF STORMS WITH GREATER THAN 2 INCHES OF TOTAL RAINFALL, TYPICAL YEAR VERSUS 2016

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Intensity (inch/hour)	Storm Recurrence Interval (24-hour)
Typical Year	12/11/1992	50	3.89	0.08	0.20	1y
	8/15/1992	72	2.91	0.04	0.66	3m
	9/22/1992	23	2.76	0.12	0.65	1y
	11/21/1992	84	2.39	0.03	0.31	3m
	5/31/1992	30	2.24	0.07	0.37	3m-6m
	10/9/1992	65	2.04	0.03	0.42	<3m
Ward Street Headworks (BO-DI-1)	10/21/2016	23.5	2.34	0.10	1.55	6m
Columbus Park Headworks (BO-DI-2)	10/9/2016	18.75	2.07	0.11	0.23	3m-6m
Chelsea Creek Headworks (CH-BO-1)	No storm with greater than 2 inches of total rainfall was recorded.					
Fresh Pond (from USGS)	No storm with greater than 2 inches of total rainfall was recorded.					

TABLE 3. COMPARISON OF STORMS WITH PEAK INTENSITIES GREATER THAN 0.40 INCHES/HOUR, TYPICAL YEAR VERSUS 2016

Rain Gauge	Date	Duration (hours)	Total Rainfall (inches)	Average Intensity (inch/hour)	Peak Intensity (inch/hour)	Storm Recurrence Interval (1-hour)
Typical Year	10/23/1992	4	1.18	0.29	1.08	1-2y
	8/11/1992	11	0.87	0.08	0.75	6m-1y
	8/15/1992	72	2.91	0.04	0.66	3m-6m
	9/22/1992	23	2.76	0.12	0.65	3m-6m
	5/2/1992	7	1.14	0.16	0.63	3m-6m
	9/9/1992	1	0.57	0.57	0.57	3m
	9/3/1992	13	1.19	0.09	0.51	< 3m
	6/5/1992	18	1.34	0.07	0.44	< 3m
	10/9/1992	65	2.04	0.03	0.42	< 3m
Ward Street Headworks (BO-DI-1)	10/21/2016	23.50	2.34	0.10	1.55	5y
	7/14/2016	1.00	0.85	0.85	0.85	6m-1y
	5/30/2016	10.25	1.32	0.13	0.55	< 3m
	6/13/2016	0.25	0.54	2.16	0.54	< 3m
	3/10/2016	21.50	0.99	0.05	0.47	< 3m
	11/15/2016	13.75	1.38	0.10	0.46	< 3m
	1/10/2016	15.00	1.42	0.09	0.43	< 3m
	8/22/2016	3.50	0.79	0.23	0.41	< 3m
Columbus Park Headworks (BO-DI-2)	10/21/2016	20.25	1.75	0.09	1.15	1y-2y
	2/24/2016	28.50	1.38	0.05	0.62	3m-6m
	5/30/2016	10.00	1.36	0.14	0.55	< 3m
	8/22/2016	3.75	0.93	0.25	0.45	< 3m
	11/15/2016	14.00	1.43	0.10	0.41	< 3m
Chelsea Creek Headworks (CH-BO-1)	10/20/2016	43.25	1.73	0.04	1.08	1y-2y
	4/14/2016	0.25	0.78	3.12	0.78	6m-1y
	5/30/2016	10.25	1.28	0.12	0.55	< 3m
	5/24/2016	4.00	0.53	0.13	0.44	< 3m
	8/22/2016	4.00	1.00	0.25	0.43	< 3m
	9/23/2016	1.50	0.46	0.31	0.43	< 3m
	2/24/2016	43.00	1.22	0.03	0.42	< 3m
	11/15/2016	14.00	1.27	0.09	0.41	< 3m
	12/29/2016	7.75	1.10	0.14	0.41	< 3m
Fresh Pond (from USGS)	10/21/2016	6.25	1.26	0.20	0.84	6m-1y
	1/10/2016	10.75	1.52	0.14	0.49	< 3m
	6/17/2016	0.50	0.44	0.88	0.44	< 3m

Table 4. Top Ten Storms Contributing the Most CSO

For 2016 Storms:

No.	Storm Event	CSO Volume By Storm		Cumulative CSO Volume	
		(MG)	% of Total CSO Discharged in 2016 (240 MG)	(MG)	% of Total CSO Discharged in 2016 (240 MG)
1	10/21/2016 Storm	65.26	27.2%	65.26	27.2%
2	1/10/2016 Storm	30.10	12.5%	95.36	39.7%
3	4/7/2016 Storm	27.14	11.3%	122.50	51.0%
4	11/15/2016 Storm	23.42	9.7%	145.91	60.7%
5	5/30/2016 Storm	15.30	6.4%	161.21	67.1%
6	12/29/2016 Storm	11.95	5.0%	173.16	72.1%
7	1/16/2016 Storm	10.77	4.5%	183.93	76.6%
8	2/16/2016 Storm	8.41	3.5%	192.34	80.1%
9	10/9/2016 Storm	7.17	3.0%	199.51	83.1%
10	6/5/2016 Storm	6.98	2.9%	206.49	86.0%

For the Typical Year Rainfall:

No.	Storm Event	CSO Volume By Storm		Cumulative CSO Volume	
		(MG)	% of Total CSO Discharged in Typical Year (432 MG)	(MG)	% of Total CSO Discharged in Typical Year (432 MG)
1	9/23/1992 Storm	79.03	18.3%	79.03	18.3%
2	12/11/1992 Storm	54.92	12.7%	133.95	31.0%
3	6/1/1992 Storm	46.64	10.8%	180.59	41.8%
4	10/23/1992 Storm	42.21	9.8%	222.80	51.6%
5	8/16/1992 Storm	35.89	8.3%	258.69	59.9%
6	11/23/1992 Storm	22.64	5.2%	281.33	65.1%
7	5/2/1992 Storm	21.63	5.0%	302.96	70.1%
8	8/11/1992 Storm	20.31	4.7%	323.27	74.8%
9	3/7/1992 Storm	18.64	4.3%	341.90	79.2%
10	6/6/1992 Storm	15.94	3.7%	357.84	82.8%

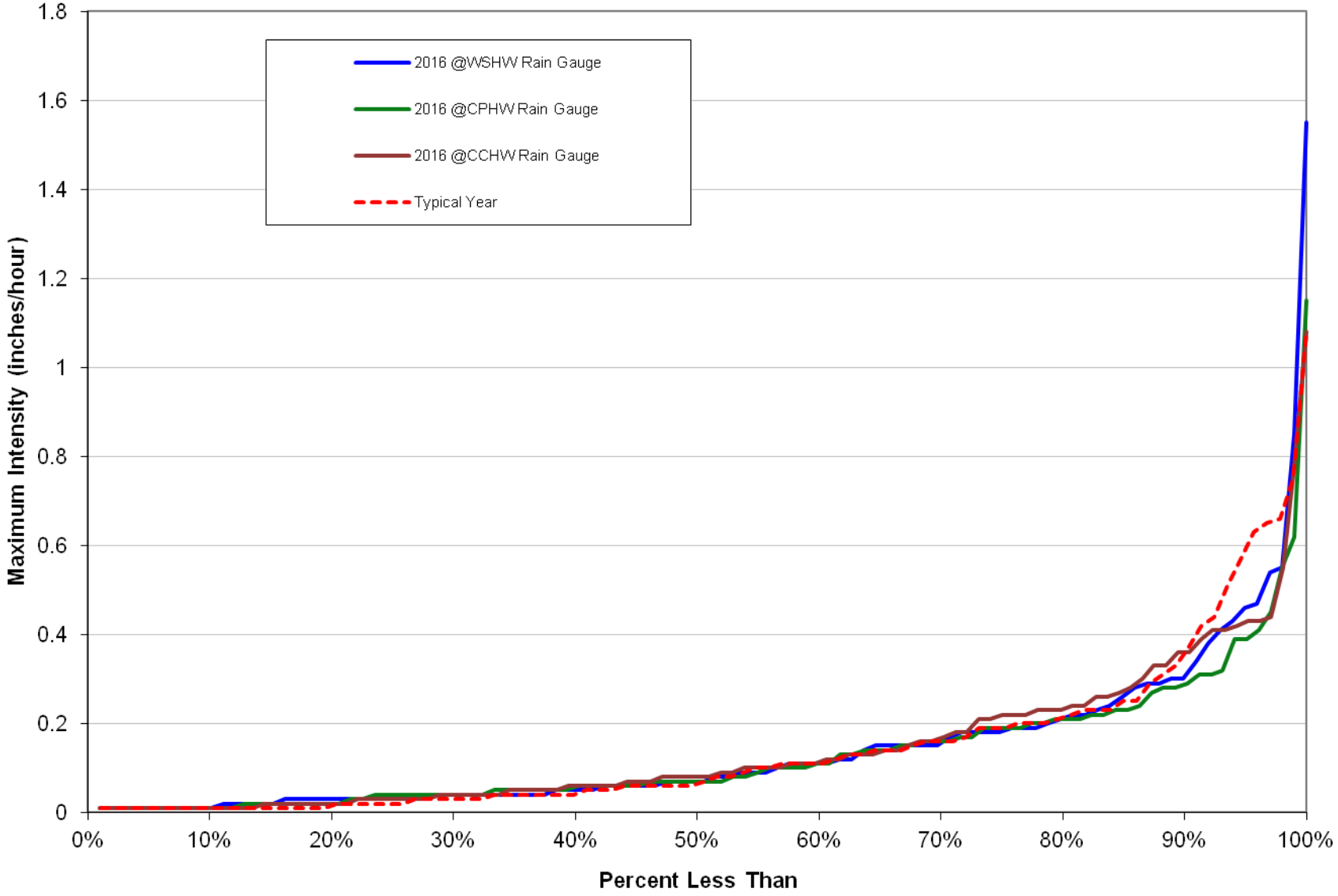

FIGURE 1. RAINFALL INTENSITY COMPARISON: 2016 VS. TYPICAL YEAR