Task 5.3 Water Quality Assessment

CSO Post Construction Monitoring and Performance Assessment – Revision 1

MWRA Contract No. 7572

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* *The numbers for Alewife Brook and Upper Mystic River have been updated in Tables 4-6, 4-7, 4-8, 5-1 and associated text was updated. The numbers were updated because during the evaluation of alternatives it was identified that a portion of the Alewife Brook was configured in the model to be wider than field conditions to simulate a flood plain. Since the application of this model is to evaluate Typical Year storms, the width was adjusted to more closely match field conditions. This change had only a small impact to the model results and did not change any of the conclusions. Also, for the Boundaries Only in the Mystic the percent compliance changed from 89% to 91% when only the points downstream of monitoring station 083 are considered. The points upstream of station 083 were considered to be beyond the upstream calibrated boundary of the model.*

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1. Introduction

1.1 Background

In the mid-1980s when the Massachusetts State Legislature created the Massachusetts Water Resources Authority (MWRA), the Boston area had the dubious reputation of having the dirtiest harbor in America. The urban beaches were frequently closed for days, even after the most modest of rain events. Residents living along the waterfront often had to close their windows because of the foul smell of the harbor. The situation was a national embarrassment for the region.

Combined sewer systems in five of the Boston area communities were a major contributor to these problems. More than 80 outfalls discharged a mixture of stormwater and sanitary sewage (called Combined Sewer Overflows, or CSO) to the nearest water body when storm-related flows exceeded the capacity of the MWRA and community sewer systems to transport flows to the Deer Island Treatment Plant for treatment. In the late 1980s it is estimated that over three billion gallons of untreated CSO were discharged annually into Boston Harbor and the Neponset, Mystic, and Charles River watersheds.

Today, the results of MWRA's and the CSO communities' efforts are an irrefutable success. In 2019, the water quality of the Charles River Lower Basin was rated as "B" and the freshwater reach of the Mystic River was rated "A minus". In fact, swimming races are held in the Charles River and efforts are afoot to reopen a bathing beach. The greater harbor has rejuvenated itself and is swimmable, even during rain events. The Boston area beaches are now considered the cleanest urban beaches in the country. It is truly an environmental success story, and the CSO program has played a critical role.

MWRA's CSO performance assessment is the last scheduled milestone in the nearly 35-year-old Federal District Court Order in the Boston Harbor Case (U.S. v. M.D.C., et al, No. 85-0489 MA). MWRA addressed 183 CSO-related court schedule milestones, including completion of the thirty-five (35) wastewater system projects that comprise the Long-Term Control Plan (LTCP) by December 2015 and commenced the CSO performance assessment in November 2017. The last court milestone requires MWRA to submit the results of its performance assessment to the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP) by December 2021.

The performance assessment, which is also required by the Water Quality Standards Variances currently in place for the Lower Charles River and the Alewife Brook/Upper Mystic River, will demonstrate whether the goals of the CSO LTCP have been 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.

Consistent with the relevant EPA guidance documents (EPA 1999, EPA 2012), MWRA has conducted an extensive flow metering and collection system hydraulic model calibration effort to improve the MWRA's collection system hydraulic model's estimates of CSO discharges and update the assessment of Typical Year CSO performance and the level of attainment of the LTCP activation and volume goals. The LTCP performance objectives are based on an annual series of rainfall events that represent a "Typical Year" based on a 40-year rainfall record (see Section 2). MWRA has documented this ongoing performance assessment effort in Semiannual progress reports from (November 2018 through October 2020, and will continue to produce semiannual reports until October 2021.

In addition to the collection system hydraulic model, hydrodynamic and water quality models of the Lower Charles River/Charles Basin and the Alewife Brook/Upper Mystic River have been developed and calibrated to support the performance assessment for the CSO variance waters. These models are intended to assess the benefits to bacterial water quality in these receiving waters resulting from the improvements made by implementing the MWRA CSO Long Term Control Plan over the last 30 years, as well as the remaining impacts of CSO and non-CSO bacteria sources. The assessments focus on bacteria as the Charles River and Alewife Brook/Upper Mystic River are listed as impaired for *E. coli* in the most recent Massachusetts Section 303(d) list of waterbodies that are not expected to meet surface water quality standards after the implementation of technology-based controls (MADEP 2019).

These water quality models are intended to:

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

This Water Quality Assessment Report presents the results of the water quality modeling evaluations for the Charles River and Alewife Brook/Upper Mystic River for the Typical Year rainfall under 2019 collection system and CSO performance conditions (see Semiannual CSO Discharge Report No. 4, April 30, 2020, for further details on 2019 system conditions). The report provides a snapshot of where these waterbodies stand in terms of attainment of numeric water quality standards for *E. coli and Enterococcus,* with emphasis on *E. coli*, as appropriate for freshwater bodies, and the relative contributions of the various loading sources to the bacteria counts in the water bodies.

1.2 CSO Control Program Accomplishments

As part of its 30-plus year CSO Control Program, MWRA has:

- Eliminated dry weather overflows, and greatly reduced CSO discharges system-wide by improving the capacity and reliability of the transport and pumping systems that convey flows to the Deer Island Treatment Plant (1987-91);
- Developed and implemented more than 100 system optimization improvements (e.g., raising overflow weirs) that reduced average annual CSO discharge volume by nearly 25% (1992-96);
- Developed the Long-Term CSO Control Plan (1992-97);
- Reassessed and refined several CSO projects recommended in the 1997 plan, including adding several CSO projects to increase the level of control for the Charles River (2001-06);
- Designed and constructed the 35 CSO projects in MWRA approved LTCP in compliance with more than 100 federal court schedule milestones (1996-2015);
- Implemented additional system optimization strategies that further reduced CSO discharges. Some of these strategies included enhancements to the operational protocols for the Cottage Farm, Prison Point and Somerville Marginal CSO treatment facilities (2007-08);
- Continued to conduct on-going system optimization reviews and to implement optimization measures.

These efforts contributed to the following CSO control accomplishments:

- Permanent closure of 35 of the 84 CSO outfalls that were active in the late 1980s;
- Elimination of CSOs to South Dorchester Bay, the Neponset River, and Constitution Beach through sewer separation;
- Effective elimination (i.e., up to a 25-year storm) of CSOs along the South Boston beaches in North Dorchester Bay and capture of separate stormwater discharges in up to the 5-year storm by the South Boston CSO Storage Conduit; this project also included re-routing of stormwater outfalls away from Pleasure Bay in South Boston;
- Decommissioning of three CSO treatment facilities (CSO elimination); treatment and reliability upgrades to three other CSO facilities; and construction of the Union Park Detention/Treatment Facility;
- Reduction of CSO to the Little Mystic Channel in Charlestown with the BOS019 Storage Conduit;
- Reduction of CSO to Alewife Brook through a major sewer separation program that included a constructed wetland for stormwater detention and treatment and habitat restoration;
- Interceptor sewer upgrade projects that reduced CSOs to the Upper and Lower Inner Harbor and Mystic/Chelsea Confluence, including Chelsea Creek;
- Reduction of CSOs to the Charles River and to the Reserved Channel through major sewer separation projects in the Stony Brook system and in South Boston, respectively; and
- Multiple smaller-scale projects targeting specific CSOs throughout the system.

MWRA has invested over $900 million through its Capital Improvement Program (CIP) to control CSO discharges. This includes past planning, MWRA project design and construction, financial assistance to communities to design and construct LTCP projects that result in facilities the communities own and operate, and the ongoing CSO performance assessment. MWRA's investment has resulted in significant reductions in CSO and corresponding improvements in water quality over the years.

From major, early improvements to MWRA's Deer Island transport and treatment systems in the period 1988 through 1992, Typical Year CSO discharge dropped from approximately 3.3 billion gallons to 1.5 billion gallons system-wide, with approximately 51% of the remaining discharge treated at five MWRA CSO screening and disinfection facilities that were in operation at that time[1]. The Charles River especially benefited from these early system improvements. As of mid-2020 conditions, annual CSO discharges based on the Typical Year rainfall have been further reduced to 426 million gallons, of which 90 percent is treated at one of MWRA's CSO treatment facilities. MWRA's environmental monitoring documents the benefits of this significant achievement in CSO control. Improvements in the public perception of regional water quality is evident in the renewed focus on water-centric activities and development along Boston Harbor and its tributary waters.

MWRA is currently evaluating additional control measures that may further reduce CSO volumes and activations. In addition, as part of the CSO variance conditions, MWRA is obligated to investigate whether further system optimization measures could result in improved performance, even where the CSOs may meet the frequency and volume goals of the Second Stipulation. A subsequent report will present evaluations of whether further investments in CSO mitigation would result in meaningful water

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

quality improvements or whether emphasis on non-CSO contributions of pollution would be more cost-effective and impactful to water quality. Regulatory options going forward must acknowledge that even though a LTCP has been completed consistent with court-ordered requirements, state water quality standards may not be met as a result of stormwater or other non-CSO contributions, regardless of whether CSO discharges meet the LTCP volume and activation goals.

1.3 Report Organization

The remainder of this report is organized into the following sections:

- Section 2 Water Quality Assessment Methods:
  - Reviews the methodology used in the LTCP for estimating the annual percent compliance with water quality criteria based on compliance for the 3-month and 1-year storms
  - Summarizes the current Massachusetts Surface Water Quality Standards for bacteria
  - Provides an overview of the Typical Year and Design Storm rainfall used as a basis for conducting the evaluations
  - Summarizes the basis for establishing bacteria counts in the various sources of bacteria loading used for the water quality modeling
  - Presents the methodology used for the current water quality modeling to compute annual percent compliance with water quality criteria
- Section 3 Charles River:
  - Presents an overview of the Charles River water quality model
  - Presents annual CSO activations and volumes by storm and by outfall for the Typical Year
  - Presents bacteria loads for the Typical Year, and 1-year and 3-month design storms, broken down by source (sanitary component of CSO, stormwater component of CSO, stormwater, dry weather sources, boundary sources), along with the volume of flow associated with those loads
  - Presents figures and tables summarizing the attainment with water quality criteria under 2019 conditions for all sources, and for component sources (CSO only, non-CSO only, stormwater only, dry weather sources only, boundary sources only)
  - Presents figures and tables summarizing sensitivity analyses of the impacts of higher CSO loadings, and lower stormwater and boundary loadings, on attainment of the water quality criteria
- Section 4 Alewife Brook/Upper Mystic River:
  - Presents an overview of the Alewife Brook/Upper Mystic River water quality model
  - Presents annual CSO activations and volumes by storm and by outfall for the Typical Year
  - Presents bacteria loads for the Typical Year, and 1-year and 3-month design storms, broken down by source (sanitary component of CSO, stormwater component of CSO, stormwater, dry weather sources, boundary sources), along with the volume of flow associated with those loads
  - Presents figures and tables summarizing the attainment with water quality criteria under 2019 conditions for all sources, and for component sources (CSO only, non-CSO only, stormwater only, dry weather sources only, boundary sources only)

- Presents figures and tables summarizing sensitivity analyses of the impacts of higher CSO loadings, and lower stormwater and boundary loadings, on attainment of the water quality criteria

- Section 5 Summary and Next Steps

2. Water Quality Assessment Methods

2.1 Review of Water Quality Goals from Previous Planning Documents

The level of attainment with water quality criteria projected to be achieved following implementation of the LTCP was first presented in the *1997 CSO Facilities Plan and Environmental Impact Report* (the "1997 FP/EIR; Metcalf & Eddy, 1997). At that time, the bacterial water quality standards were based on fecal coliform, with the Class B criteria based on requiring a geometric mean of 200 colonies/100mL, and a 90th percentile limit of 400 colonies/100mL. Per MADEP, inland Class B waters are designated as habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. Where designated they shall be suitable as a source of water supply with appropriate treatment. They shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value.

The standards in vigor at the time of the LTCP did not have a single sample maximum component. The projected annual attainment with the water quality criteria presented in the 1997 FP/EIR for the waterbody segments of the Upper and Lower Charles River, Alewife Brook, and Upper Mystic River ranged between 99-100% under "CSO only" conditions.

The methodologies and assumptions behind the development of the attainment values in the 1997 FP/EIR are summarized as follows:

- One-dimensional receiving water quality models of the Charles River and the Alewife Brook/Upper Mystic River were used to develop the levels of attainment with water quality criteria. The one-dimensional models broke the waterbodies down into a series of segments, and the model computed a single bacteria count value for each segment for each model timestep. Variations in bacteria counts across the width of the waterbodies or vertically through the depth of the waterbodies could not be determined.
- The water quality models did not have the capability to simulate an entire continuous year of rainfall. Rather, the models were run to establish the hours of exceedance of the criteria for the 3-month and 1-year design storms. The CSO volumes from storms causing CSO discharges to a particular water body in the Typical Year were then compared to the volumes for the 3-month and 1-year storms. Storms with CSO volumes up to the 3-month storm CSO volume were assigned the duration of impact associated with the 3-month storm. Storms with CSO volumes greater than the 3-month storm CSO volume were assigned the duration of impact associated with the 1-year storm. The percent of time that the waterbody was estimated to be in exceedance of the water quality criteria was then computed as the sum of the assigned durations for each CSO-causing storm in the Typical Year (in hours) divided by the total number of hours in a year. The percent of the time in compliance was then one minus that value.
- Although the existing water quality standards at the time were based on geometric mean and 90th percentile values for fecal coliform, the calculation of compliance was based on the number of hours above 200 colonies/100mL (the geometric mean standard). The analysis essentially considered the 200 colonies/100mL value as a "single-sample maximum" standard. This approach was considered to be conservative, given that the geometric mean standard was intended as a geometric mean of intermittently sampled data. Since the model could generate significantly more data points than could reasonably be sampled in the real world, calculating a geometric mean from the model output was not considered to be consistent with the intent of the standard.

Of the supplemental planning documents listed in the Second Stipulation, two included additional water quality modeling for the Charles River or Alewife Brook/Upper Mystic River:

- *2003 Final Variance Report for Alewife Brook/Upper Mystic River; and*
- *2004 Cottage Farm CSO Facility Assessment Report.*

Each of these reports is discussed briefly below.

2.1.1 2003 Final Variance Report for Alewife Brook/Upper Mystic River

This report summarized modifications to the recommended plan for the Alewife Brook/Upper Mystic River receiving waters. As part of this report, the collection system model for the Alewife Brook/Upper Mystic River was updated and recalibrated to the existing conditions at the time of the report, then further revised to reflect the revised recommended plan. The same 1-dimensional receiving water model that was used for the 1997 FP/EIR was updated and recalibrated for use in assessing the percent attainment with water quality criteria. The approach to estimating the annual percent attainment was similar to the approach used in the 1997 FP/EIR, except that instead of running the water quality model for the 3-month and 1-year storms, the model was run for two specific storms in the Typical Year (8/17/92 and 10/23/92). The duration of exceedance for other storms in the Typical Year that caused CSO activations was then assigned a value based on the CSO volumes relative to the CSO volumes from the 8/17/92 and 10/23/92 storms. This approach similarly considered the 200 colonies/100mL standard for fecal coliform to be a single-sample maximum criterion. This evaluation resulted in an updated target of 98.5 percent annual attainment of water quality criterion for fecal coliform for the Alewife Brook/Upper Mystic River, for conditions with CSO discharges only.

2.1.2 2004 Cottage Farm CSO Facility Assessment Report

This report presented an evaluation of the feasibility and cost-effectiveness of providing additional storage capacity at the Cottage Farm CSO Facility. As part of this work, a new 2-dimensional water quality model of the Charles River was developed and calibrated. The model development and calibration process incorporated data from recent sampling programs conducted by MWRA, USGS (United States Geological Survey), EPA and others. The two-dimensional model allowed for differentiation of bacterial concentrations across the width of the river as well as along the length of the river. Bacteria concentrations remained vertically averaged over the depth of the river. The intent of the updated water quality model was to assess potential benefits of additional storage at Cottage Farm on the duration and/or area of exceedance of the water quality criteria for fecal coliform. The model was run for the 3-month and 1-year storms, and results were generated for the “all sources” case only. A new target for annual percent compliance for the case of “CSO sources only” was not established as part of this report.

2.2 Current Water Quality Standards

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

The Charles River and Alewife Brook/Upper Mystic River are each currently under a Variance for CSO Discharges*. A water quality standards variance (WQS variance) is a time-limited designated use and* *criterion for a specific pollutant(s) or water quality parameter(s) that reflects the highest attainable condition during the term of the WQS*[2]. This Variance authorizes limited CSO discharges from the MWRA and the Cities of Cambridge and Somerville subject to their National Pollutant Discharge Elimination System (NPDES) permits. During wet weather events where the limited CSO discharges are authorized, Class B requirements for bacteria, solids, color and turbidity, and taste and odor may not be met. The Variance is a water quality standards revision subject to EPA review and approval, and EPA approved the current Variances for the Charles River and Alewife Brook/Upper Mystic River on May 29, 2020.

For the Water Quality Assessment presented herein, attainment with water quality standards has been based on attainment of the existing Class B criteria for non-bathing beach waters. MADEP is currently going through the process of modifying the water quality standards, but as of the date of this report these new standards have not been promulgated. Table 2-1 presents the existing Class B criteria and the potential future criteria for non-bathing beach waters.

Table 2-1. Existing and Proposed Class B Criteria

Parameter	Class B Criteria for Non-Bathing Beach Waters(1)			
	Existing Class B Criteria		Proposed Class B Criteria	
	6-month Geometric Mean (colonies/100 mL)	Single Sample Maximum (colonies/100 mL)	90-day Geometric Mean (colonies/100 mL)	90-day 90th Percentile Statistical Threshold Value (STV) (colonies/100 mL)
E. coli	126	235	126	410
Enterococcus	33	61	35	130

Notes:

(1) Bathing beach criteria are the same except for the duration used in computing the geometric mean.

The way the current modeling applies these existing criteria is explained in Section 2.5.

2.3 Typical Year Rainfall and Design Storms

As noted above in Section 1, the targets established in the Second Stipulation for average annual CSO activations and volumes were based on the Typical Year rainfall. The Typical Year was developed during the CSO LTCP project based on comparison with 40-year rainfall records (Kubaska and Brocard, 1993). Year 1992 was selected as the basis of the Typical Year because it was the only year for which 15-minute rainfall data were available and modeling had shown that this data frequency was needed to provide accurate CSO predictions. Changes were made to the 1992 rainfall data to better match the long-term record in terms of total rainfall, and the distribution of storms of different sizes. Eight storms between 0.25 and 0.50 inches of total rainfall were removed from the 1992 rainfall series, and two storms between one and two inches of total rainfall were added. The storms removed and added were selected to bring the month-by-month distribution of storms closer to the long-term average. The Typical Year includes a total of 93 rain events, with a total accumulation of 46.8 inches. The largest storm in the Typical Year in terms of total accumulation is the December 11, 1992 storm, with a total depth of 3.88 inches, while the largest storm in terms of peak intensity is the October 23, 1992 storm, with a peak intensity of 1.08 inches/hour.

[2] 40 CFR 131.3 (o)

Representative 3-month and 1-year, 24-hour storms were also established early in the CSO planning process. The 3-month storm was represented by a historical storm that occurred on July 18, 1982, and the 1-year storm was represented by a historical storm that occurred on September 20, 1961. The September 20, 1961 storm was one of the storms added into the Typical Year. Table 2-2 presents the characteristics of the 3-month and 1-year storms, as well as examples of some of the larger storms in the Typical Year. Where storms were added into the Typical Year, the original date of the historical storm is indicated in parentheses. As indicated in Table 2-2, the March 7, 1992 storm from the Typical Year had rainfall characteristics that closely matched the previously-used 3-month storm. Since the 1-year storm was already in the Typical Year, the March 7, 1992 storm was used in the current analysis to represent a 3-month, 24-hour storm. With this approach, a single run of the Typical Year would also provide results for the 3-month and 1-year storms.

Table 2-2. Rainfall Characteristics for the Design Storms and Typical Year

Date	Depth (in)	Duration (hrs)	Peak Intensity (in/hr)	Average Intensity (in/hr)
3-Month Storm				
July 18, 1982	1.84	21	0.40	0.09
1-year Storm				
September 20, 1961[(1)]	2.8	22	0.65	0.13
Typical Year – Larger Storms				
March 7, 1992 (3/21/55)[(2)]	1.89	34	0.42	0.06
February 2, 1992	1.14	6	0.42	0.19
May 6, 1992	1.29	19	0.43	0.07
July 11, 1992	0.22	2	0.20	0.11
August 17, 1992	1.27	25	0.47	0.05
September 22, 1992 (9/20/61)	2.8	22	0.65	0.13
September 26, 1992	0.99	9	0.51	0.11
October 23, 1992 (10/3/79)	1.18	3	1.08	0.39
December 11, 1992	3.88	40	0.22	0.10

1. The 1-year storm is also inserted into the Typical Year on September 22, 1992.
2. Where two dates are noted, the storm was added to the actual 1992 rainfall series to create the Typical Year. The first date is where the storm occurs in the Typical Year, and the date in parenthesis is the actual date of storm that was added to the 1992 record.

2.4 Flows and Loads used in the Water Quality Models

The water quality models of the Charles River and Alewife Brook/Upper Mystic River compute time-varying and spatially-varying concentrations of *E. coli* and *Enterococcus* in the rivers, taking into account the influence of river flow and geometry, and the impacts of dilution, dispersion, and die-off. The various sources of flows and bacteria loads into the receiving waters represented in the models include the following:

- Untreated and treated CSO;
- Stormwater;
- Dry weather baseflow (infiltration flow from storm drains or groundwater flow directly to a waterbody; can also include flow from illicit sanitary connections to storm drains); and

- Boundary conditions.

The methods for modeling and estimating the basis for the modeled flows and loads from these sources were described in detail in the *Task 5.2 Receiving Water Quality Model Development and Calibration Report* (AECOM 2020) and are summarized below.

2.4.1 Untreated CSO

In the water quality modeling conducted for the 1997 FP/EIR and the *2003 Final Variance Report for Alewife Brook/Upper Mystic River*, a single, constant value for fecal coliform bacteria was assigned to all untreated CSO discharges based on system-wide sampling that had been conducted at the time. For the current Water Quality Assessment, sampling was conducted on wet weather influent to the MWRA's Cottage Farm and Prison Point CSO facilities, and at outfalls SOM001A and CAM401A, to support the development of *E. coli* and *Enterococcus* counts to apply to untreated CSOs discharging to the Charles River and Alewife Brook. The results of this sampling program are presented in Table 2-3. As indicated in Table 2-3, the *E. coli* and *Enterococcus* counts measured in the Cottage Farm influent were substantially higher than the counts measured in the Prison Point influent, and the *E. coli* counts measured in the Prison Point influent were substantially higher than the counts measured in the SOM001A and CAM401A discharges.

Table 2-3. Summary of Untreated CSO Sampling Results

Parameter		Cottage Farm(1)	Prison Point(2)	SOM001A(3)	CAM401A(3)
	Number of Measurements	31	18	4	8
	Number of Storms	7	9	2	2
E. coli (#/100 mL)	Arithmetic Average of all samples	1,306,000	169,000	65,000	56,000
	Geometric Mean of all samples	865,000	134,000	63,000	42,000
Enterococcus (#/100 mL)	Arithmetic Average of all samples	206,000	48,000	22,000	37,000
	Geometric Mean of all samples	171,000	39,000	20,000	33,000

(1) Data collected between October 2017 and August 2019
(2) Data collected between January 2018 and December 2019
(3) Data collected on August 29, 2019 and October 17, 2020

The difference in the influent bacteria counts at the Cottage Farm and Prison Point facilities can be explained by the different sources of flow to each facility. Cottage Farm receives flow diverted from the South Charles Relief Sewer, the North Charles Metropolitan Sewer, and the North Charles Relief Sewer, which are all major interceptors. The South Charles Relief Sewer extends far west into separately sewered towns (Watertown, etc.), while the North Charles systems serve primarily combined sewer areas.

For Prison Point, the main contributors of flow are the Old Stony Brook Conduit, and some internal relief points in Cambridge, Charlestown, and downtown Boston. The amount of dry weather sanitary sewage in the conduits tributary to Prison Point is relatively low (there is a small dry weather pump station at Prison Point). Therefore, it can be expected that the flow to Prison Point would have a higher percentage of stormwater, and a lower percentage of direct sanitary flow, than the flow to Cottage Farm. This difference in relative stormwater versus sanitary flow fractions explains the differences in the bacteria counts measured at the influents to Cottage Farm and Prison Point.

Given these distinct measured differences in bacteria counts, which could be tied to differences in the sanitary and stormwater fractions in the influent combined sewage, it did not seem appropriate to assign a single, average value of bacteria count to untreated CSO. Rather, it would be more appropriate to compute time-varying CSO counts based on the relative fraction of stormwater and sanitary flow in the CSO.

The fraction of sanitary and stormwater flow in the influents to the CSO facilities can be calculated by the collection system hydraulic/hydrologic model by assigning a tracer concentration of 1.0 to the sanitary flow and 0 to stormwater. The model can then calculate the tracer concentration in the combined sewage flow, and that concentration would equal the sanitary fraction in the flow. This approach is well-established and has been utilized in water quality modeling of CSO impacts by a number of municipalities and agencies, including New York City and San Francisco. The efficacy of this approach was demonstrated in model calibration by generating plots comparing model-predicted counts to measurements, which showed that the model could replicate the observed variations in bacterial counts in the CSO.

To provide a sense of the computed time-varying bacterial counts in the CSO, the model computed the flow weighted counts during the periods of CSO discharge during the Typical Year. The range of flow-weighted counts for the untreated CSOs to the Charles River and Alewife Brook during the Typical Year are presented in Table 2-4. Also presented in Table 2-4 are the arithmetic averages of the sampling results from Table 2-3. As indicated in Table 2-4, the model-computed flow-weighted average counts are consistent with the sampling results. Outfall-specific flow-weighted counts and sanitary fractions, along with total computed loads for the Typical Year, are presented below for the Charles River and Alewife Brook/Upper Mystic River in Sections 3 and 4, respectively.

Table 2-4. Range of Model-Predicted Sanitary Fraction and Flow-weighted Counts in Untreated CSO for the Typical Year, and Arithmetic Means of Sampling Results

Location	Sanitary Fraction (%)[1]	Flow-weighted Counts (#/100 mL)	
		E. coli	***Enterococcus***
Untreated CSOs to the Charles River	0.08% - 1.02%	19,285 – 84,959	10,749 – 20,056
Untreated CSOs to Alewife Brook	0.97% - 4.90%	38,167 – 135,703	16,356 – 55,327
Location		**Arithmetic Mean of Sampling Results (#/100 mL)**	
		E. coli	***Enterococcus***
CAM401A		55,838	36,838
SOM001A		64,775	22,050

(1) The range of sanitary fractions shown is based on the flow weighted average in the discharge pipes over the periods when the outfalls were discharging flow.

Figure 2-1 to Figure 2-4 present examples of how the bacterial counts and sanitary fractions are predicted to vary over time for outfalls to the Charles River and Alewife Brook.

Figure 2-1 shows an example calibration plot on the left, comparing model-predicted influent *Enterococcus* counts to measurements at Cottage Farm and Prison Point for a storm that occurred in

November 2018. This calibration plot demonstrates that the model can replicate the differing influent counts at the two facilities. The plot on the right presents the model-predicted sanitary fraction vs. time for the influent to the two facilities. The pattern of the model-predicted counts on the left mirrors the model-predicted sanitary fractions on the right. Figure 2-2 presents a similar example for outfall CAM401A which discharges to Alewife Brook, for a storm that occurred in August 2019.

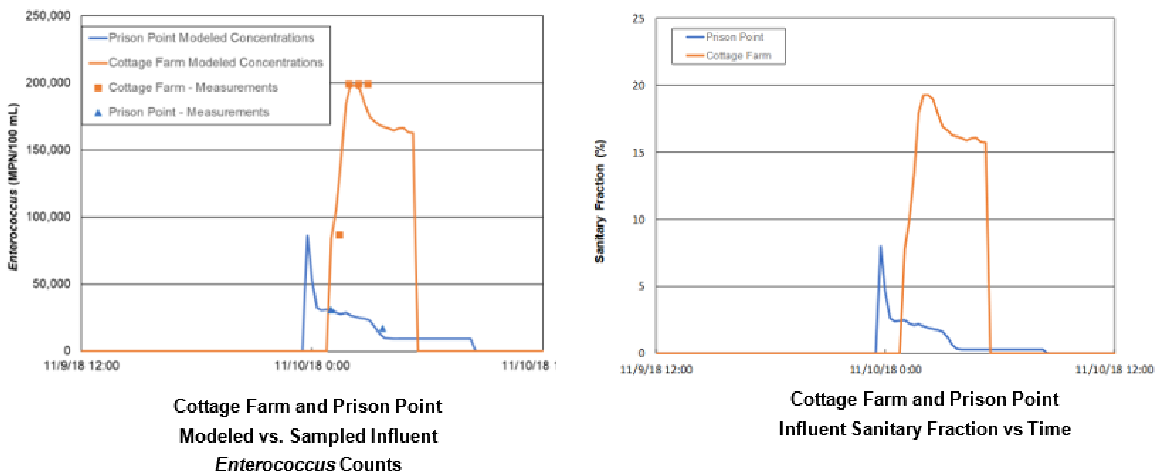


Figure 2-1. Influent Counts and Sanitary Fractions at Cottage Farm and Prison Point

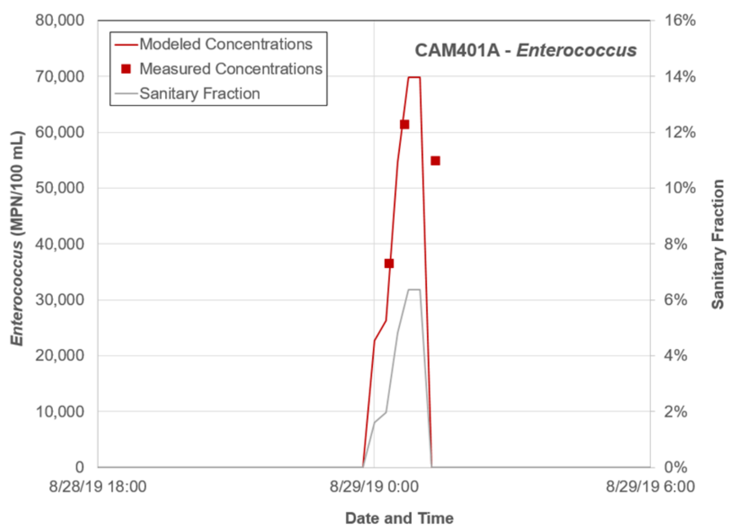


Figure 2-2. Influent Counts and Sanitary Fractions at Outfall CAM401A

Figure 2-3 presents an example of flow, sanitary fraction and bacterial counts versus time for outfall CAM005. The image on the left shows how the computed sanitary and non-sanitary fraction change with the overflow flow rate. The image on the right shows how the computed bacterial counts in the discharge change with overflow flow rate. The total duration of discharge for this event was one hour, and the inflection points on the curve represent the 15-minute model output. As indicated in Figure 2-3, at this outfall for this storm event, the highest sanitary fraction and corresponding bacterial counts occurred in the first 15 minutes of the discharge, after which the sanitary fraction and corresponding counts dropped for the remainder of the event. Thus, while the peak Enterococcus count reached approximately 150,000 #/100mL, the flow-weighted average count for this event was approximately 21,000 #/100mL.

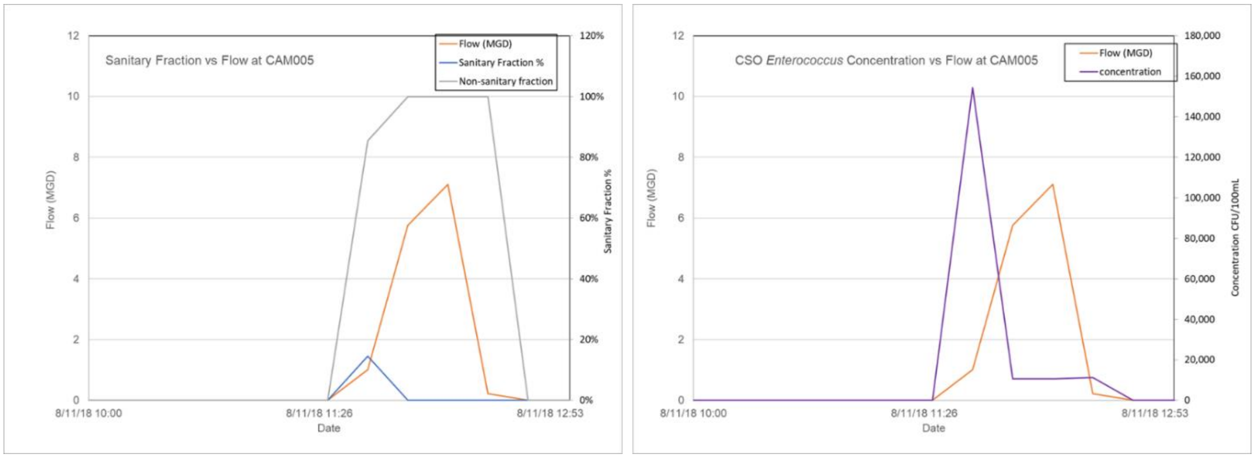


Figure 2-3. Example of Sanitary Fraction, Flow and *Enterococcus* Counts vs. Time at CAM005

Figure 2-4 presents similar plots for outfall CAM017. In this case, the discharge lasts for 30 minutes, and the sanitary fraction remains relatively constant for the duration of the discharge.

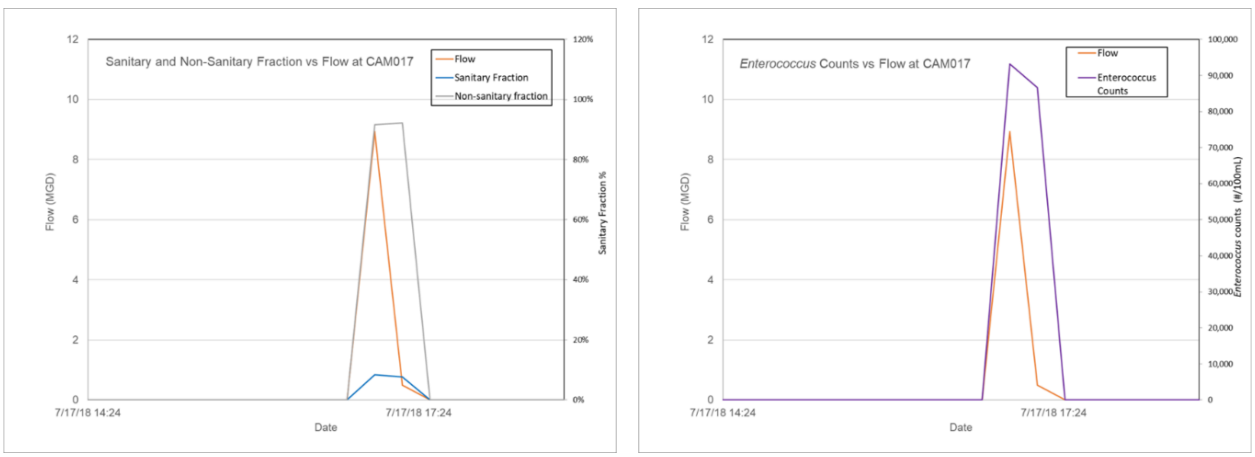


Figure 2-4. Example of Sanitary Fraction, Flow and Enterococcus Counts vs. Time at CAM017

2.4.2 Treated CSO

The MWRA's Cottage Farm CSO Facility discharges to the Charles River, and when the MWRA's Somerville Marginal CSO Facility activates during high tide, a portion of the treated effluent can discharge to the Upper Mystic River upstream of the Amelia Earhart Dam through outfall MWR205A. The Cottage Farm facility provides screening, sedimentation, and disinfection with dechlorination prior to discharge, while the Somerville Marginal facility provides screening and disinfection with dechlorination. The bacteria counts used for modeling the treated facility discharge were based on measurements of effluent quality from the facilities.

For the treated discharges from the Cottage Farm CSO Facility, the arithmetic mean of 14 effluent bacterial counts measured between July 2018 and April 2019 was used to represent the effluent quality in the model. These values were 394 #/100 mL for *E. coli* and 212 #/100 mL for *Enterococcus*.

For the treated discharges from the Somerville Marginal CSO Facility, the average of 17 effluent bacteria counts measured in 2018 was assessed to represent the effluent quality. These values were 18 #/100 mL for *E. coli* and 17 #/100 mL for *Enterococcus.* The average value for *Enterococcus* excluded one outlier data point. The model also incorporated separate stormwater flows that enter the Somerville Marginal outfall conduit downstream of the facility.

Prison Point data were discussed and used earlier in the section to justify and develop CSO bacterial loads that vary by sanitary input. Prison Point is not discussed here because it discharges into saltwater downstream of the Charles River dam and therefore is not part of the model simulations.

2.4.3 Stormwater

Stormwater flows discharging into the Charles River were simulated by models of the separate stormwater systems tributary to the Charles River from the cities of Cambridge and Boston. These models included the Boston Water and Sewer Commission (BWSC) Drain model, the USGS Charles River Stormwater Model, and the City of Cambridge InfoWorks ICM (Integrated Catchment Modeling) Model. Stormwater flows into the Alewife Brook/Upper Mystic River were simulated by the InfoWorks ICM Mystic River Basin Model.

The bacteria concentrations applied to those flows to generate the time-varying bacterial loads to the receiving waters from stormwater were based on the results of a stormwater sampling program conducted in 2019 and 2020. Grab samples were collected in 2019 at two stations in Cambridge discharging to the Charles River shown in Figure 2-5, and at multiple stations discharging to the Alewife Brook/Upper Mystic River in Arlington, Cambridge, and Medford shown in Figure 2-6. Grab samples were collected at the Somerville stations shown in Figure 2-6 in 2020. The tributary areas to the sampled outfalls for the Alewife Brook/Upper Mystic River are outlined in red in Figure 2-6.

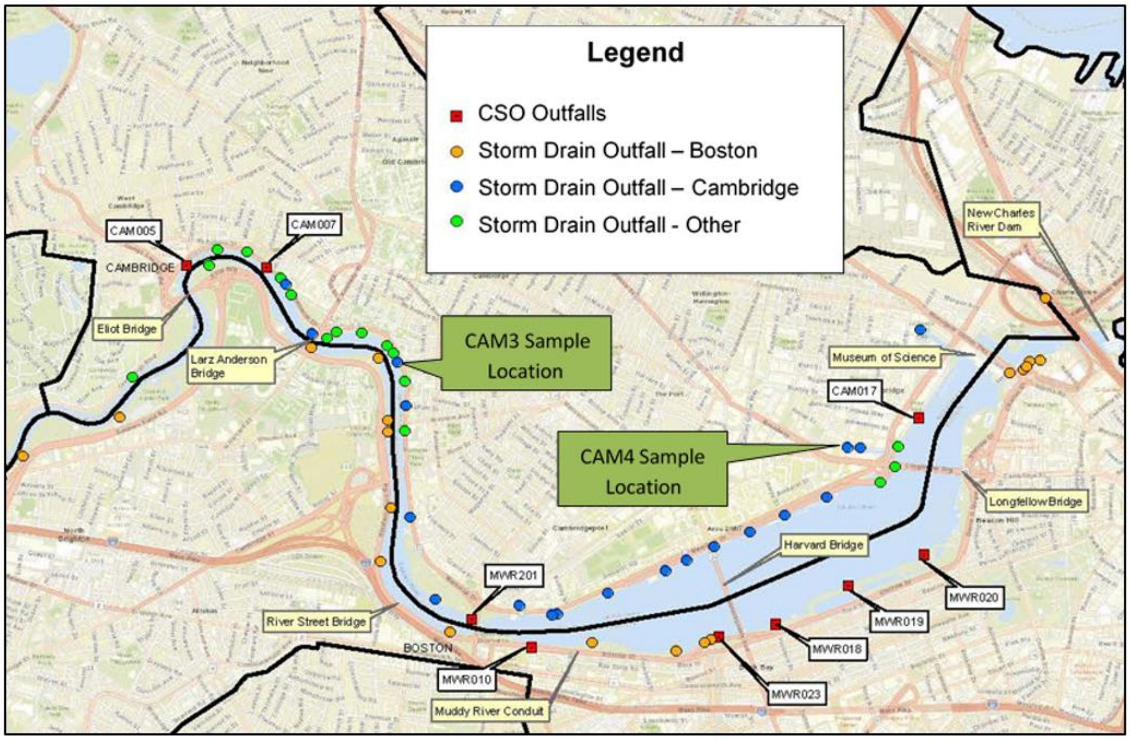


Figure 2-5. Stormwater Monitoring Stations for the Charles River

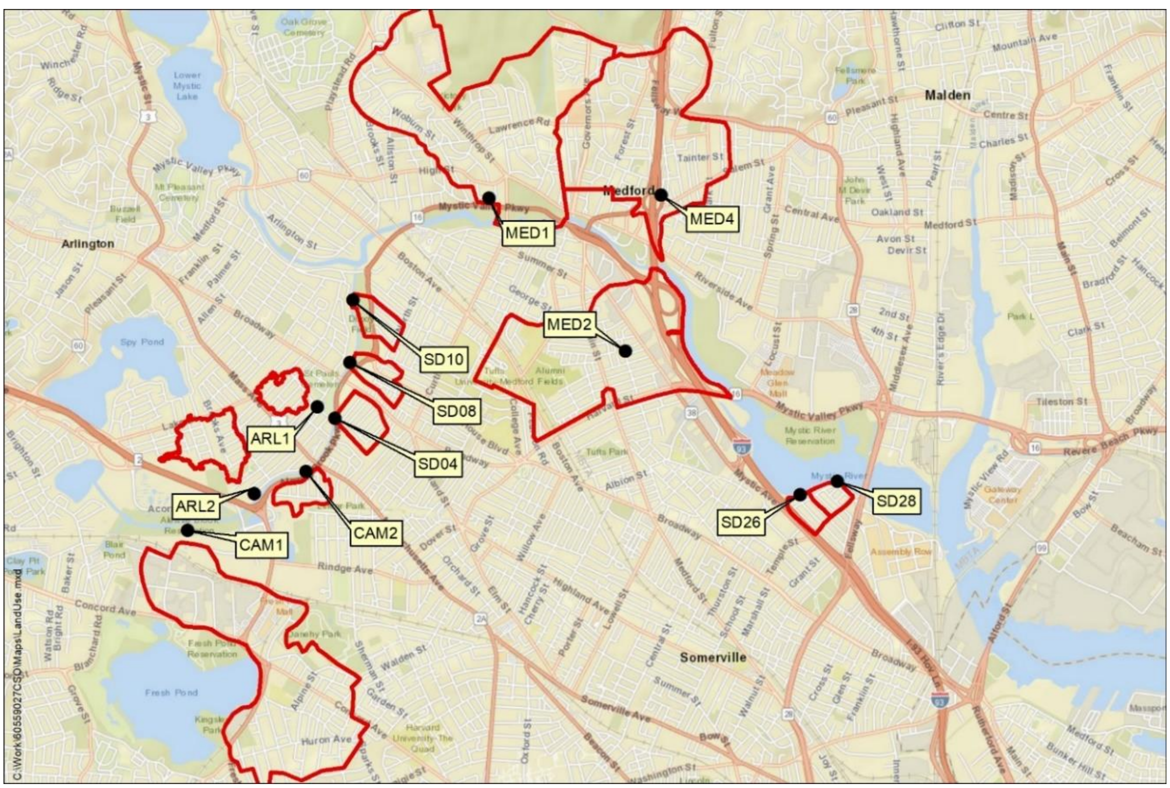


Figure 2-6. Stormwater Monitoring Stations for Alewife Brook/Upper Mystic River

Table 2-5 presents a summary of the stormwater monitoring results, along with the values applied to stormwater in the water quality models. The monitoring program included over 180 individual samples taken during wet weather over the course of six rain events (five in 2019, one in 2020). Table 2-5 presents the overall 25th, 50th, 75th, and 90th percentile values, maximum and arithmetic mean of all the samples. The arithmetic mean values for *E. coli* and *Enterococcus* were used as the initial values for bacteria counts in the stormwater discharges for the water quality model calibration. These values were adjusted during calibration to better match measured in-receiving water bacteria counts to arrive at the “Model Values” presented in Table 2-5.

Table 2-5. Summary of Stormwater Sampling Results and Modeled Values

Parameter	Monitoring Results (#/100 mL)						Model Values (#/100 mL)	
	Percentile				Maximum	Arithmetic Mean	Charles River	Alewife Brook/ Upper Mystic River
	25th	50th	75th	90th				
E. coli	1,110	4,500	15,600	46,200	75,000	13,500	14,000	25,000
Enterococcus	1,154	3,400	4,700	9,200	78,300	6,000	10,000	6,700

The stormwater monitoring program took samples at or near the end of the stormwater outfalls, and the measurements of bacterial counts would have included the influence of illicit sanitary connections if they existed. The sensitivity of predicted in-receiving water bacterial counts to variations in the counts assigned to stormwater in the model is presented below in Sections 3.3.5 and 4.3.5 for the Charles River and Alewife Brook/Upper Mystic River, respectively.

A key question to resolve prior to starting the water quality model calibration was whether to use constant average values for *E. coli* and *Enterococcus* counts for all stormwater inputs, or if a basis could be established for varying the stormwater counts based on factors such as rainfall or tributary area parameters. Plots were developed of measured *E. coli* and *Enterococcus* counts as a function of the following parameters:

- Storm depth;
- Number of prior dry days;
- Total tributary area;
- Percent undeveloped area;
- Total undeveloped area;
- Percent residential area; and
- Total residential area.

None of the plots showed a clear relationship between the parameter assessed and measured *E. coli* or *Enterococcus* counts. Since no clear correlations could be established between bacteria counts and rainfall depth, antecedent dry days, or land use, the average of all individual wet weather sample results for *E. coli* and *Enterococcus* (shown in Table 2-5), were used for the purpose of computing bacteria loading inputs to the Charles River and Alewife Brook/Upper Mystic River water quality models.

Regarding the issue of using time-varying bacteria counts for stormwater versus using a single value based on an arithmetic mean of measurements, for modeling, it is not practical to specify variable bacterial counts based on measurements whose relationship with the storm start, peak and end is variable. From a conservation of mass (bacterial counts) point of view, flow-weighted counts would be best, but these would require flow-based sampling or concomitant flow measurements, which were not available for the samples collected. Given these realities, averaging measured bacterial counts during each storm was a reasonable approach for coming up with an initial representation of the counts in the stormwater. In the absence of flow-weighted bacterial counts, arithmetic averages were used. Geometric means are indicators of the central tendency of log-normal distributed data, and are appropriately used to compare different distributions, but are not as appropriate for estimating total load. Use of the geometric mean would generally underestimate the total loading. Whether the arithmetic mean or geometric mean were used as the starting point for calibration, the initial values would have had to be adjusted in either case during calibration to match measured counts in the receiving waters during wet weather.

Ongoing efforts by the communities to address stormwater issues through their MS4 (Municipal Separate Storm Sewer Systems) permits are acknowledged. This is addressed in the sensitivity analyses presented in Sections 3.3.5 and 4.3.5, where the benefits of several reductions of stormwater bacterial counts are examined.

2.4.4 Other Dry Weather Flows

The in-stream monitoring showed elevated bacterial counts in the Charles River and Alewife Brook/Upper Mystic River during dry weather. Previous modeling indicated that some of the dry weather bacterial counts were due to previous discharges, whose effect can last for several days. Dry weather sources, for example illicit sanitary connections to storm drains, can also contribute to dry weather bacterial counts in the river.

The stormwater monitoring described in Section 2.4.3 also included collection of dry weather samples before the start of rain. The data are summarized in Table 2-6. Only 32 sets of measurements were available and, as a result, the statistics are approximate.

Table 2-6. Summary of Dry Weather Sampling Results and Modeled Values

Parameter	Monitoring Results (#/100 mL)						Model Values (#/100 mL)	
	Percentile				Maximum	Arithmetic Mean	Charles River	Alewife Brook/ Upper Mystic River
	25^{th}	50^{th}	75^{th}	90^{th}				
E. coli	50	410	3,450	15,000	21,000	3,095	134	134
Enterococcus	100	100	1,090	3,990	8240	888	45	45

Since the water quality models can be run in a continuous simulation mode for an entire year, the models account for residual loads from previous discharges. However, during model calibration, the residual loads from wet weather events alone were not sufficient to match measured dry weather counts in the rivers, so additional dry weather loading sources needed to be added.

For the Charles River, the BWSC and USGS stormwater models included dry weather flows. For the Alewife Brook/Upper Mystic River, dry weather baseflows were generated from the "soil store" component of the groundwater module. Based on model calibration, *E. coli* counts of 134 #/100mL and *Enterococcus* counts of 45 #/100mL were added to the baseflows discharging at stormwater outfalls during dry weather for the Charles River and for the Alewife Brook/Upper Mystic River downstream of Station 083. As described above, the dry weather counts to the Mystic River upstream of Station 083 were increased to account for the loading from the Mystic Lakes. The model values are generally lower than the measurements, but they are the values that were found to provide the best match with the in-stream monitoring data. Higher dry weather counts lead to in-stream counts that exceeded measurements.

2.4.5 Upstream Boundary Conditions

Flows and bacterial counts at the upstream boundaries of the Charles River and Alewife Brook/Upper Mystic River water quality models were represented using different approaches tailored to the specific conditions in each model. For the Charles River, bacterial counts at the upstream boundary (Watertown Dam) were identified using a buildup/washoff model calibrated to in-stream water quality measurements conducted by MWRA (AECOM 2020). The buildup/washoff model was based on stream flows at the Watertown Dam. These flows were taken from flow measurements at the USGS Waltham Gauge. The approach for estimating flows for the storms in the Typical Year that were inserted into the 1992 rainfall series is summarized in Section 3 below.

The Alewife Brook/Upper Mystic River has three upstream boundaries:

- The upstream end of Alewife Brook;
- The upstream end of the Malden River; and
- The upstream end of the Mystic River at the outlet of the Lower Mystic Lake.

Flows at the upstream ends of Alewife Brook and the Malden River were generated by the modeled tributary catchments. Based on calibration, these sources were assigned baseflow (dry weather) counts of 134 #/100 mL and 45 #/100 mL for *E. coli* and *Enterococcus*, respectively. Runoff flows during wet weather were assigned counts of 25,000 #/100 mL and 6,700 #/100 mL for *E. coli* and *Enterococcus*, respectively.

For the Mystic River downstream of the Mystic Lakes, flows were specified based on the results of the model extending to the upstream USGS gauge in the Aberjona River. However, the model-generated bacterial counts were not sufficient to reproduce the bacterial counts measured at MWRA Station 083, approximately 0.8 mile downstream of the Lower Mystic Lake. Therefore, relatively high bacterial counts were specified in the stormwater and dry weather flow from the catchments discharging upstream of Station 083 to account for loadings from the Lower Mystic Lake, as follows:

- Stormwater: 50,000 #/100mL for *E. coli* and 20,000 #/100mL for *Enterococcus* were applied upstream of Station 083.
- Dry Weather Flow: 2,000 #/100mL for *E. coli* and 3,000 #/100mL for *Enterococcus* were applied upstream of Station 083.

The Task 5.2 Receiving Water Quality Model Development and Calibration Report dated December 15, 2020 listed the dry weather flow count for *Enterococcus* as 10,000#/mL. Subsequent to the report submittal, the *Enterococcus* calibration of the Alewife Brook/Upper Mystic River model was reviewed and updated and the dry weather flow count for *Enterococcus* was revised to be 3,000#/mL. A memorandum documenting the recalibration is provided in Appendix A.

2.5 Approach to Assessing Compliance with Current Water Quality Criteria

The analyses presented below are based on attainment with the existing Class B single sample maximum criteria for non-bathing beach waters (235 colonies/100mL for *E. coli* and 61 colonies/100mL for *Enterococcus*). This approach is consistent with the approach taken in the 1997 FP/EIR and the *2003 Final Variance Report for Alewife Brook/Upper Mystic River*, where compliance was based on a single-sample maximum of 200 colonies/100mL for fecal coliform. Since the Variance waters are freshwater waterbodies, the focus of compliance for the current water quality assessment is on the *E. coli* criterion. Attainment with the *Enterococcus* criterion is presented in Appendix B.

Sections 3 and 4 below present the results of the baseline water quality assessments for the Charles River and Alewife Brook/Upper Mystic River, respectively. The baseline assessments are based on a continuous simulation of the Typical Year rainfall, with MWRA system conditions as represented by the 2019 Conditions version of the MWRA's InfoWorks ICM collection system model. In each section, tables are provided of the bacterial loadings from the various sources for the Typical Year, as well as for the 3-month and 1-year storms that are embedded within the Typical Year. Also presented are tables of CSO volumes by outfall and by storm for the Typical Year, and the outfall-specific flow-weighted average bacterial counts in the CSO.

For the Charles River, 2-dimensional isopleth plots of bacterial counts at specific time increments for the 1-year storm are presented, along with 2-dimensional isopleths of hours of exceedance of the existing single-sample maximum criteria for *E. coli* and *Enterococcus*. The hours of exceedance plots are presented for conditions representing all sources, non-CSO sources only, and CSO sources only. The results from the isopleth plots are also summarized in tabular format. The results of initial sensitivity analyses using varying bacterial counts in the stormwater or CSO are then presented. Similar information is presented for the Alewife Brook/Upper Mystic River, with the exception that the plots of bacterial counts and hours of exceedance are 1-dimensional along the length of Alewife Brook and the Upper Mystic River.

Section 5 below presents an overall summary of the findings.

3. Charles River

3.1 Model Characteristics

The Charles River model is a horizontally two-dimensional model based on the Delft3D software. The model includes a hydrodynamic part, which calculates water levels and depth-averaged velocities, and a water quality part, which calculates depth-averaged *E. coli* and *Enterococcus* counts.

The model extends from the New Charles River Dam and locks to the Watertown Dam as shown in Figure 3-1. The area was divided into 4,400 grid cells. In general, the river width was divided into at least 5 cells, and many more in wider sections. Stormwater and CSO flow inputs as a function of time were specified at 85 outfalls shown in Figure 3-1. As described above in Section 2, CSO flow inputs were based on the 2019 Conditions version of the MWRA's collection system hydraulic and hydrologic (H&H) model, and the stormwater flow inputs were based on the Cambridge InfoWorks ICM model, the BWSC Personal Computer Storm Water Management Model (PSWMM), and a Storm Water Management Model (SWMM) model developed by the USGS (USGS, 2002a). The stormwater input locations on Figure 3-1 are color-coded based on the model used to generate the inputs. The input locations modeled by the USGS include outfalls not specifically covered by either the Cambridge or BWSC stormwater models, and may include outfalls under the jurisdiction of Department of Conservation and Recreation (DCR), Massachusetts Department of Transportation (Mass DOT), or other entities, as well as direct stream inflows.

As described in Section 2 above, the buildup/washoff model used to establish upstream boundary conditions for the Charles River model is based on stream flows at the Watertown Dam. These flows were taken from flow measurements at the USGS Waltham Gauge. Data at that gauge were available for the 1992 period, which is the basis of the Typical Year, but not for the earlier periods that were used for replacement storms in the Typical Year. For these replacement storms, equivalent storms (in terms of depth, duration and intensity) were identified in 2017 and 2018 and measured flows for these equivalent storms were used. Baseflow and wet weather flows were separated for both the 1992 and 2017/18 storms and new flows were calculated as the 1992 baseflow plus the 2017/18 wet weather flow. An example is shown in Figure 3-2.

Because water levels at the New Charles River Dam were not available for 1992, the basis of the Typical Year, a constant water level was specified at the downstream model boundary. This approximation is not expected to have significant effect on the calculated water quality parameters.

Bacteria counts were applied to each of the inflows to the model area, as well as the inflow from the Watertown Dam, as described above in Section 2. The values for all the inflow categories computed through model calibration are summarized in Table 3-1. The flow-weighted average sanitary fraction and bacteria counts for the discharge from each CSO outfall in the Typical Year are presented in Table 3-2.

Table 3-1. Selected Model Parameters based on Model Calibration – Charles River

	Stormwater Counts (#/100 mL)	Dry Weather Baseflow Counts[(1)] (#/100 mL)	CSO Sanitary Fraction Counts (#/100 mL)	CSO non-Sanitary Fraction Counts (#/100 mL)	Die-off Rate (Day^{-1})
E. coli	14,000	134	7,000,000	14,000	0.8
Enterococcus	10,000	45	1,000,000	10,000	0.8

(1) These counts were applied to modeled baseflow during dry weather. In wet weather, the baseflow was assigned the same counts as the stormwater.

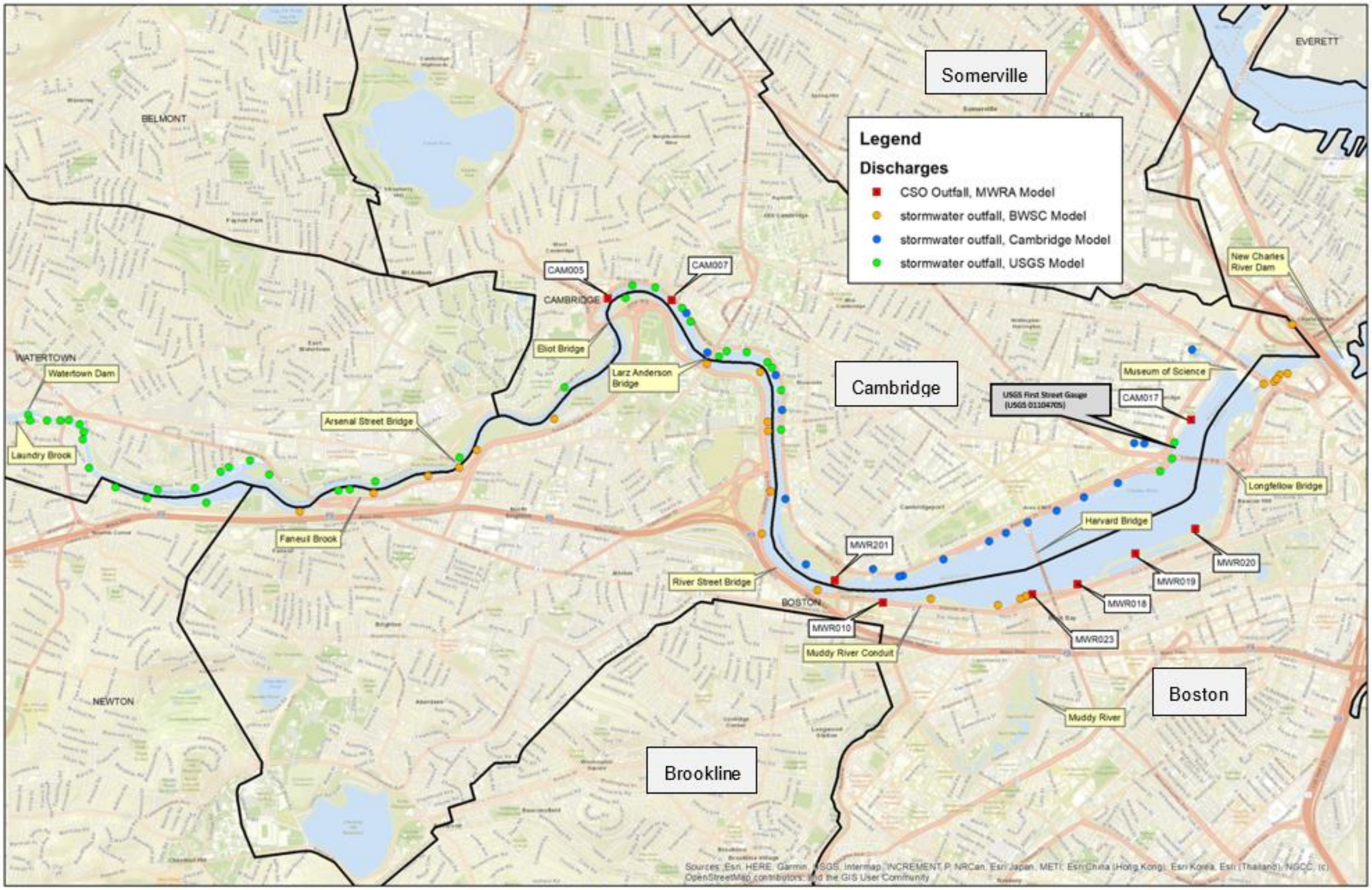


Figure 3-1. Stormwater and CSO Discharges to the Charles River

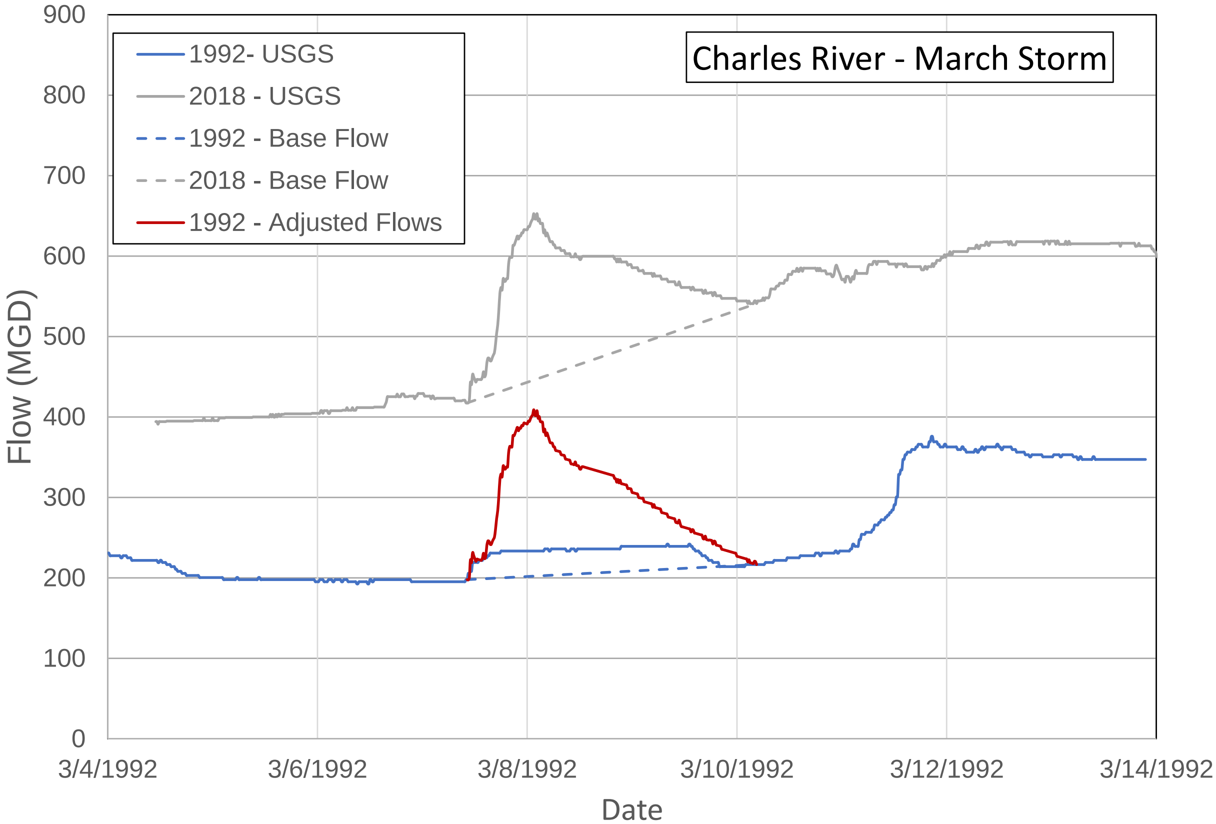


Figure 3-2. Example of Watertown Dam Flow Adjustment for Typical Year Replacement Storm

Table 3-2. Predicted Sanitary Fractions and Flow-weighted Counts for the Typical Year

Location	Flow-weighted Sanitary Fraction (%)[(1)]	Flow-weighted Counts (#/100 mL)	
		E. coli	*Enterococcus*
CAM005	0.18%	26,409	11,759
CAM007	0.46%	45,994	14,534
MWR010[(2)]	N/A	N/A	N/A
MWR023	0.08%	19,285	10,749
MWR018	0.40%	42,197	13,996
MWR019	1.02%	84,959	20,056
MWR020	0.26%	32,032	12,555
CAM017[(2)]	N/A	N/A	N/A
MWR201 (Cottage Farm CSO Facility Treated Discharge)[(3)]	N/A	394	212

(1) For each untreated CSO outfall, the sanitary fraction shown is the flow weighted average in the discharge pipe over the periods when the outfalls were discharging flow.
(2) Outfall did not discharge CSO during the Typical Year.
(3) For outfall MWR201 the sanitary fraction method was not applied to the treated discharge. The flow-weighted counts reflect the average treated discharge counts sampled from the Cottage Farm CSO Facility effluent between July 2018 and April 2019.

3.2 CSO Activations

The CSO activations during the Typical Year at the CSOs discharging to the Charles River based on the collection system hydraulic model representative of 2019 system conditions are summarized in Table 3-3. A total of nine storms were predicted to cause CSO discharges to the Charles River in the Typical Year. The most active CSO outfall was CAM005, with eight activations, although the largest individual storm discharge volume at CAM005 was 0.26 million gallons (MG) and six of the eight activations had volumes less than 0.10 MG. Overall, only one untreated discharge to the Charles River exceeded 1 MG (MWR018 for the 9/22 storm), and five storms resulted in discharges at only one outfall. The largest discharge volumes were at MWR201 (Cottage Farm) and these discharges were treated. The 0.14 MG discharge under MWR023 on 10/23 reflects the sum of the discharges from three upstream CSO regulators in the Stony Brook System. The total untreated CSO discharge volume to the Charles River during the Typical Year was 4.1 MG.

Table 3-3. 2019 System Conditions Charles River CSO Activations during Typical Year

Date	Rainfall		CSO Volume (MGD)						
	Peak 15-Min Intensity (in/hr)	Depth (in)	CAM005	CAM007	MWR018	MWR019	MWR020	MWR201 (Cottage Farm)	MWR023
1/4/1992	0.48	1.15							
1/14/1992	0.52	0.49							
1/23/1992	0.4	1.38							
2/15/1992	0.2	0.87							
2/25/1992	0.24	0.84							
3/7/1992 (3-mo Storm)	0.22	1.89							
3/11/1992	0.48	0.97							
3/19/1992	0.08	0.42							
3/26/1992	0.16	0.67							
3/28/1992	0.08	0.42							
4/11/1992	0.4	0.52							
4/16/1992	0.28	1.02							
4/24/1992	0.24	0.88							
5/2/1992	1.32	1.14	0.06						
6/1/1992	0.48	2.24						0.40	
6/6/1992	1	1.34	0.02						
6/20/1992	0.56	0.45							
6/24/1992	0.24	0.56							
7/6/1992	0.36	0.38							
7/15/1992	0.32	0.5							
7/23/1992	0.28	0.42							
7/31/1992	0.68	0.59							
8/11/1992	1.24	0.87	0.13						
8/18/1992	0.8	2.91	0.07					0.25	
9/3/1992	0.68	1.19	0.02						
9/9/1992	1.72	0.57	0.08	0.06					
9/11/1992	0.36	0.38							
9/22/1992 (1-yr Storm)	0.65	2.8	0.09		1.11	0.19	0.02	8.40	
9/26/1992	0.36	0.74							
10/10/1992	0.72	2.04							
10/23/1992	1.08	1.18	0.26	0.33	0.81	0.37	0.30	3.31	0.14
10/24/1992	0.16	0.38							
11/3/1992	0.2	0.94							
11/5/1992	0.16	0.31							
11/21/1992	0.36	1.93							
11/23/1992	0.36	1.93							
11/26/1992	0.24	0.51							
12/3/1992	0.2	0.82							
12/12/1992	0.24	3.89							
12/17/1992	0.2	0.58							
12/29/1992	0.16	0.37							
12/30/1992	0.12	0.44							
Total CSO Volume in Typical Year			**0.73**	**0.39**	**1.92**	**0.56**	**0.32**	**12.36**	**0.14**

Note: CAM017 and MWR010, do not activate during the Typical Year

3.3 Water Quality Impact Assessment

3.3.1 Approach

The Charles River hydrodynamic and water quality model was run for the entire Typical Year. As explained above in Section 2.1, the previous water quality impact assessments conducted for the CSO LTCP and subsequent analyses were based on model simulations for the 3-month and 1-year storms from which annual impacts were estimated. With improvements in computer capabilities it is now possible to run the entire Typical Year. Nevertheless, impacts for the 3-month and 1-year storms are of interest. The 1-year storm previously used was a storm that occurred on September 20, 1961. This storm was included in the Typical Year in replacement of a smaller storm that occurred on September 22, 1992. Therefore, results for the 1-year storm can be extracted from the Typical Year model runs. The 3-month storm previously used was a storm that occurred on July 18, 1962. This storm was not included in the Typical Year. However, a Typical Year storm occurring on March 7, 1992 (itself a replacement storm that actually occurred on April 21, 1955) has characteristics that are very close to the LTCP 3-month storm. This Typical Year storm was therefore used to characterize the impacts of the 3-month storm.

As previously mentioned, bacterial loadings were input to the model from treated and untreated CSOs, stormwater, and upstream boundaries. Because the mass balance equation solved by the model is linear, in-stream bacterial counts from different sources are additive (provided the hydrodynamics are the same). Therefore, impacts from different sources are assessed separately and together by specifying zero or actual bacterial counts to the different inputs, but keeping their flows unchanged. For example, if the bacterial count due to stormwater alone (all other inputs to the river with zero bacterial count) at one location and at one time is “x”, and the bacterial count at the same location and time due to CSO alone is “y”, the bacterial count due to stormwater and CSOs is “x+y”.

3.3.2 Source Volumes and Bacterial Loadings

Prior to describing the model results, it is instructive to review the inflow volumes and loadings (number of bacteria discharged) for different sources for the 3-month and 1-year storms as well as the Typical Year. These are summarized in Table 3-4 and Table 3-5.

Note that the dry weather and boundary flows for the 3-month storm are slightly higher than those for the 1-year storm because the 3-month storm selected for analysis occurs in March, during high groundwater and upstream river flow, while the 1-year storm selected for analysis occurs in September, when groundwater and upstream flow are low.

Table 3-4. Source Volumes to the Charles River

Source	Source Volumes[1]					
	3-Month Storm[2]		1-Year Storm[3]		Typical Year	
	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total	Volume (MG)	Percent of Total
Untreated CSOs[1]	0.0	0%	1.4	0.2%	4.06	<0.01%
Treated CSOs[1]	0.0	0%	8.4	1%	12.4	0.01%
Stormwater	264	38%	430	58%	7,016	6%
Dry Weather	64	9%	38	5%	9,238	8%
Boundary	363	53%	259	35%	98,825	86%
Total	691	100%	737	100%	115,096	100%

Notes:
(1) CSO volumes based on MWRA 2019 System Conditions collection system model
(2) March 7, in the Typical Year
(3) September 22 in the Typical Tear

Table 3-5. *E. coli* Loadings to the Charles River

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

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

As indicated in Table 3-4, CSOs to the Charles River were not active in the 3-month storm. In the 1-year storm and for the Typical Year, the CSO volumes represented a very small fraction of the total volume from all sources tributary to the river. As would be expected, the boundary flow over the Watertown Dam dominates the total volume for the Typical Year. For the 3-month storm, the boundary flow volume is slightly greater than the stormwater volume, while that relationship was reversed for the 1-year storm.

Table 3-5 shows that the *E. coli* loadings from untreated CSOs are small fractions of the loadings due to the other sources. CSOs contribute no loadings for the 3-month storm. For the 1-year storm, the untreated CSO loadings are 0.8% of the total loadings for *E. coli*. For the Typical Year this fraction decreases to 0.1%. The fraction is less for the Typical Year than for the 1-year storm because many storms during the Typical Year do not have CSO activations. The loadings of the sanitary and stormwater components of the untreated CSOs are of comparable magnitude because while the sanitary fractions are low, the sanitary bacterial counts are much higher than those of stormwater.

For all cases, stormwater yields the largest loadings, followed by the upstream boundary. Dry weather sources contribute relatively small loadings. These patterns of relative loadings are generally consistent with the findings from the 1997 CSO FP/EIR for the Charles River.

3.3.3 Model Results

As indicated above, the water quality model was run for the entire Typical Year. Model output was generated in the form of *E. coli* and *Enterococcus* counts at 15-minute intervals at each of the 4,400 grid cells in the model, amounting to 154 million data points for each model run. Simulations were conducted for the following conditions for both *E. coli* and *Enterococcus*.

- All sources;
- Non-CSO sources only;
- Stormwater only;
- Dry weather sources only;
- Boundaries only; and
- CSO only.

Because the water quality model is linear, in-stream bacterial counts due to the different sources are additive, as described in Section 3.3.1. In the model runs for the individual sources, the bacterial counts in the other sources were set to zero, but the discharges from the other sources were retained. Note that the dry weather sources are not included in the simulations with the other sources. The dry weather sources are only included in the "Dry Weather Sources Only" simulations.

To provide a view of the magnitude and change in predicted bacteria counts over time due to wet weather, plots of calculated *E. coli* contours at different times during and after the 1-year storm are presented in Figure 3-3 for "All Sources" and in Figure 3-4 for "CSOs Only". The 1-year storm had untreated CSO discharges at CAM005, CAM007, MWR018, MWR019, MWR020 and MWR023.

Plots are included for the following times:

- before the storm
- peak of the storm taken as the approximate time of peak CSO discharge
- 6 hours after the peak of the storm
- 12 hours after the peak of the storm
- 24 hours after the peak of the storm

"All Sources" plots are also provided for the following times:

- 48 hours after the peak of the storm
- 72 hours after the peak of the storm

On the "All Sources" plots shown in Figure 3-3, the impact of the boundary discharge is dominant. Although the total *E. coli* loading of the upstream boundary is less than that of stormwater for the 1-year storm, its impact is greater because its *E. coli* counts (up to 35,000 #/100 mL) are greater than those of stormwater (14,000 #/100 mL) and because stormwater is distributed along the river, while the upstream load is concentrated at a single location in the narrowest reach of the river. A localized stormwater impact is apparent near the discharge from the Stony Brook Conduit. It takes approximately 3.0 days for the Charles River to return to pre-storm conditions after the end of the 1-year storm.

The "CSO Only" plots in Figure 3-4 show minimal impacts due to the low CSO volumes and loadings. Note that the color-coding is on a different scale for Figure 3-4 compared to Figure 3-3, due to the difference in the magnitude of the in-stream *E. coli* counts.

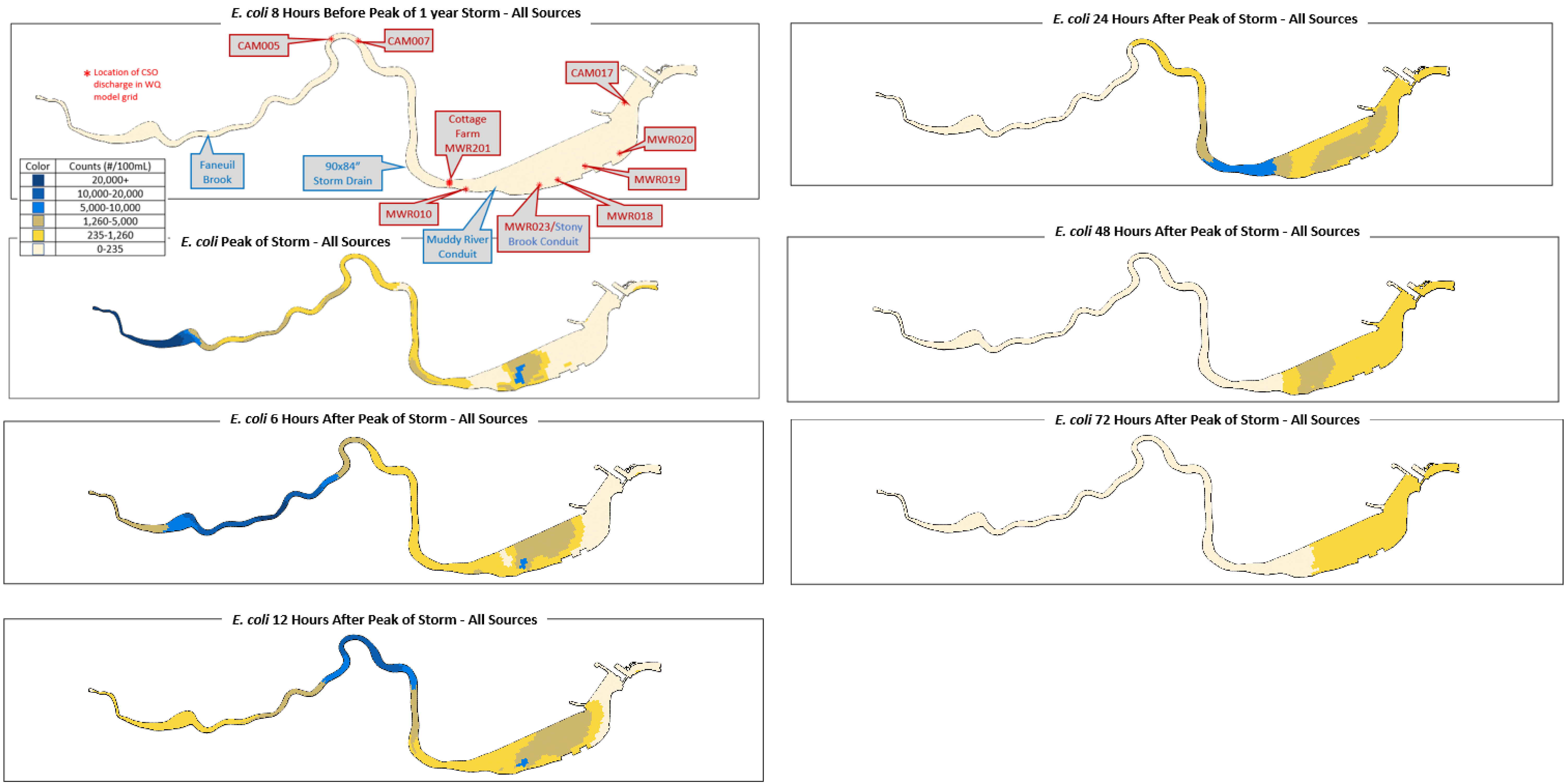


Figure 3-3. *E. coli* Count Contours during the 1-Year Storm for "All Sources"

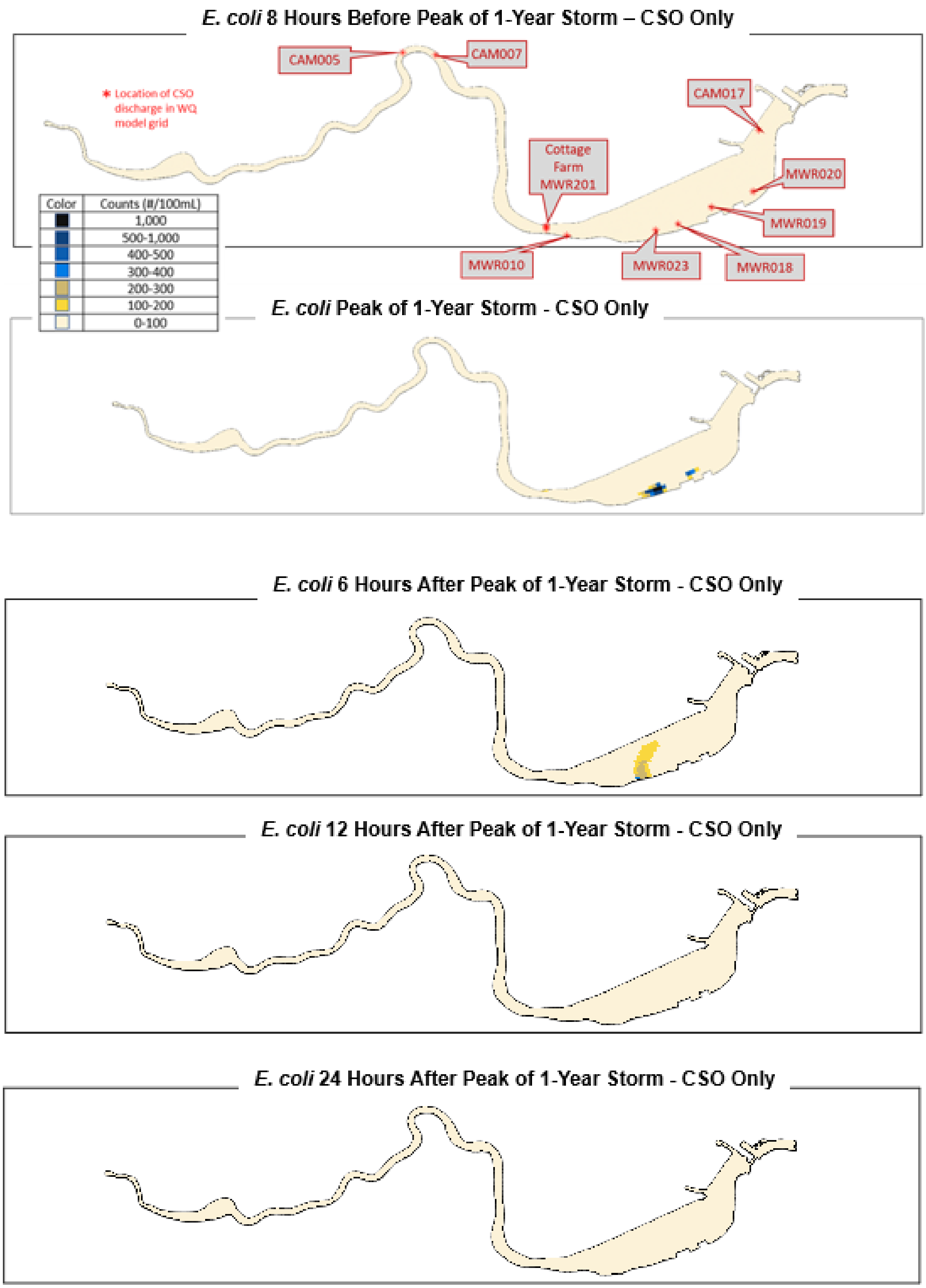


Figure 3-4. *E. coli* Count Contours during the 1-Year Storm for "CSO Only" Sources

3.3.4 Criteria Exceedances

To assess compliance with the current water quality criteria for bacteria, the model was used to compute the total duration that the bacteria count in each model cell was predicted to exceed the single-sample maximum criterion for *E. coli* and *Enterococcus* over the course of the Typical Year. The resulting values for percent annual attainment of the criterion would be generally analogous to the values for annual percent attainment presented in the 1997 FP/EIR. The hours of exceedance for the 3-month storm, 1-year storm and the Typical Year as well as the percent annual compliance for *E. coli* are presented in Table 3-6 for the six different simulation conditions that were listed above in Section 3.3.3 (see Appendix B for *Enterococcus* results). Because the water quality model is linear, bacterial counts due to different sources are additive, however, the hours of exceedance due to different sources are not additive. The hours shown in Table 3-6 are the number of hours the *E. coli* bacterial counts do not meet the criterion anywhere in the model area. This is extremely stringent, as the model cells where exceedances occur shift in time, and the area of exceedance will nearly always be a fraction of the total river area. At any fixed point in the river, the hours of exceedance would be less than those listed in the table.

Table 3-6. Hours of the *E. coli* Single Sample Maximum Criterion Exceedance at any point in the Lower Charles River During the 3-Month Storm, 1-Year Storm and Typical Year

	E. coli Single Sample Maximum Criterion (235 colonies/100 mL)			
	Hours of Exceedance[(1)]			Percent Annual Compliance
	3-Month Storm[(2)]	1-Year Storm[(2)]	Typical Year	
All Sources	88	108[(3)]	4,570	48%
Non-CSO Sources Only	88	108[(3)]	4,561	48%
Stormwater Only	79	84	3,121	64%
Dry Weather Sources Only	0	0	0	100%
Boundary Only	77	102	3,612	59%
CSO Only	0	8.3	37	99.6%

Notes:

(1) The hours of exceedance are totalized from the time when the single sample maximum criterion is exceeded after the start of the storm until the *E. coli* count drops again below the criterion.

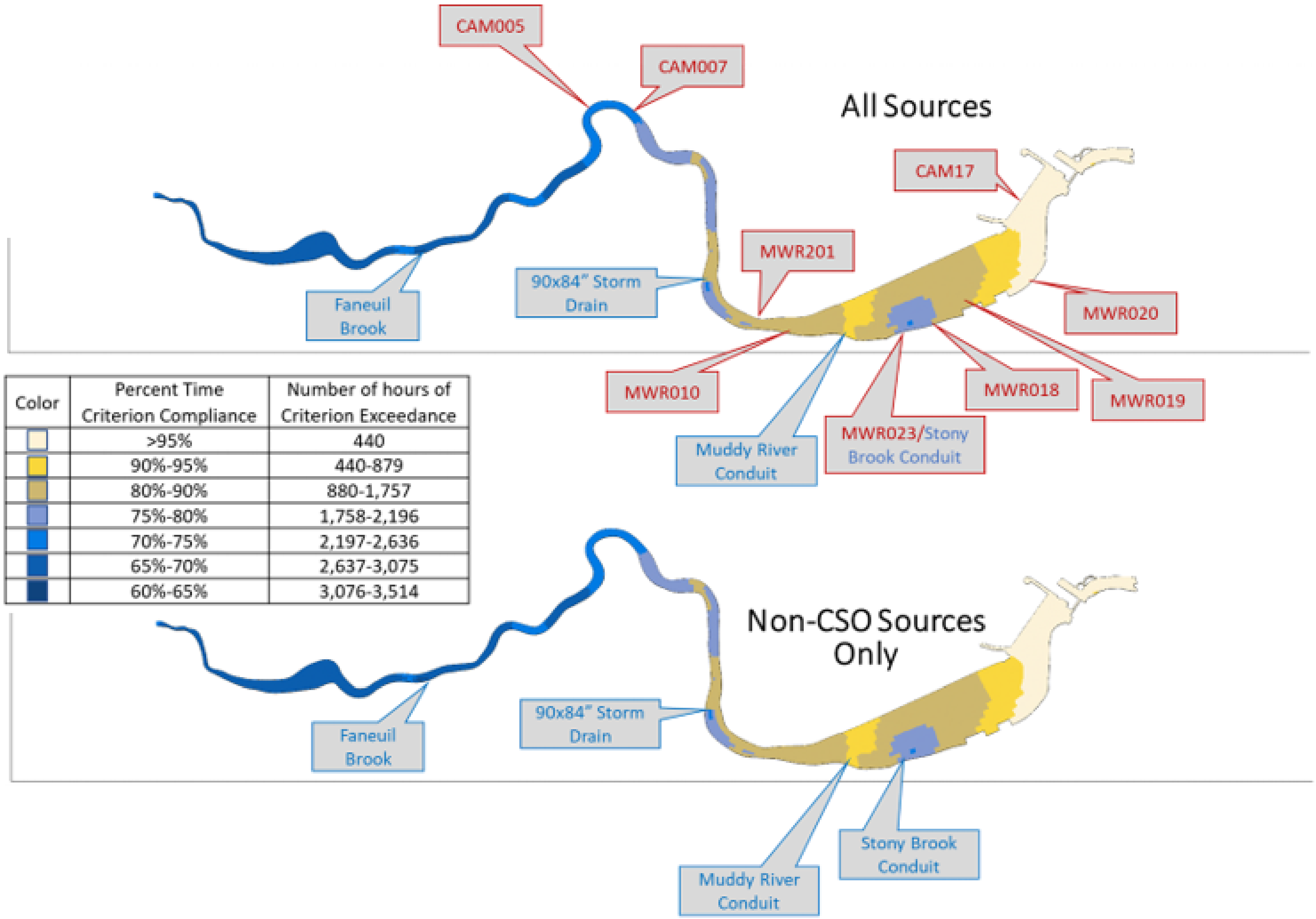
(2) The 3-month storm (03/07/1992) and 1-year storm (09/22/1992) are modeled as part of the full Typical Year model run. Refer to Table 3-3 for the dates and characteristics of each of the storm events in the Typical Year. For both of these storm events the next event starts about 4 days after the start of the first event.

(3) The *E. coli* bacteria count did not drop below the criterion before the next storm began in the Typical Year rainfall series. The hours of exceedance represent an extrapolation of the time required to drop below the criteria assuming the next storm did not occur.

Based on Table 3-6 above, for the 3-month storm with All Sources the model predicts it would take 88 hours (3.7 days) for the *E. coli* counts in the entire reach of Charles River to drop below the single sample maximum criterion. For the 1-year storm with All Sources the model predicts it would take 108 hours (4.5 days) for the *E. coli* counts in the entire reach of Charles River to drop below the single sample maximum criterion. It should be noted that there is some uncertainty associated with the duration of exceedance for the 1-year storm. As described in footnote 3 in Table 3-6, the *E. coli* bacteria count did not drop below the criterion before the next storm began in the Typical Year rainfall series. The hours of exceedance represent an extrapolation of the time required to drop below the criteria assuming the next storm did not occur.

Figure 3-5 presents isopleths of the hours of exceedance of the *E. coli* single sample maximum criterion over the Typical Year for “All Sources” and “Non-CSO Sources Only”. Observations include:

- The maximum ranges of hours of exceedance displayed on the figure are considerably smaller than the hours of exceedance listed in Table 3-6. As noted above, the hours of exceedance listed in Table 3-6 are for any one spatial or temporal point in the river, while the figure presents the values at fixed points. For most of the river, the hours of exceedance at any one point are substantially lower than maximum durations for the river as a whole shown in Table 3-6.
- The hours of exceedance for the “All Sources” and “Non-CSO Sources Only” cases are indistinguishable. This is because the bacterial loads from the CSOs are low relative to the other sources, and CSOs activate infrequently compared to stormwater discharges and the continuous boundary flows. For all but eight storms in the Typical Year, untreated CSOs contribute zero bacterial loadings to the Charles River and thus make no contribution to the duration of criteria exceedance. For the eight storms where untreated CSOs do occur, the volumes and loadings from CSOs are far exceeded by the loadings from stormwater and upstream sources. The values in Table 3-6 for “All Sources” and “Non-CSO Sources Only” show a similar pattern, with the hours of exceedance for the two conditions being very close.



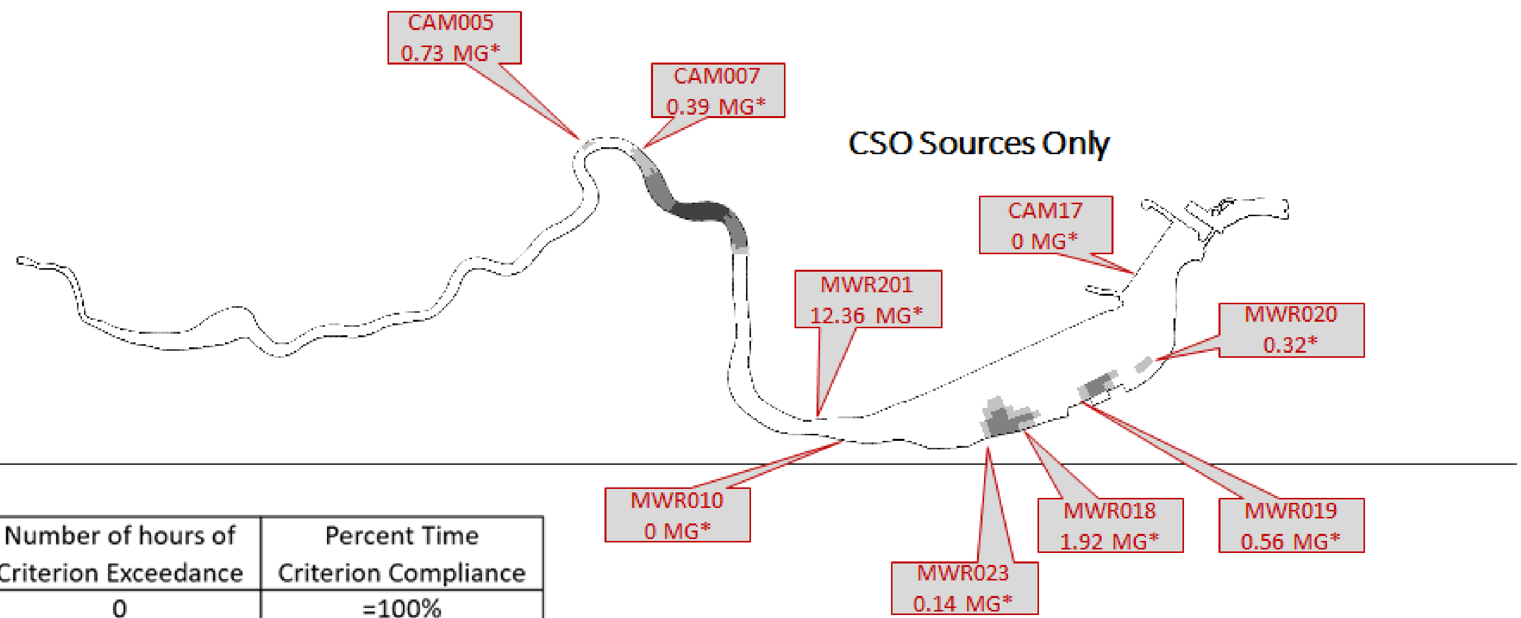
Color	Percent Time Criterion Compliance	Number of hours of Criterion Exceedance
	>95%	440
	90%-95%	440-879
	80%-90%	880-1,757
	75%-80%	1,758-2,196
	70%-75%	2,197-2,636
	65%-70%	2,637-3,075
	60%-65%	3,076-3,514

Figure 3-5. Hours of Exceedance and Percent Compliance with 235 Colonies/100mL *E. coli* Single-Sample Max. Criterion for the Typical Year

Figure 3-6 shows the hours of exceedance of the single sample maximum criterion for *E. coli* over the Typical Year for "CSO Sources Only". The scale is very different than in with hours of exceedance maximizing at no greater than 16 and many areas having 100% criterion compliance over the year. As in Figure 3-5 the hours of exceedance displayed in Figure 3-6 are considerably smaller than the numbers listed in Table 3-6 because the figure looks at exceedances at fixed points rather than anywhere among the 4,400 model grid cells in the river. Results for *Enterococcus* are similar (Appendix B.)

The areas of impact in Figure 3-6 downstream of outfall CAM007 are likely the result of localized river hydrodynamics and the cumulative effect of the discharges from CAM005 and CAM007. In the lower reach of the Charles River, the impacts from outfalls MWR023, MWR018, MWR019 and MWR020 remained local to the outfalls. At each of these locations, however, the total duration of impact over the entire year due to CSOs only was relatively short (<16 hours).

Although the number of hours of exceedance due to stormwater is much higher than the number of hours of exceedance due to CSOs, the in-stream counts due to CSOs are often much higher than those due to stormwater. But the single sample maximum criterion only considers exceedance of the criterion value, without regard of the degree of exceedance. In other words, an in-stream *E. coli* count of 10,000 #/100 mL for one hour yields one hour of exceedance as does an in-stream *E. coli* count of 1,000 #/100 mL. The hours of exceedance due to stormwater are higher than the number of hours of exceedance due to CSOs in part because stormwater discharges to the river for all storms, while CSOs only discharge for a few large storms. Also, the CSOs cause spikes of limited special extent, which dissipate more rapidly than the large scale impacts due to numerous stormwater discharges along the river.



Color	Number of hours of Criterion Exceedance	Percent Time Criterion Compliance
☐ (white)	0	=100%
(light gray)	0-4	99.95%-100%
(medium gray)	4-8	99.91%-99.95%
(dark gray)	8-12	99.86%-99.91%
(black)	12-16	99.82%-99.86%

Figure 3-6. Hours of Exceedance and Percent Compliance with 235 Colonies/100mL *E. coli* Single-Sample Max. Criterion for the Typical Year for CSO Sources Only

3.3.5 Sensitivity Analysis

The *E. coli* counts associated with the different sources were based on monitoring and model calibration and therefore suitable for impact assessment. However, it is instructive to see how the impacts described above would change for hypothetical changes in these bacterial counts. An initial set of sensitivity evaluations is summarized in Table 3-7, where stormwater bacterial counts were decreased by factors of 2 and 5, and to the 25th percentile value from the sampling data (possibly representing stormwater quality improvements associated with community undertaking as part of their MS4 permits), CSO bacterial counts were increased by a factor of 2 (to gauge the robustness of the CSO impact assessment) and boundary values were multiplied by 0.5 and 0.2 (see Appendix B for *Enterococcus* results).

Table 3-7. Single Sample Maximum Sensitivity Analysis

<table>
<tr><th colspan="5">Charles River</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Source Count Multiplier</th><th rowspan="2">E. coli Value (#/100 mL)</th><th colspan="2">E. coli
Single Sample Maximum Criterion
(235 Colonies/100 mL)</th></tr>
<tr><th>Hours of Exceedance</th><th>Percent Compliance</th></tr>
<tr><td rowspan="4">Stormwater Only</td><td>1.0</td><td>14,000</td><td>3,121</td><td>64%</td></tr>
<tr><td>0.5</td><td>7,000</td><td>2,305</td><td>74%</td></tr>
<tr><td>0.2</td><td>2,800</td><td>1,491</td><td>83%</td></tr>
<tr><td>25th Percentile</td><td>1,110</td><td>935</td><td>89%</td></tr>
<tr><td rowspan="2">CSO Only</td><td>1.0</td><td>Time varying Computed by Mass Balance</td><td>37</td><td>99.6%</td></tr>
<tr><td>2.0</td><td>2x Time varying Computed by Mass Balance</td><td>67</td><td>99.2%</td></tr>
<tr><td rowspan="3">Boundary Only</td><td>1.0</td><td>Time varying Computed by Boundary Condition Model</td><td>3,612</td><td>59%</td></tr>
<tr><td>0.5</td><td>0.5 x Time varying Computed by Boundary Condition Model</td><td>2,727</td><td>69%</td></tr>
<tr><td>0.2</td><td>0.2 x Time varying Computed by Boundary Condition Model</td><td>1,502</td><td>83%</td></tr>
</table>

In Table 3-7, the values in the rows associated with "Source Count Multiplier" of 1.0 reflect the baseline stormwater or CSO counts as described in Section 2 above. For the stormwater-only case, the "Source Count Multiplier" of 0.5 reflects a 50 percent reduction in the *E. coli* counts in the stormwater discharges, and the "Source Count Multiplier" of 0.2 reflects an 80 percent reduction in the bacterial counts in stormwater. As described in Section 2, the bacterial counts in the CSO were time-varying based on the sanitary fraction, with the model computing a unique bacterial count for each model timestep at each outfall. For the CSO loading sensitivity analysis, the Source Count Multiplier simply multiplied the computed value at each timestep by a factor of 2. The time-varying boundary source loadings were similarly reduced for the boundary loading sensitivity analysis.

As could be expected, percent compliance increases as stormwater and boundary source quality improves and decreases as CSO counts increase. However, for both stormwater and the boundary sources, even an 80 percent reduction in the value of the bacterial counts would still leave approximately 1,500 hours of non-compliance with the *E. coli* criterion. For stormwater, as indicated above in Table 2-5, the value of 2,800 #/100mL for *E. coli* would fall between the 25^{th} and 50^{th} percentile of the stormwater samples collected. It is also worth noting that the *2004 Cottage Farm CSO Facility Assessment Report* described an assessment of the potential to reduce bacterial loads from stormwater tributary to the Charles River conducted by the USGS. The following is an excerpt from the *2004 Cottage Farm Report* (Metcalf & Eddy, 2004):

> *As part of its work related to the Charles River, USGS conducted an assessment of the potential effectiveness of various BMPs in terms of removal of stormwater pollutant loads. The outcome of this study was presented in a report titled,* Potential Effects of Structural Controls and Street Sweeping on Stormwater Loads to the Lower Charles River, Massachusetts *(USGS, 2002). In terms of bacteria, USGS presented a range of performance that could potentially be achieved through aggressive street sweeping and regular catch basin cleaning and maintenance. The maximum realistic removal of bacteria in stormwater was estimated at 18 percent, and a minimum or reasonable low-end of performance was set at 8 percent.*

On-going efforts by communities to identify and address illicit sanitary connections to storm drains would also contribute to reductions in bacterial counts in the stormwater discharges. But even with those continued efforts, the sampling data and model results indicate that stormwater would continue to be a significant contributor to non-attainment of the water quality criteria for bacteria in the Charles River. Similarly, boundary bacterial counts, even if reduced, would continue to cause water quality criteria exceedances.

Regarding the sensitivity analysis for CSO counts, doubling of the counts nearly doubled the duration of exceedance of the criteria. However, even with the hours of exceedance nearly doubled, the annual percent attainment would still be greater than 99 percent. This highlights the relatively small impact that CSOs have on the overall bacteria counts in the Charles River, consistent with the relative flow volume and bacterial count loadings of CSOs in comparison to stormwater and upstream sources.

3.3.6 Summary

Salient results of the Charles River water quality impact assessment are summarized below:

- Stormwater contributes bacterial loadings each time it rains, over 90 times/year on average, and is the largest source of bacterial loading for both the design storms and on an annual basis.
- The upstream boundary at Watertown Dam contributes bacterial loadings 24/7, and is the second-largest source of bacterial loading.
- CSOs contribute loadings only during the larger storms during a Typical Year, on average eight times/year (at CAM005, less often at the other CSOs, and Cottage Farm discharge is treated).
- In a 1-year storm, CSOs contribute less than 1 percent of the total bacterial load.
- Typical Year performance:
  - With CSO loadings only, the single sample maximum criterion for *E. coli* is met everywhere in the Lower Charles River Basin approximately 99.5% of the time.

- Even if the modeled CSO concentrations were doubled, attainment of the single sample maximum criterion for *E. coli* would still be 99.1%.
- These results are consistent with the findings from the water quality modeling conducted for the 1997 LTCP (99-100% of time <200 colonies/100mL fecal coliform for CSO loads, only).
- An 80 percent reduction in the bacteria counts in either stormwater or the boundary loads would reduce the hours of exceedance of water quality criteria for bacteria attributable to stormwater to these sources but would still leave approximately 1,500 hours of exceedance of the *E. coli* criterion based on either stormwater or boundary loadings only.

4. Alewife Brook/Upper Mystic River

4.1 Model Characteristics

The Alewife Brook/Upper Mystic River model is a one-dimensional model based on the InfoWorks ICM software. The model includes a hydrodynamic part, which calculates water levels and cross section-averaged velocities, and a water quality part, which calculates cross section-averaged *E. coli* and *Enterococcus* counts. The model extends from the Amelia Earhart Dam to the Lower Mystic Lake and covers the Alewife Brook in its entirety, as shown in Figure 4-1. This figure shows the cross sections where stream bathymetry was specified.

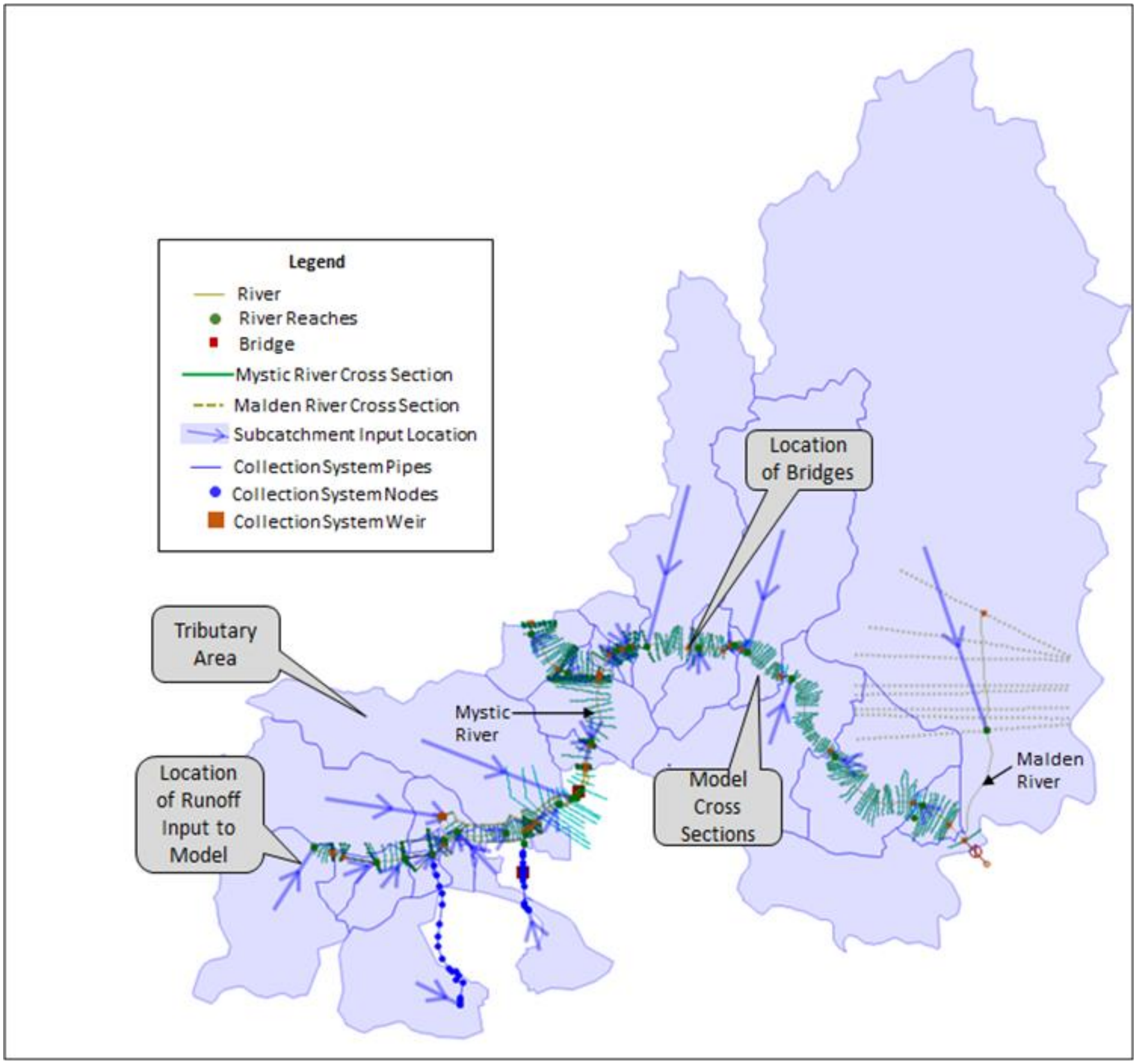


Figure 4-1. Mystic River Basin Model Coverage and Transects

As described above in Section 2, CSO flow inputs were based on the 2019 Conditions version of the MWRA's collection system hydraulic model, and the stormwater and dry weather discharges to the system were calculated using a calibrated hydrologic model based on the SWMM methodology, including groundwater discharges from the "soil store" component.

Flows at the upstream boundaries of Alewife Brook and the Malden River were generated by the tributary runoff sub-catchments at those locations, while flows at the upstream boundary of the Mystic River with the Lower Mystic Lake were generated by the Mystic River watershed model.

Bacteria counts were applied to each of the inflows to the model area as described above in Section 2. The values for all the inflow categories determined through model calibration are summarized in Table 4-1. The flow-weighted average sanitary fraction and bacteria counts for the discharge from each CSO outfall in the Typical Year are presented in Table 4-2.

Table 4-1. Selected Model Parameters based on Model Calibration – Alewife Brook/Upper Mystic River

	Stormwater Counts (1) (#/100 mL)	Baseflow Inflow Counts (2) (#/100 mL)	CSO Sanitary Fraction Counts (#/100 mL)	CSO non-Sanitary Fraction Counts (#/100 mL)	Die-off Rate (Day^{-1})
E. coli	25,000	134	2,500,000	14,000	0.8
Enterococcus	6,700	45	1,000,000	6,700	0.8

(1) For runoff areas tributary to the Mystic River between station 083 and the Lower Mystic Lake, stormwater counts of 50,000 #/100mL for *E. coli* and 20,000 #/100mL for *Enterococcus* were applied, to account for loadings from the Lower Mystic Lake.

(2) For baseflow inputs to the Mystic River between station 083 and the Lower Mystic Lake, counts of 2,000 #/100mL for *E. coli* and 3,000 #/100mL for *Enterococcus* were applied, to account for loadings from the Lower Mystic Lake.

Table 4-2. Predicted Sanitary Fractions and Flow-weighted Counts for the Typical Year

Location	Flow-weighted Sanitary Fraction (%)(1)	Flow-weighted Counts (#/100 mL)	
		E. coli	*Enterococcus*
MWR003	2.33%	71,902	29,835
CAM401B	4.90%	135,703	55,327
CAM401A	2.62%	79,100	32,711
CAM002(2)	N/A	N/A	N/A
CAM001	0.97%	38,167	16,356
SOM001A	2.22%	69,206	28,758
SOM007A (Somerville Marginal CSO Facility Treated Discharge) (3)	N/A	18	17

(1) For each untreated CSO outfall, the sanitary fraction shown is the flow weighted average in the discharge pipe over the periods when the outfalls were discharging flow.

(2) Outfall did not discharge CSO during the Typical Year.

(3) For outfall SOM007A the sanitary fraction method was not applied to the treated discharge. The flow-weighted counts reflect the average treated discharge counts sampled from the Somerville Marginal CSO Facility effluent in 2018.

4.2 CSO Activations

The CSO activations during the Typical Year at the CSOs discharging to the Alewife Brook/Upper Mystic River based on the collection system hydraulic model representative of 2019 system conditions are summarized in Table 4-3. SOM007A is the treated discharge from the Somerville Marginal CSO facility, which only occurs upstream of the Amelia Earhart Dam during certain tide conditions. Other than SOM007A, no other CSOs discharge to the Upper Mystic River; CSOs discharging to Alewife Brook are all untreated. The total treated CSO discharge volume to the Upper Mystic River during the Typical Year was 4.95 MG.

A total of 10 storms were predicted to cause untreated CSO discharges to Alewife Brook in the Typical Year. The most active CSO outfall was CAM401A, with 10 activations, although the largest individual storm discharge volume at CAM401A was 0.98 MG and four of the activations had volumes less than 0.10 MG. Activation frequencies and volumes at CAM401A have been significantly reduced since 2019 as a result of sewer cleaning operations conducted by the City of Cambridge.

Overall, only two untreated discharges to Alewife Brook exceeded 1 MG (at SOM001A), and four storms resulted in discharges at only one outfall in Alewife Brook. The largest discharge volumes were at SOM001A, and that outfall had the largest total volume (3.6 MG). The total untreated CSO discharge volume to Alewife Brook during the Typical Year was 9.5 MG.

Table 4-3. CSO Activations to the Alewife Brook and Upper Mystic River during the Typical Year

Date	Rainfall		CSO Volume (MG)					
	Peak 15-Min Intensity (in/hr)	Depth (in)	CAM001	MWR003	CAM401A	CAM401B	SOM001A	SOM007A
1/4/1992	0.48	1.15						
1/14/1992	0.52	0.49						
1/23/1992	0.4	1.38						
2/15/1992	0.2	0.87						
2/25/1992	0.24	0.84						
3/7/1992 (3-mo Storm)	0.22	1.89						0.04
3/11/1992	0.48	0.97						
3/19/1992	0.08	0.42						
3/26/1992	0.16	0.67						
3/28/1992	0.08	0.42						
4/11/1992	0.4	0.52						
4/16/1992	0.28	1.02						
4/24/1992	0.24	0.88						
5/2/1992	1.32	1.14			0.45	0.07	0.07	3.41
6/1/1992	0.48	2.24			0.22			
6/6/1992	1	1.34			0.22			
6/20/1992	0.56	0.45						
6/24/1992	0.24	0.56						
7/6/1992	0.36	0.38						
7/15/1992	0.32	0.5						
7/23/1992	0.28	0.42						
7/31/1992	0.68	0.59						
8/11/1992	1.24	0.87			0.09	0.03	0.33	
8/18/1992	0.8	2.91		0.06	0.75	0.10	0.54	
9/3/1992	0.68	1.19			0.09			
9/9/1992	1.72	0.57			0.08		0.05	
9/11/1992	0.36	0.38						
9/22/1992 (1-yr Storm)	0.65	2.8		0.73	0.98	0.32	1.06	0.33
9/26/1992	0.36	0.74						
10/10/1992	0.72	2.04			0.04			
10/23/1992	1.08	1.18	0.02	0.80	0.67	0.21	1.54	0.47
10/24/1992	0.16	0.38						
11/3/1992	0.2	0.94						
11/5/1992	0.16	0.31						
11/21/1992	0.36	1.93						
11/23/1992	0.36	1.93						
11/26/1992	0.24	0.51						
12/3/1992	0.2	0.82						0.53
12/12/1992	0.24	3.89						0.17
12/17/1992	0.2	0.58						
12/29/1992	0.16	0.37						
12/30/1992	0.12	0.44						
Total CSO Volume in Typical Year			**0.02**	**1.60**	**3.59**	**0.73**	**3.60**	**4.95**

Note: CAM002 does not activate during the Typical Year

4.3 Water Quality Impact Assessment

4.3.1 Approach

The Alewife Brook hydrodynamic and water quality model was run for the entire Typical Year, which as described above also allowed for extraction of values for the 3-month and 1-year storms. As described for the Charles River, bacterial loadings were input to the model from treated and untreated CSOs, stormwater, and upstream boundaries, and impacts from different sources could be assessed separately and together. Presenting results due to different sources separately is justified by the fact that the water quality model is linear and, consequently, in-stream bacterial counts due to different sources are additive, as described in Section 3.3.1. In the model runs for the individual sources, the bacterial counts in the other sources were set to zero, but the discharges from the other sources were retained. Where appropriate, output was tabulated separately for the Alewife Brook and the Upper Mystic River.

4.3.2 Source Volumes and Bacterial Loadings

The flow volumes discharged to the Alewife Brook and Upper Mystic River are summarized by source in Table 4-4. Alewife Brook has no treated CSO discharges and no separately-generated upstream boundary flow; all flows to the upstream end of the brook are from sub-catchment discharges, either as runoff or soil store discharge. No untreated CSOs discharge directly to the Upper Mystic River, but treated CSO discharges from the Somerville Marginal facility can discharge to the Upper Mystic River when the facility activates during high tide. Note that the dry weather and boundary flows for the 3-month storm are slightly higher than those for the 1-year storm because the 3-month storm selected for analysis occurs in March, during high groundwater and upstream river flow, while the 1-year storm selected for analysis occurs in September, when groundwater and upstream flow are low.

The *E. coli* loadings to the Alewife Brook and Upper Mystic River during the 3-month and 1-year storms and during the Typical Year are summarized in Table 4-5 (see Appendix B for *Enterococcus* results). As indicated in this table, stormwater is by far the largest source of *E. coli* loadings. In a 1-year storm, CSOs contribute approximately 30 percent of the total bacterial load to Alewife Brook, but the contribution drops to 5 percent in the 3-month storm and constitutes about 10 percent on an annual basis. Boundary sources are not as significant as for the Charles River, and dry weather sources contribute relatively small loadings. These patterns of relative loadings are generally consistent with the findings from the *2003 Final Variance Report for Alewife Brook/Upper Mystic River*.

Table 4-4. Source Volumes to the Alewife Brook/Upper Mystic River

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

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

Table 4-5. *E. coli* Loadings to the Alewife Brook/Upper Mystic River

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

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

4.3.3 Model Results

The water quality model was run for the entire Typical Year. Model output was generated in the form of *E. coli* and *Enterococcus* counts at 15-minute intervals at each defined segment along the linear model.

Simulations were conducted for the following conditions for both *E. coli* and *Enterococcus*:

- All sources;
- Non-CSO sources only;
- Stormwater only;
- Dry weather sources only;
- Boundaries only; and
- CSOs only.

Longitudinal *E. coli* counts profiles before, during and after the 1-year storm are presented below. This storm caused untreated CSO discharges at MWR003 (0.73 MG), CAM401A (0.98 MG), CAM401B (0.32 MG) and SOM001A (1.06 MG), as well as a treated discharge at SOM007A/MWR205A (0.33 MG). As indicated in Figure 4-2, the untreated CSOs to Alewife Brook started at about 5:30 and ended at 8:00, while the treated discharge at SOM007A/MWR205A occurred approximately four hours later, as a result of tidal impacts redirecting some of the discharge from MWR205 to this discharge upstream of the Amelia Earhart Dam. The largest untreated CSO flows were associated with SOM001A and CAM401A, and the peak CSO flows occurred at about 6:30.

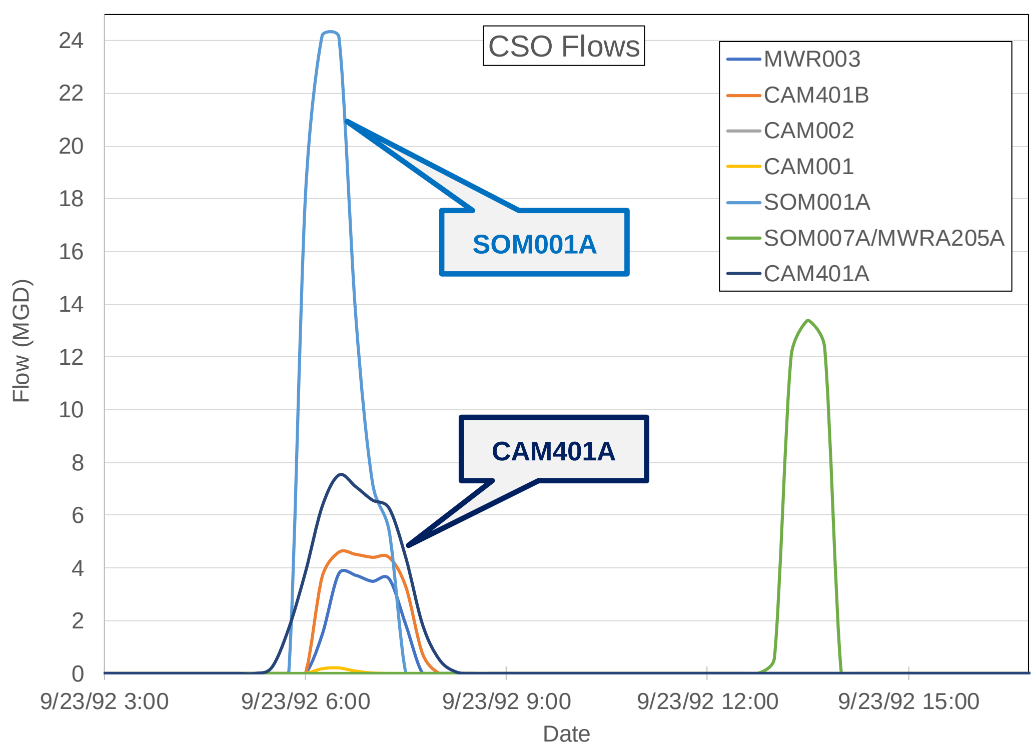


Figure 4-2. CSO Flows during the 1-Year Storm

Figure 4-3 below provides a location plan for Alewife Brook/Upper Mystic River CSOs as well as the longitudinal measurements from the upstream end at the Alewife Brook Source (0 ft) to the Amelia Earhart Dam (38,040 ft).

<u>All Sources</u>

The longitudinal *E. coli* profiles for all sources at 3-hour intervals starting prior to the start of the 1-year storm are shown in Figure 4-4 to Figure 4-12. Profiles are shown on each plot for the Alewife Brook and sections of the Mystic River upstream and downstream of the Alewife Brook confluence. For the reach of the Mystic River upstream of the confluence with Alewife Brook, the reported model values start at sampling station 083, which was the most upstream point used for model calibration.

The first plot (at hour 0:00) shows conditions before the storm, with low *E. coli* counts. The next plot (at hour 3:00) shows the impact of stormwater discharges prior to CSO activation. The following plot (at hour 6:00) is at the beginning of the untreated CSO activations to Alewife Brook, showing a large *E. coli* count spike in the vicinity of SOM001A, but the high counts have not yet reached the Mystic River. The next plot (at hour 9:00) is after the end of the CSO discharges to Alewife Brook. It shows a wider area of high counts in the region of Alewife Brook with the CSOs, and a spike in counts has reached the Mystic River. In the following plots, the spikes in *E. coli* counts travel downstream and decrease in amplitude. The treated discharge from SOM007A/MWR205 has no observable impact on the *E. coli* counts, as expected.

<u>CSO Only</u>

Longitudinal *E. coli* profiles for CSO sources only at 3-hour intervals starting prior to the start of the 1-year storm are shown in Figure 4-14 to Figure 4-20. The CSO discharges first appear in Figure 4-14, at hour 6:00, which is approximately 30 minutes after the CSOs started to discharge. Compared to the “All Sources” plot of the same hour for all sources, the *E. coli* spikes are of the same magnitude but narrower. It is interesting to note that by hour 12:00, about 6 hours after the start of CSO discharges, the contribution of CSO to the *E. coli* counts in Alewife Brook has ended. From Table 4-3 above, the 1-year storm had the second largest total CSO volume to Alewife Brook in the Typical Year. Thus, only one other storm in the Typical Year would likely have a slightly longer duration of impact to Alewife Brook from CSO sources only. Because the Somerville Marginal effluent is treated, impacts to the Mystic River of the “CSO Only” scenario are entirely due to CSO discharges to the Alewife Brook.

Figure 4-3. Alewife Brook/Upper Mystic River CSO Location Plan and Longitudinal Measurements from Alewife Brook Source (0 ft) to Amelia Earhart Dam (38,040 ft)

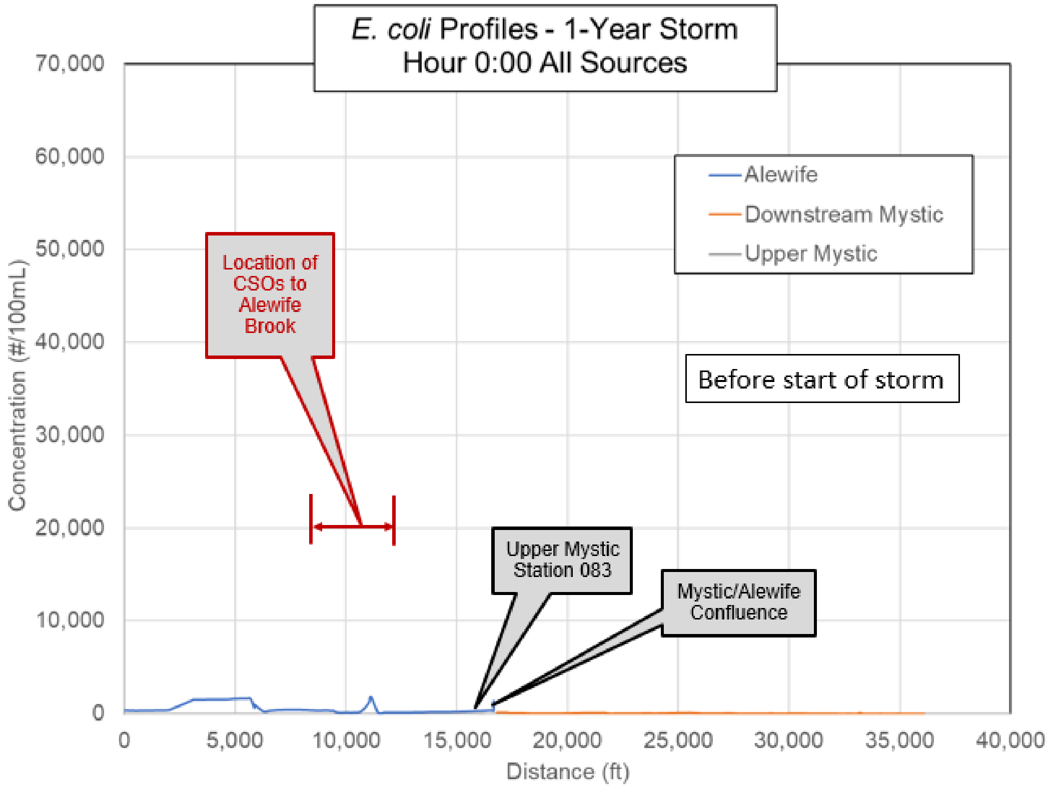


Figure 4-4. *E. coli* Profile Before Start of the 1-Year Storm – All Sources

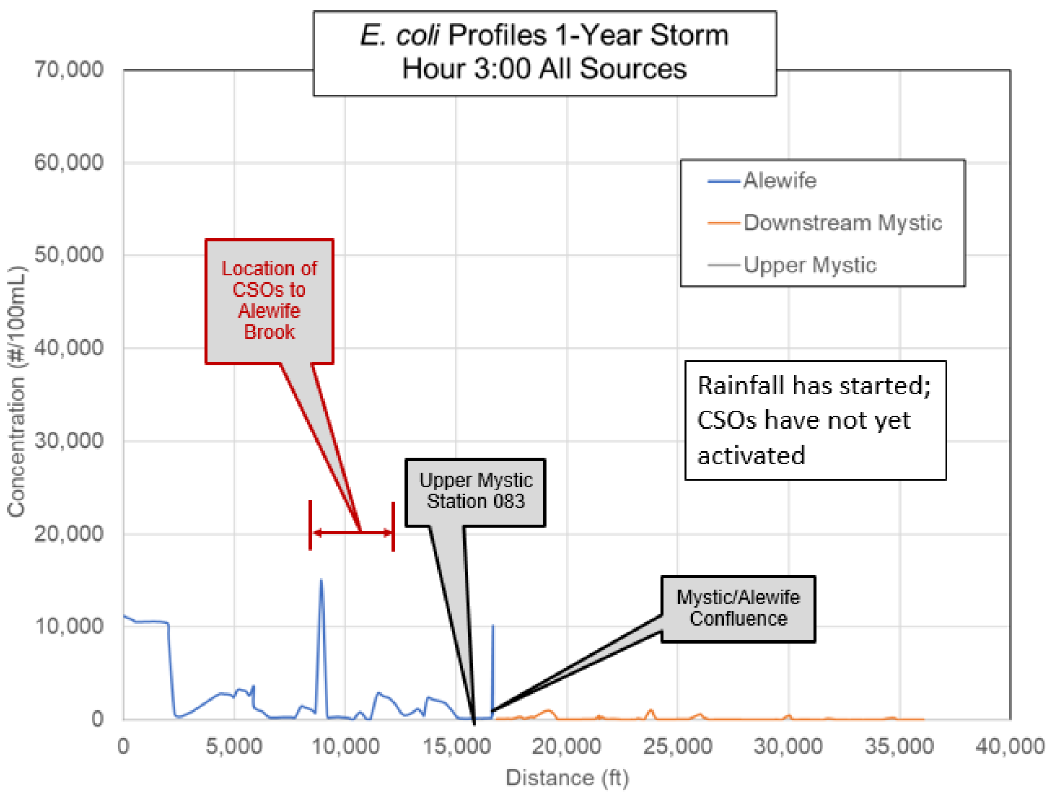


Figure 4-5. *E. coli* Profile at Hour 3:00, 1-Year Storm – All Sources

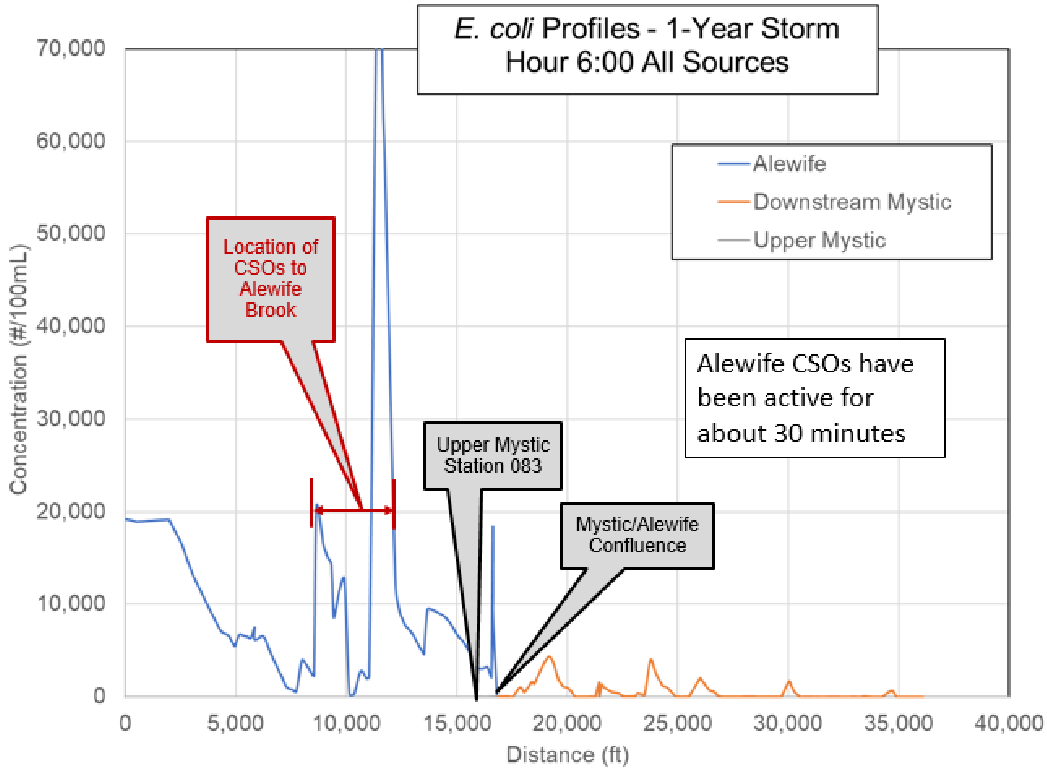


Figure 4-6. ***E. coli*** **Profile at Hour 6:00, 1-Year Storm – All Sources**

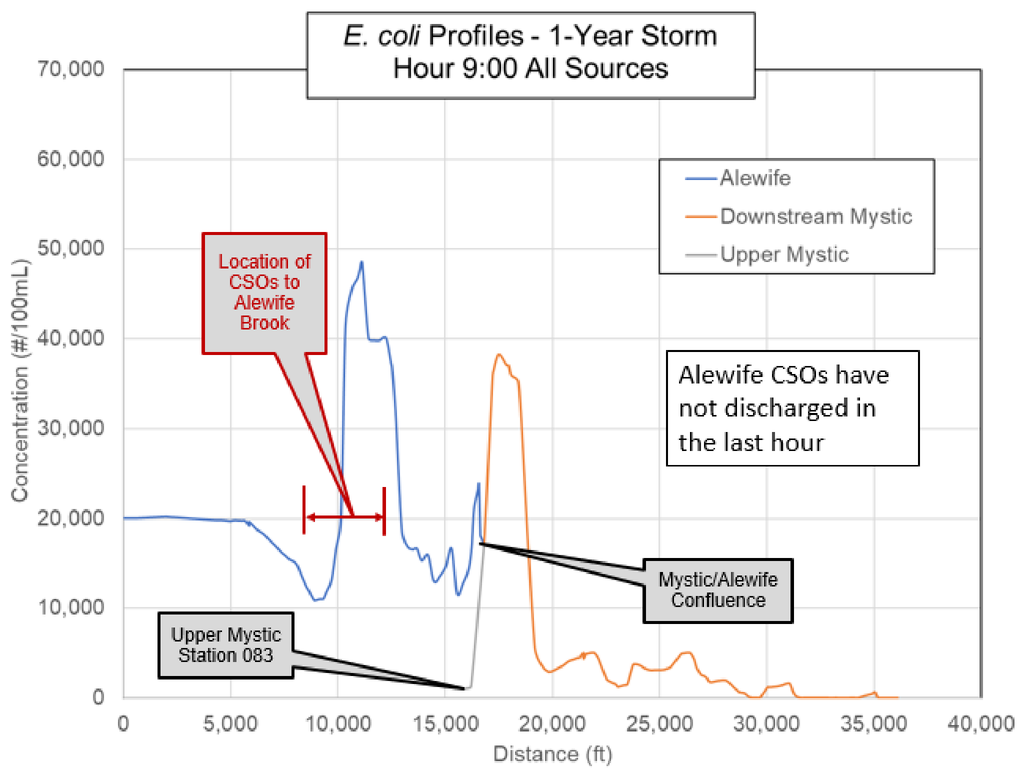


Figure 4-7. ***E. coli*** **Profile at Hour 9:00, 1-Year Storm – All Sources**

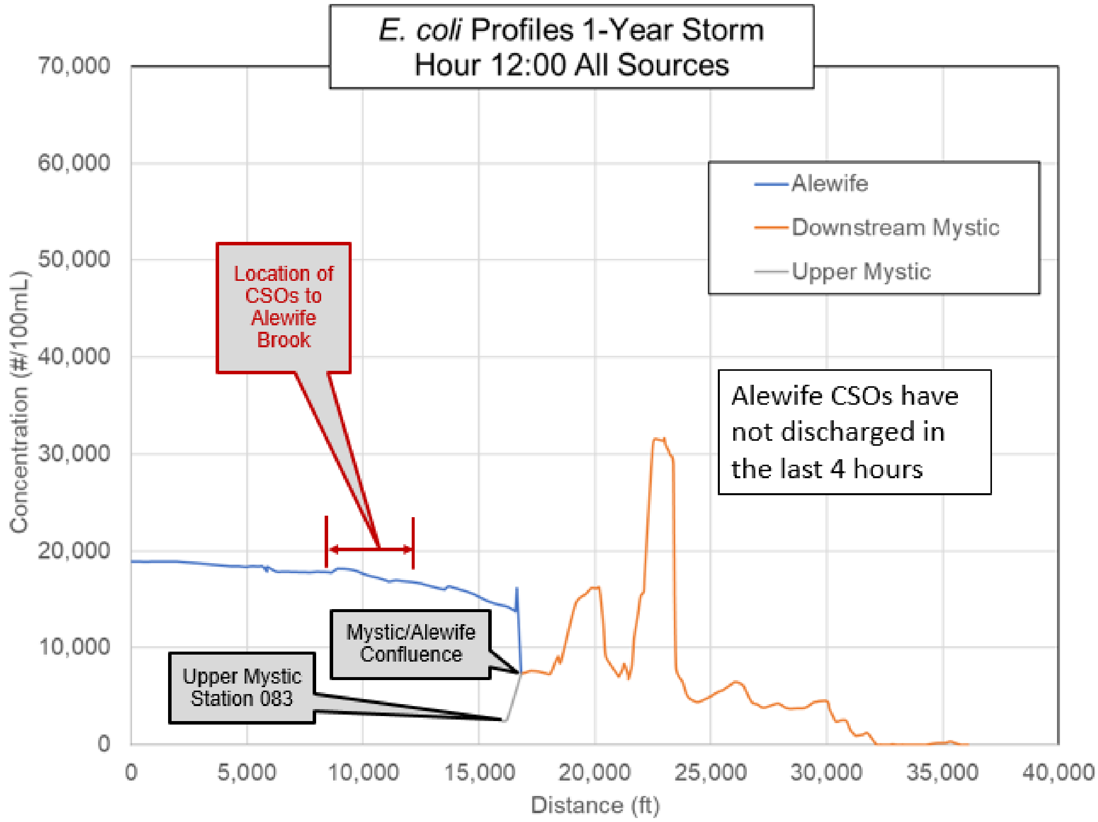


Figure 4-8. *E. coli* Profile at Hour 12:00, 1-Year Storm – All Sources

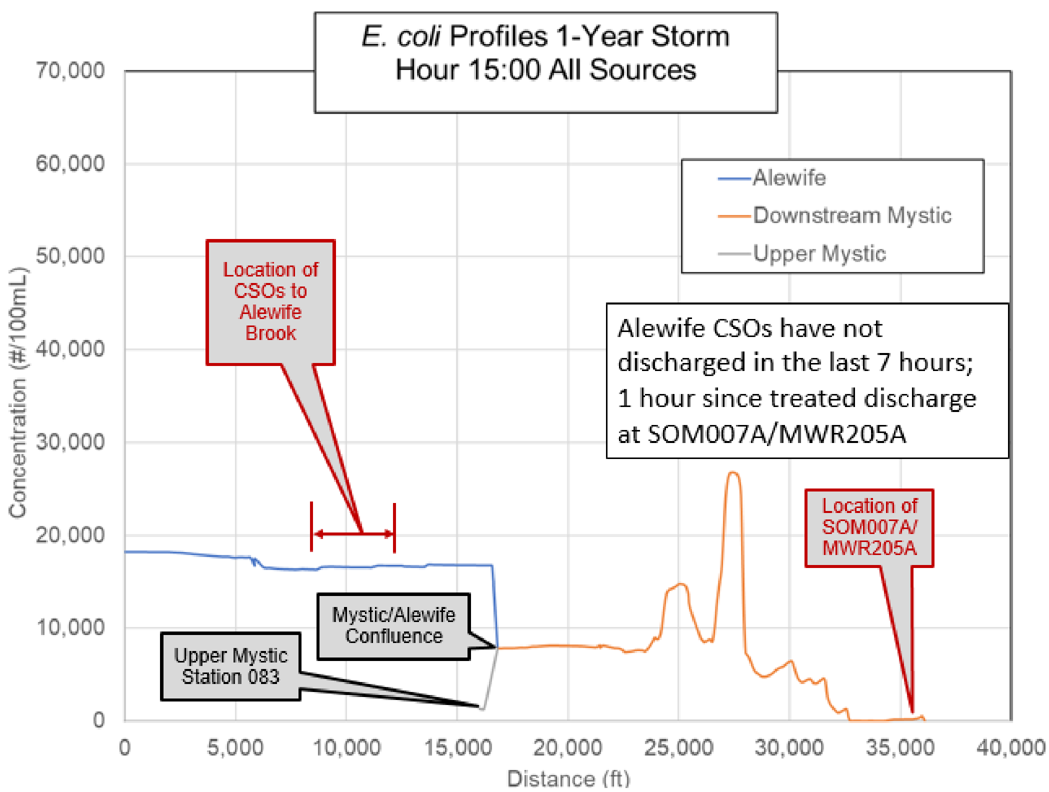


Figure 4-9. *E. coli* Profile at Hour 15:00, 1-Year Storm – All Sources

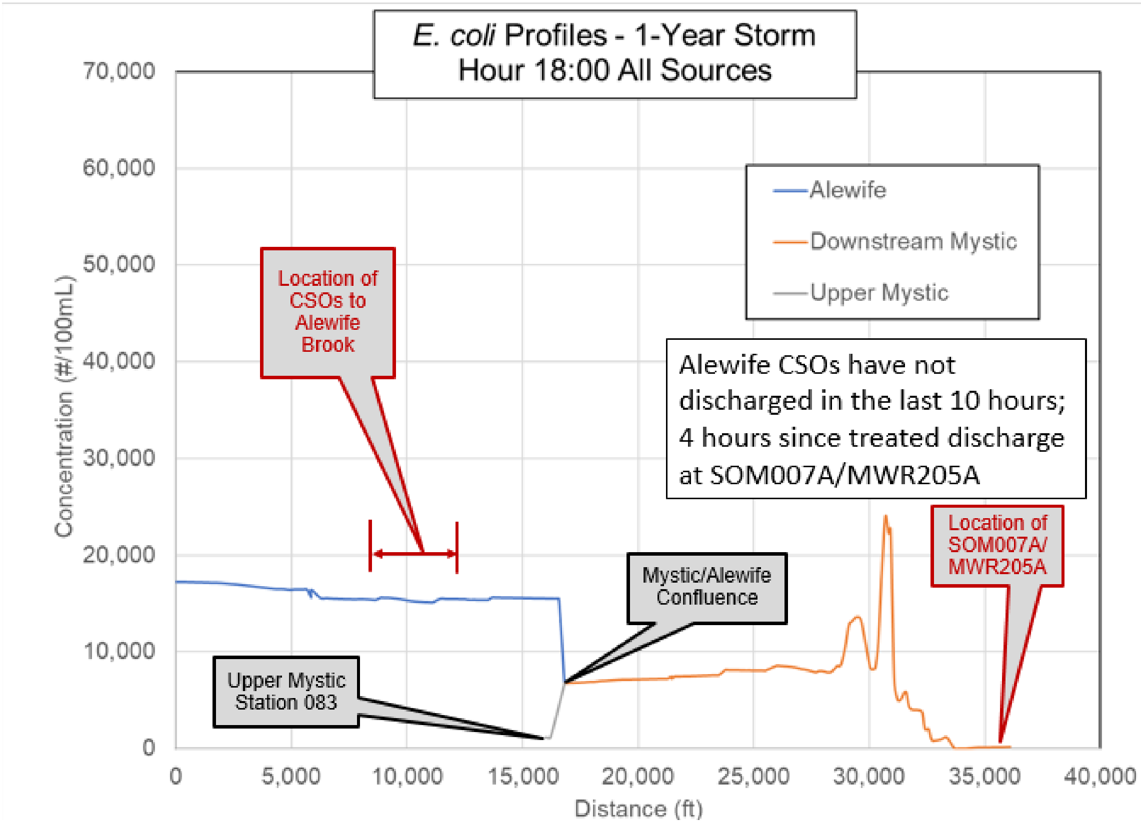


Figure 4-10. *E. coli* Profile at hour 18:00, 1-Year Storm – All Sources

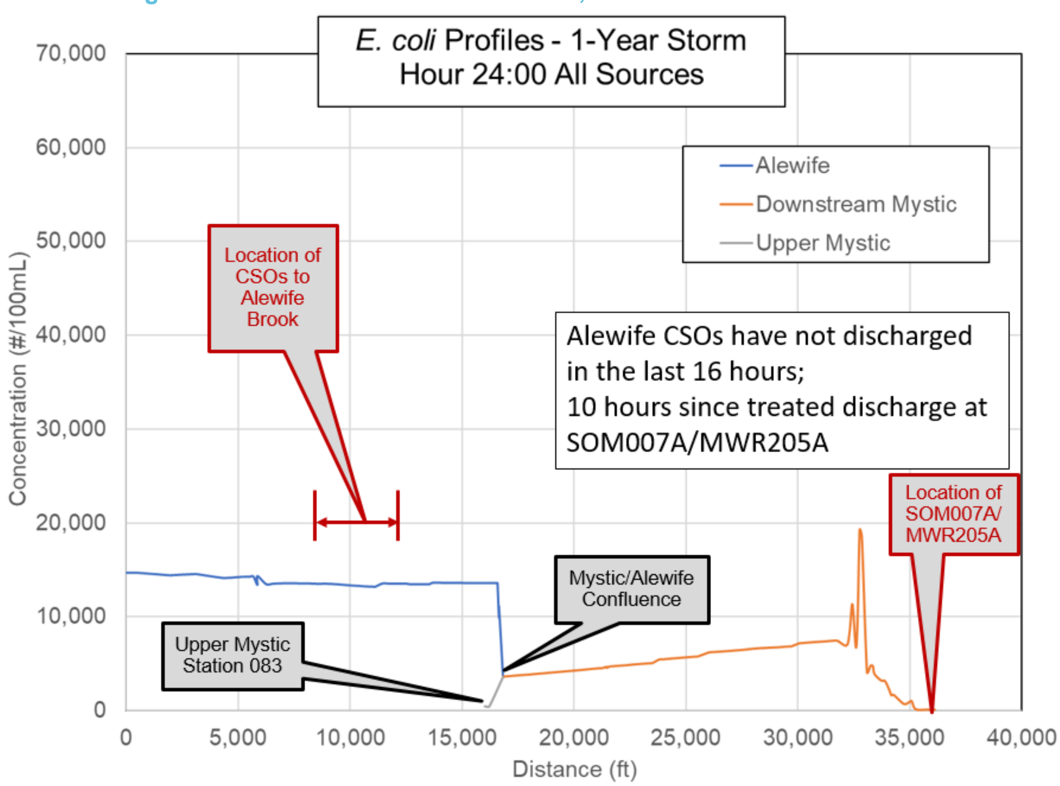


Figure 4-11. *E. coli* Profile at Hour 24:00, 1-Year Storm – All Sources

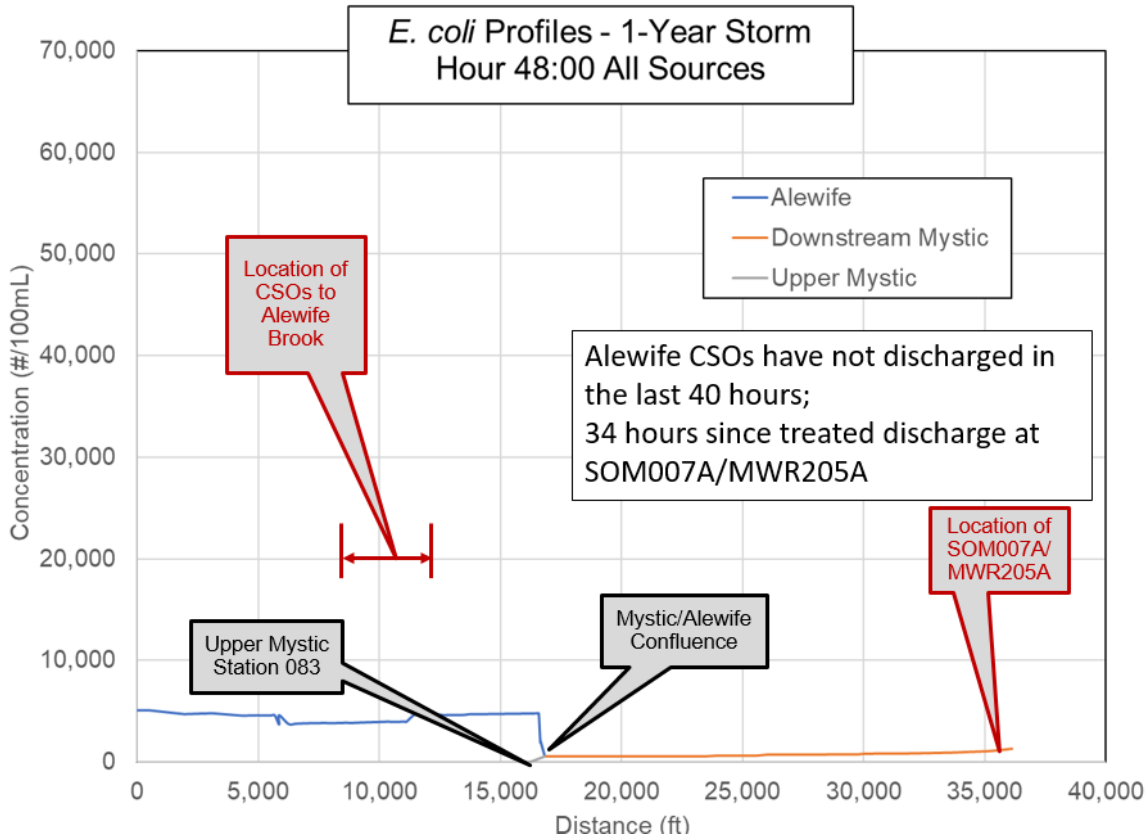


Figure 4-12. *E. coli* Profile at Hour 48:00, 1-Year Storm – All Sources

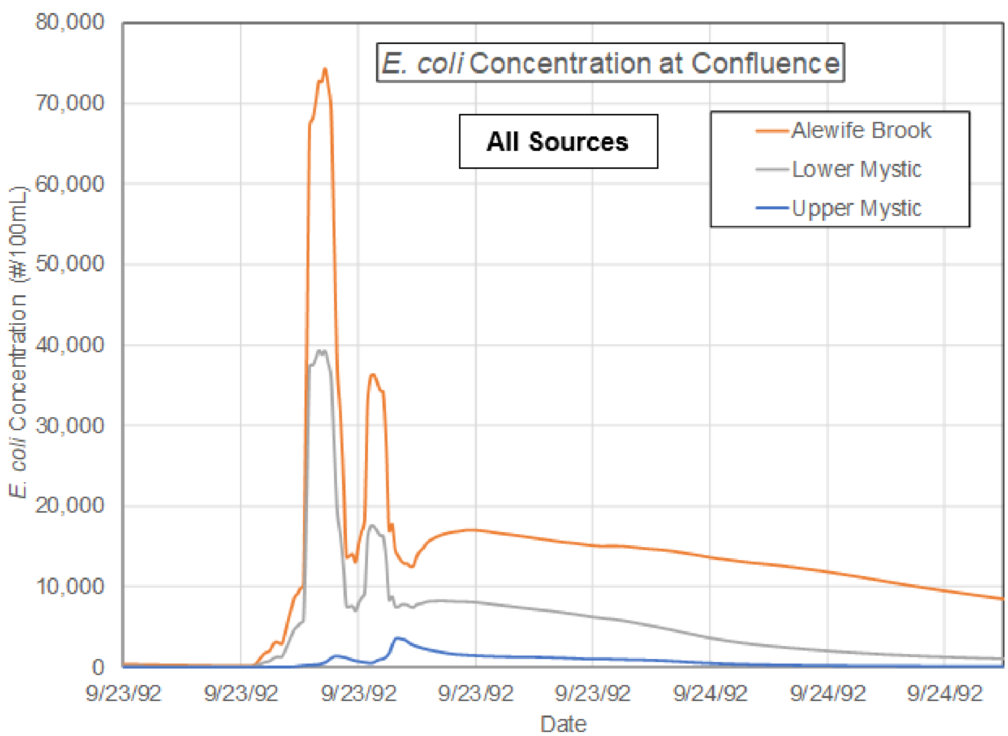


Figure 4-13. *E. coli* Counts Upstream and Downstream of the Alewife/Mystic Confluence, 1-Year Storm – All Sources

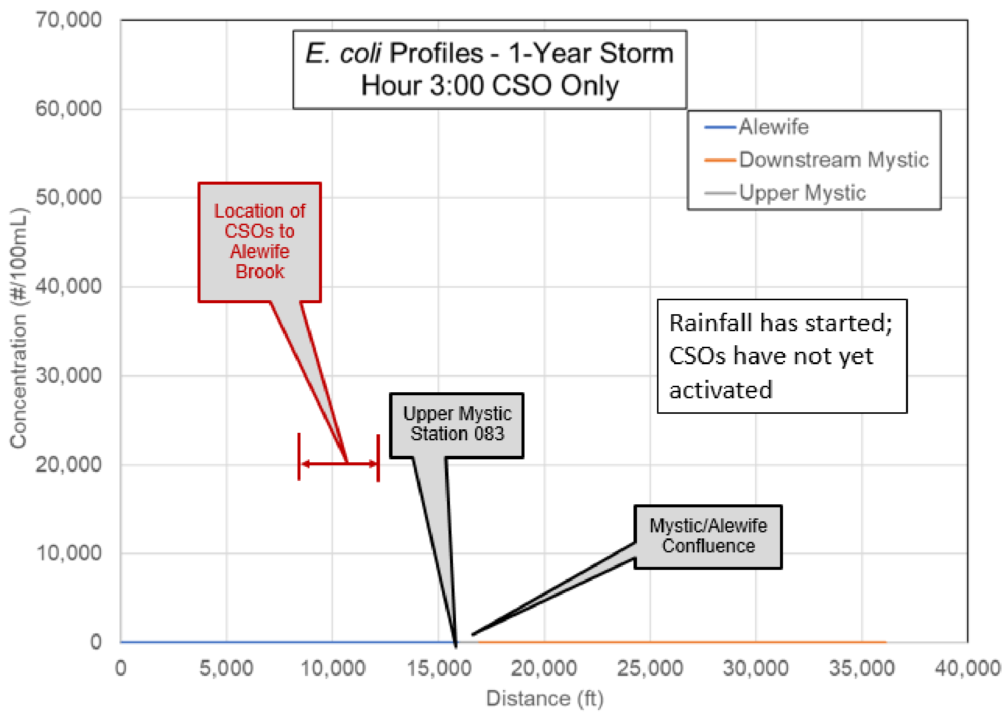


Figure 4-14. ***E. coli*** **Profile at Hour 3:00, 1-Year Storm – CSO Only**

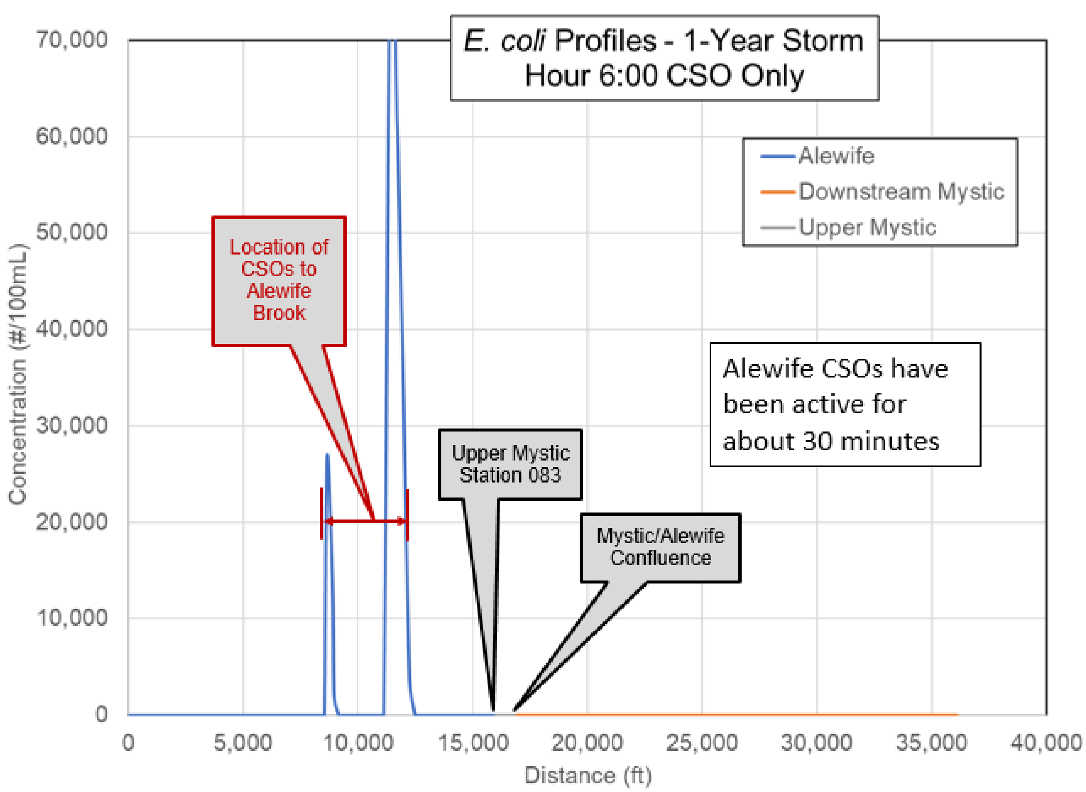


Figure 4-15. ***E. coli*** **Profile at Hour 6:00, 1-Year Storm – CSO Only**

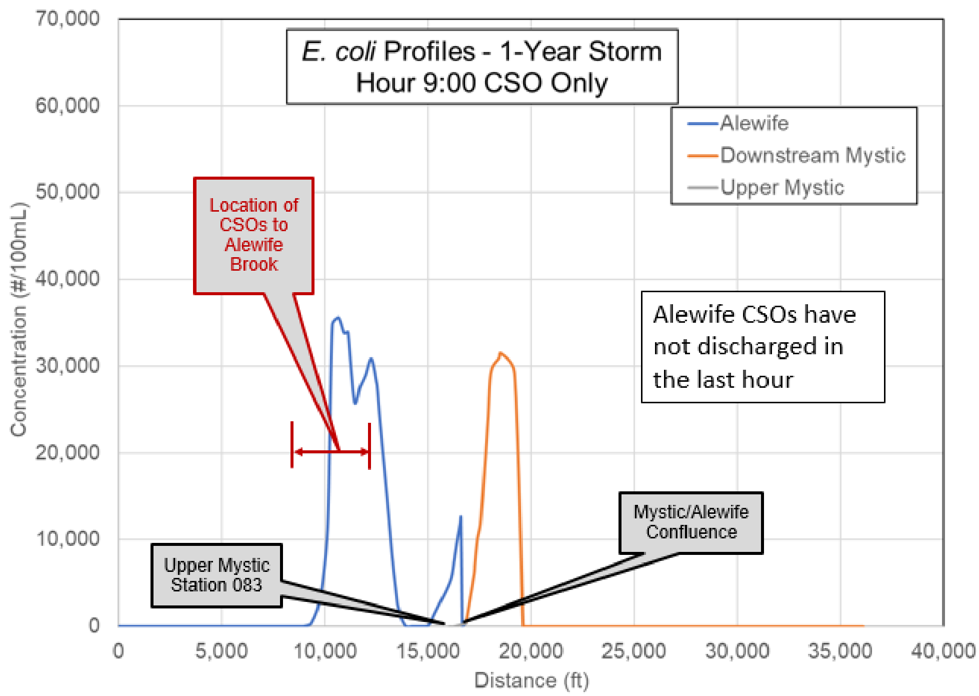


Figure 4-16. *E. coli* Profile at Hour 9:00, 1-Year Storm – CSO Only

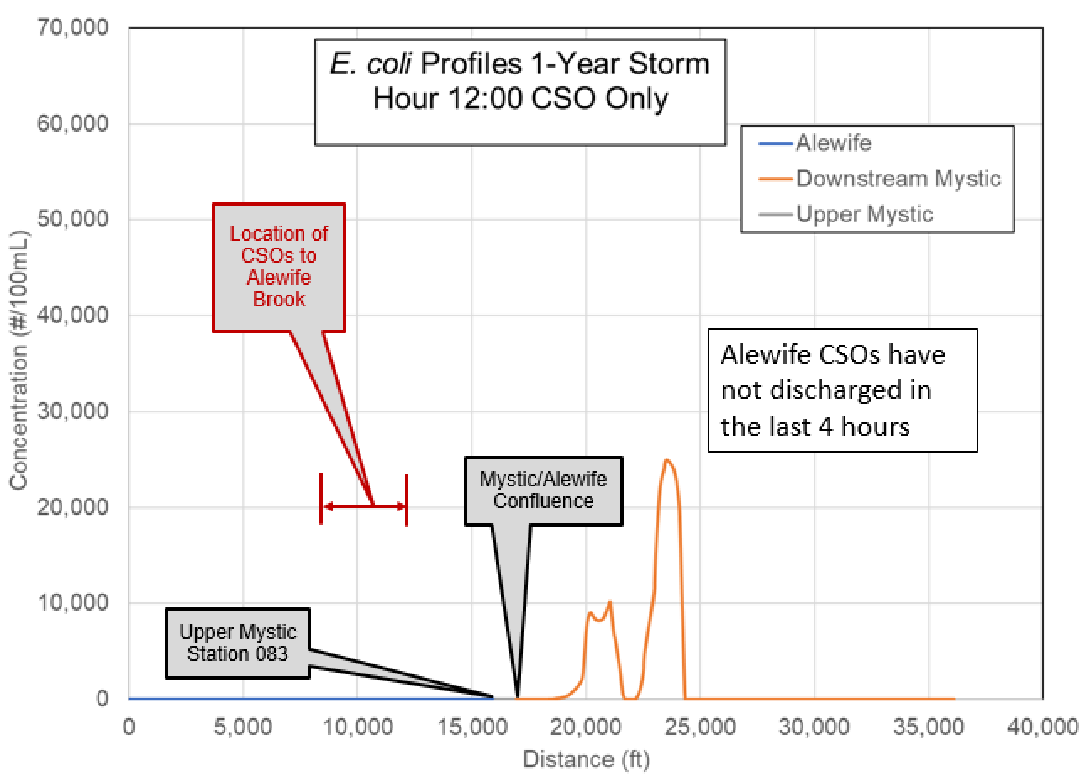


Figure 4-17. *E. coli* Profile at Hour 12:00, 1-Year Storm – CSO Only

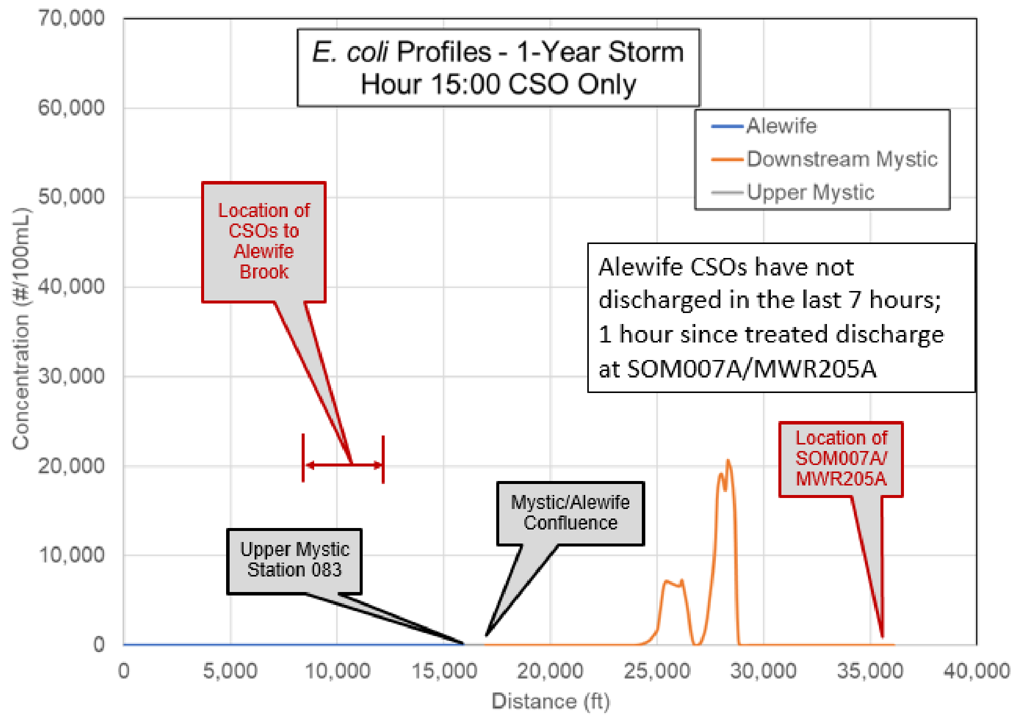


Figure 4-18. ***E. coli*** **Profile at Hour 15:00, 1-Year Storm – CSO Only**

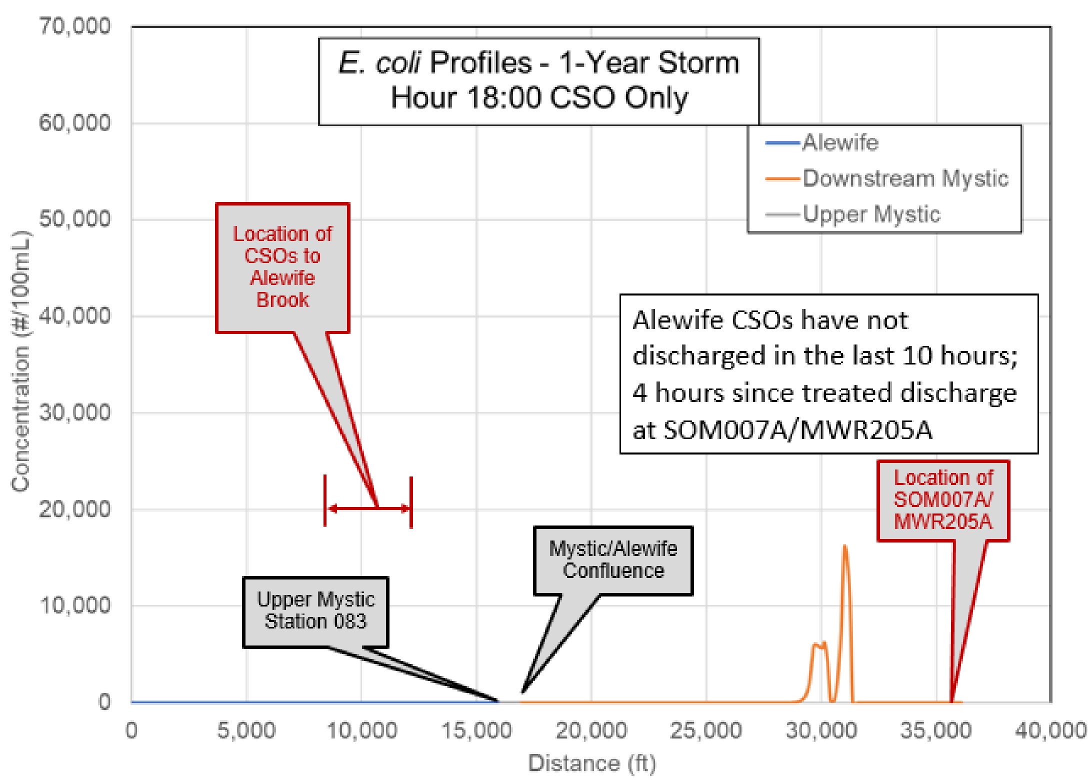


Figure 4-19. ***E. coli*** **Profile at Hour 18:00, 1-Year Storm – CSO Only**

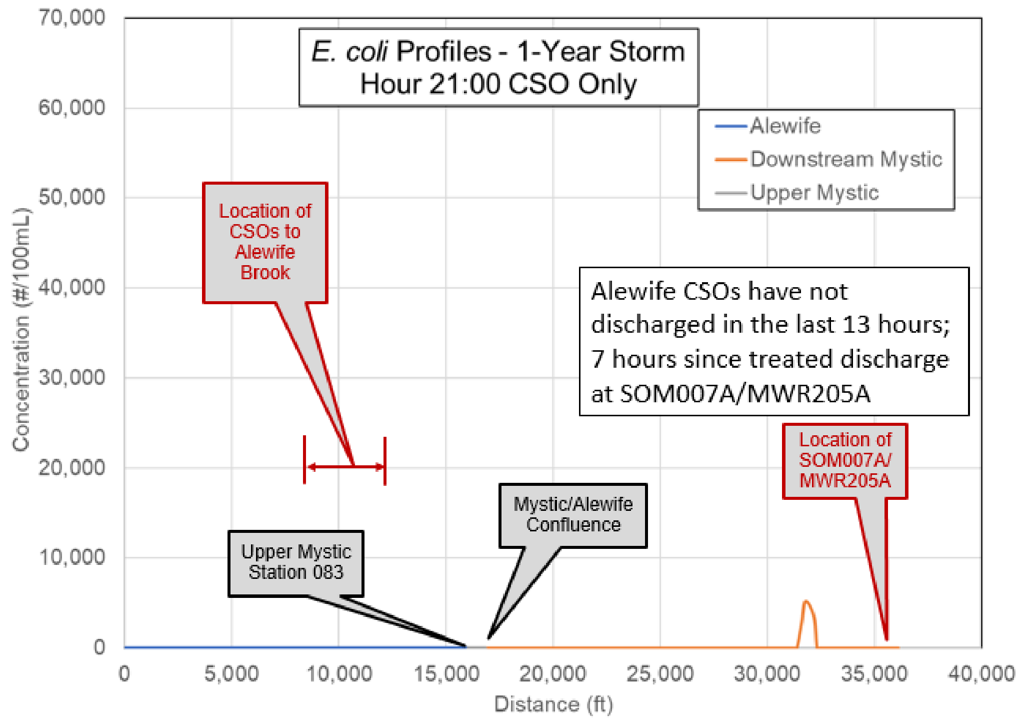


Figure 4-20. *E. coli* Profile at Hour 21:00, 1-Year Storm – CSO Only

4.3.4 Criteria Exceedances

To assess compliance with the current water quality criteria for bacteria, the model was used to compute the total duration that the bacteria count in each segment along the linear model was predicted to exceed the single-sample maximum criterion for *E. coli* over the course of the Typical Year. The resulting values for percent annual attainment of the criteria would be generally analogous to the values for annual percent attainment presented in the 1997 FP/EIR. The hours of exceedance for the 3-month storm, 1-year storm and the Typical Year as well as the percent annual compliance for the *E. coli* single-sample maximum criterion in Alewife Brook are presented in Table 4-6 for the six different simulation conditions that were listed above in Section 3.3.3. Similar output is provided for the Mystic River in Table 4-7 (see Appendix B for *Enterococcus* results). For the Mystic River upstream of the confluence with Alewife Brook, the calculations of hours of exceedance start at station 083. Because the model is linear, bacterial counts due to different sources are additive, however, the hours of exceedance due to different sources are not additive.

The hours shown in Table 4-6 and Table 4-7 are the number of hours the *E. coli* bacterial counts exceed the criterion anywhere along Alewife Brook for Table 4-6 or Mystic River downstream of station 083 for Table 4-7. As noted for the Charles River, this metric is extremely stringent, as the model segments where exceedances occur shift in time, and the area of exceedance is almost always a fraction of the river. At any fixed point in the river, the hours of exceedance would be less than those listed in the tables, as is apparent in Figure 4-21 and Figure 4-22. For the "CSOs Only" condition, the hours of exceedance are less in the Alewife Brook than in the Mystic River, although there are no direct untreated CSO discharges to the Mystic River. The reason for this apparent discrepancy is that the impact of the CSO discharges to the Alewife Brook quickly move to the Mystic River (as was noted in Section 4.3.3) where bacterial counts take some time to decay below the standard.

Table 4-6. Hours of the *E. coli* Single Sample Maximum Criterion Exceedance at any point in the Alewife Brook During the 3-Month Storm, 1-Year Storm and the Typical Year

Alewife Brook				
	E. coli **Single Sample Maximum Criterion (235 colonies/100 mL)**			
	Hours of Exceedance(1)			**Percent Annual Compliance**
	3-Month Storm(2)	**1-Year Storm(2)**	**Typical Year**	
All Sources	137(3)	130(3)	4,818	45%
Non-CSO Sources Only	137(3)	130(3)	4,818	45%
Stormwater Only	137(3)	130(3)	4,514	48%
Dry Weather sources Only	0	0	0	100%
Boundaries Only	0	0	0	100%
CSOs Only	4	6	111	98.7%

Notes:

(1) The hours of exceedance are totalized from the time when the single sample maximum criterion is exceeded after the start of the storm until the *E. coli* count drops again below the criterion.

(2) The 3-month storm (03/07/1992) and 1-year storm (09/22/1992) are modeled as part of the full Typical Year model run. Refer to Table 4-3 for the dates and characteristics of each of the storm events in the Typical Year. For both of these storm events the next event starts about 4 days after the start of the first event.

(3) The *E. coli* bacteria count did not drop below the criterion before the next storm began in the Typical Year rainfall series. The hours of exceedance represent an extrapolation of the time required to drop below the criteria assuming the next storm did not occur.

Table 4-7. Hours of the *E. coli* Single Sample Maximum Criterion Exceedance at any point in the Upper Mystic River During the 3-Month Storm, 1-Year Storm and the Typical Year

Upper Mystic River				
	E. coli **Single Sample Maximum Criterion (235 colonies/100 mL)**			
	Hours of Exceedance(1)			**Percent Annual Compliance**
	3-Month Storm(2)	**1-Year Storm(2)**	**Typical Year**	
All Sources	144(3)	124(3)	4,030	54%
Non-CSO Sources Only	144(3)	124(3)	3,966	55%
Stormwater Only	144(3)	124(3)	3,814	56%
Dry Weather Sources Only	0	0	0	100%
Boundaries Only	25	41	819	91%
CSOs Only	19	28	360	95.8%

Notes:

(1) The hours of exceedance are totalized from the time when the single sample maximum criterion is exceeded after the start of the storm until the *E. coli* count drops again below the criterion.

(2) The 3-month storm (03/07/1992) and 1-year storm (09/22/1992) are modeled as part of the full Typical Year model run. Refer to Table 4-3 for the dates and characteristics of each of the storm events in the Typical Year. For both of these storm events the next event starts about 4 days after the start of the first event.

(3) The *E. coli* bacteria count did not drop below the criterion before the next storm began in the Typical Year rainfall series. The hours of exceedance represent an extrapolation of the time required to drop below the criteria assuming the next storm did not occur.

Based on Table 4-6 above, for the 3-month storm with All Sources the model predicts it would take 137 hours (5.7 days) for the *E. coli* counts in the entire reach of Alewife Brook to drop below the single sample maximum criterion. For the 1-year storm with All Sources the model predicts it would take 130 hours (5.4 days) for the *E. coli* counts in the entire reach of Alewife to drop below the single sample maximum criterion.

Based on Table 4-7 above, for the 3-month storm with All Sources the model predicts it would take 144 hours (6.0 days) for the *E. coli* counts in the entire reach of Mystic River to drop below the single sample maximum criterion. For the 1-year storm with All Sources the model predicts it would take 124 hours (5.2 days) for the *E. coli* counts in the entire reach of Mystic River to drop below the single sample maximum criterion.

It should be noted that there is some uncertainty associated with the duration of exceedance for the 3-month and 1-year storms. As described in footnote 3 in Table 4-6 and Table 4-7, the *E. coli* bacteria count did not drop below the criterion before the next storm began in the Typical Year rainfall series. The hours of exceedance represent an extrapolation of the time required to drop below the criteria assuming the next storm did not occur.

Plots of hours of criteria exceedances over the Typical Year along Alewife Brook and Upper Mystic River for all sources are presented in Figure 4-21, and for CSO sources only in Figure 4-22. Similar to the Charles River, plots of criteria exceedances over the Typical Year for the condition of Non-CSO sources only except CSOs were identical to the "All Sources" plots, so the plots are not repeated here.

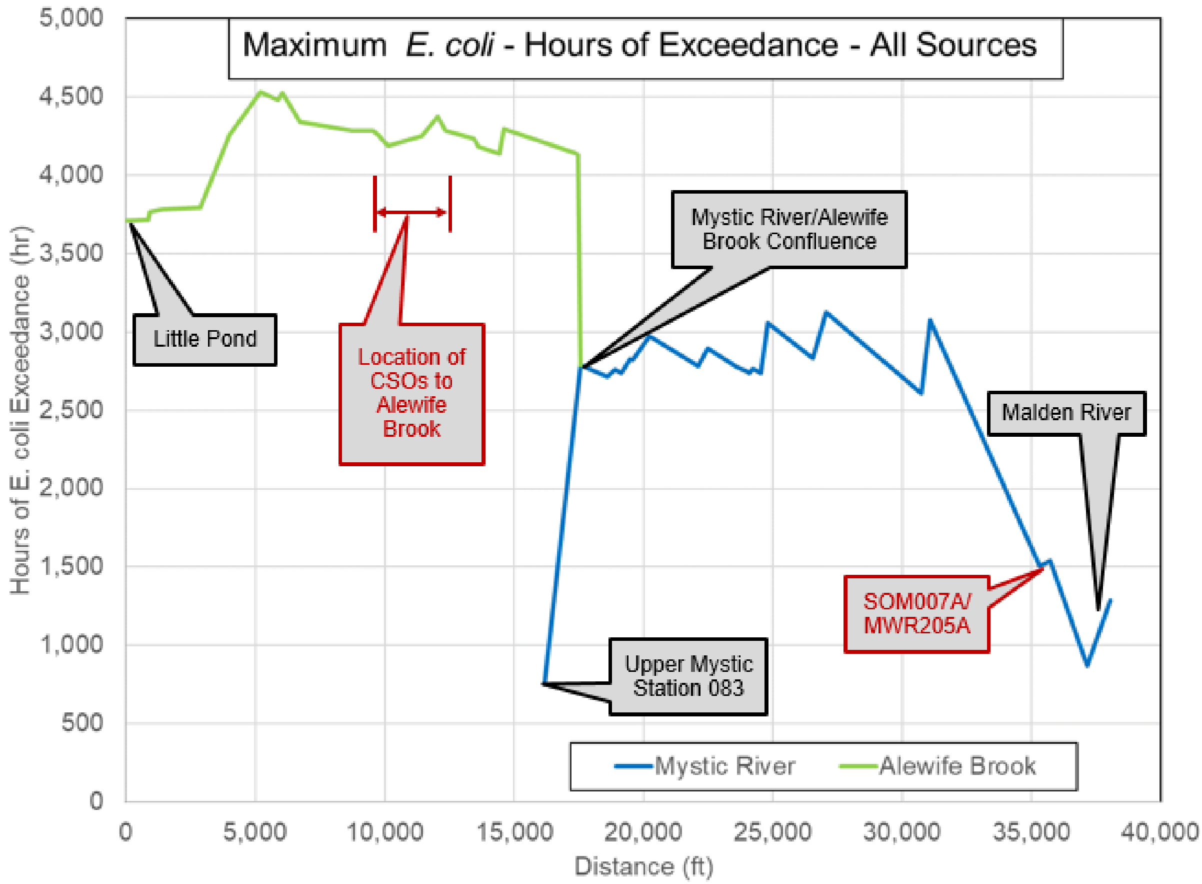


Figure 4-21. Hours of Exceedance of Single Sample Max Criterion *E. coli*, All Sources, Typical Year

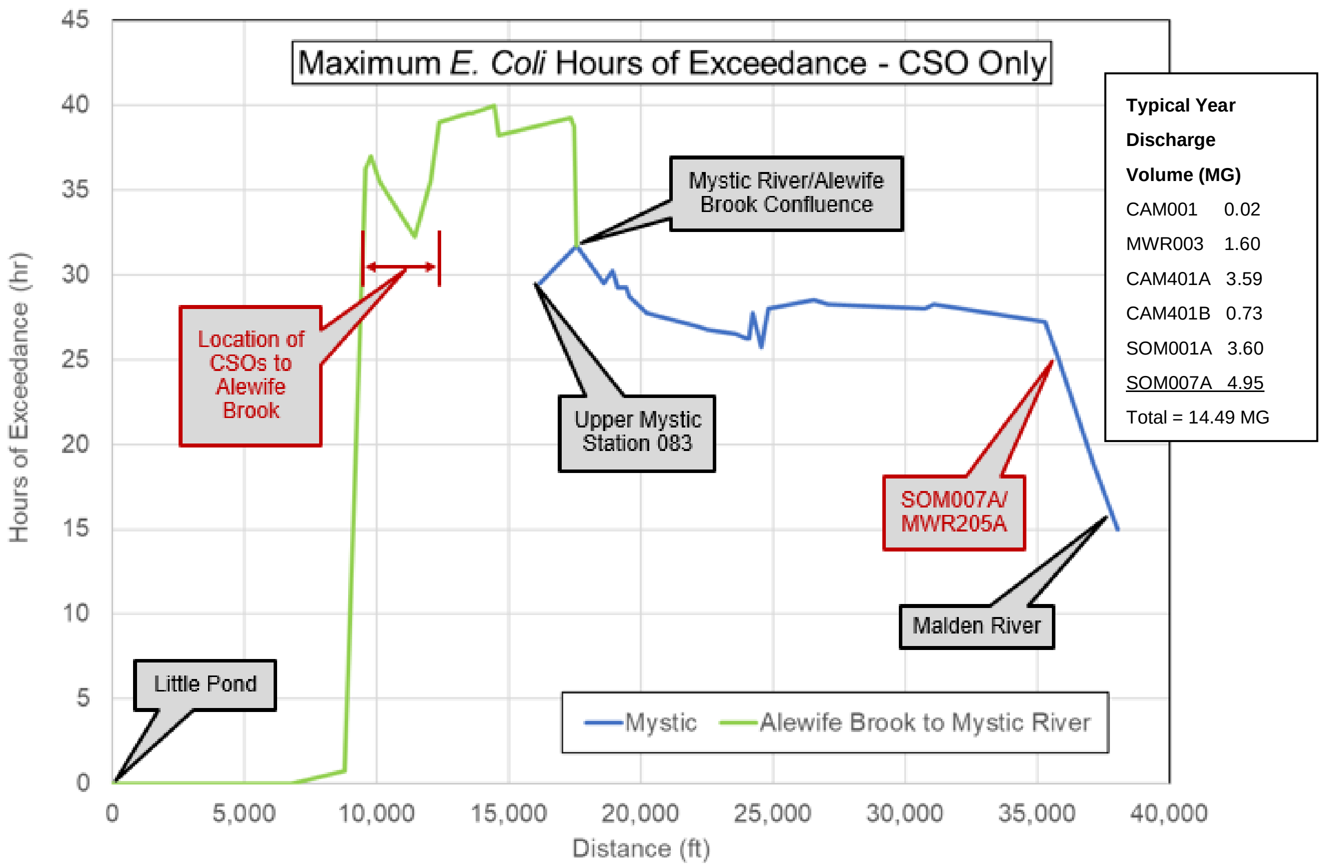


Figure 4-22. Hours of Exceedance of Single Sample Max Criterion *E. coli*, CSOs Only, Typical Year. Note change in scale from "All Sources"

Observations from these figures include:

- The maximum ranges of hours of exceedance displayed on the figures are considerably smaller than the hours of exceedance listed in Table 4-7 and Table 4-8. As noted above, the hours of exceedance listed in Table 4-7 and Table 4-8 are for any one point in the river, while the figures present the values at fixed points. For most of the river, the hours of exceedance at any one point are substantially lower than maximum durations for the river as a whole shown in Table 4-7 and Table 4-8.
- In the CSO-only plots for *E. coli*, some CSO impacts are apparent in the Mystic River in the area just upstream of the confluence with Alewife Brook. The model hydrodynamics (and river gage readings) indicate the occasional reversal of flow in the Mystic River, which would explain the migration of CSO impacts in the Mystic River just upstream of the confluence. This phenomenon resulted in a brief exceedance of the *E. coli* criteria up to station 083 upstream of the confluence.
- While CSOs that discharge to Alewife Brook would theoretically result in exceedances of the *E. coli* criterion in the Mystic River downstream of Alewife Brook in the absence of all other sources, the durations of exceedance for the CSO-only case are two orders of magnitude lower than the duration of exceedance in the Mystic River downstream of Alewife Brook when all sources are included.

Eliminating the CSOs to Alewife Brook would not significantly change the duration of exceedance in the Mystic River.

- A similar relationship exists in the Alewife Brook itself. While CSOs that discharge to Alewife Brook would theoretically result in exceedances of the *E. coli* criterion in the Alewife Brook in the absence of all other sources, the durations of exceedance for the CSO-only case are two orders of magnitude lower than the duration of exceedance in the Alewife Brook when all sources are included. Eliminating the CSOs to Alewife Brook would not significantly change the duration of exceedance in the Alewife Brook.

4.3.5 Sensitivity Analysis

As was done for the Charles River, hours of exceedance of the *E. coli* and *Enterococcus* criteria were calculated for variations in the bacterial counts in stormwater, CSOs and boundary conditions. This initial set of sensitivity evaluations is summarized in Table 4-8, where stormwater bacterial counts were decreased by factors of 2 and 5, and to the 25th percentile value from the sampling data (possibly representing stormwater quality improvements associated with community undertaking as part of their MS4 permits), CSO bacterial counts were increased by a factor of 2 (to gauge the robustness of the CSO impact assessment), and boundary source bacterial counts were decreased by factors of 2 and 5 (see Appendix B for *Enterococcus* results).

Table 4-8. Single Sample Maximum Sensitivity Analysis

Alewife Brook and Upper Mystic River				
	Source Count Multiplier	***E. coli* Value (#/100 mL)**	***E. coli* Single Sample Maximum Criterion (235 colonies/100 mL)**	
			Hours of Exceedance	**Percent Compliance**
Stormwater Only	1.0	25,000	4,800	44%
	0.5	12,500	4,154	52%
	0.2	5,000	3,379	61%
	25th Percentile	1,110	1,818	79%
CSO Only	1.0	Time varying Computed by Mass Balance	367	96%
	2.0	2x Time varying Computed by Mass Balance	419	95%
Boundary Only	1	SW = 50,000[(1)] SS= 2,000[(2)]	819	91%
	0.5	SW = 25,000 SS = 1,000	286	97%
	0.2	SW = 10,000 SS = 400	23	99.7%

Notes:

(1) SW = Stormwater *E. coli* count upstream of Monitoring Station 083

(2) SS = Soil Store *E. coli* count upstream of Monitoring Station 083

In Table 4-8, the values in the rows associated with “Source Count Multiplier” of 1.0 reflect the baseline stormwater or CSO counts as described in Section 2 above. For the stormwater-only case, the “Source Count Multiplier” of 0.5 reflects a 50 percent reduction in the *E. coli* counts in the stormwater discharges, and the “Source Count Multiplier” of 0.2 reflects and 80 percent reduction in the bacterial counts in stormwater. As described in Section 2, the bacterial counts in the CSO were time- varying based on the sanitary fraction, with the model computing a unique bacterial count for each model timestep at each outfall. For the CSO loading sensitivity analysis, the Source Count Multiplier simply multiplied the computed value at each timestep by a factor of 2.

As could be expected, percent compliance increases as stormwater and boundary source quality improves and decreases as CSO counts increase. However, for stormwater, even an 80 percent reduction in the value of the bacterial counts would still leave over 3,300 hours of non-compliance with the *E. coli* criterion. As indicated above in Table 2-5, the value of 5,000 #/100mL for *E. coli* would fall between the 75th and 90th percentile of the stormwater samples collected. These values would therefore be on the high end of the samples collected for *E. coli*.

On-going efforts by communities to identify and address illicit sanitary connections to storm drains would contribute to reductions in bacterial counts in the stormwater discharges. But even with those continued efforts, the sampling data and model results indicate that stormwater would continue to be a significant contributor to non-attainment of the water quality criteria for bacteria in the Alewife Brook/Upper Mystic River.

Regarding the sensitivity analysis for CSO counts, doubling of the counts increased the duration of exceedance of the criteria by about 15 percent. Even with this increase, the annual percent attainment would still be at least 95 percent. This highlights the relatively small impact that CSOs have on the overall bacteria counts in the Alewife Brook/Upper Mystic River, consistent with the relative flow volume and bacterial count loadings of CSOs in comparison to stormwater and upstream sources.

The relatively high attainment associated with the boundary sources only condition indicates that upstream boundary sources are a less-significant source of non-attainment of the criteria compared to stormwater and CSOs.

4.3.6 Summary

Salient results of the Alewife Brook/Upper Mystic River water quality impact assessment are summarized below:

- Stormwater contributes bacterial loadings each time it rains, over 90 times/year on average, and is the largest source of bacterial loading for both the design storms and on an annual basis.
- The upstream boundary sources are not as significant a contributor to the total loadings to Alewife Brook/Upper Mystic River as compared to the Charles River.
- CSOs contribute loadings directly to Alewife Brook only during the larger storms during a Typical Year, on average 10 times/year (at CAM401A, less often at the other CSOs). No untreated CSOs discharge to the Mystic River, but *E. coli* loadings from the Alewife Brook CSOs do migrate into the Mystic River.
- In a 1-year storm, CSOs contribute approximately 30 percent of the total bacterial load to Alewife Brook, but the contribution drops to 5 percent in the 3-month storm.

- Typical Year performance:
  - With CSO loadings only, the single sample maximum criterion for *E. coli* is met everywhere in Alewife Brook more than 98% of the time, and everywhere in the Mystic River approximately 96% of the time.
  - Even if the modeled CSO concentrations were doubled, attainment of the single sample maximum criterion for *E. coli* would still be at least 95%.
  - These results are consistent with the findings from the water quality modeling conducted for the *2003 Final Variance Report for Alewife Brook/Upper Mystic River* (98.5 percent of time <200 colonies/100mL fecal coliform for CSO loads, only).
  - An 80 percent reduction in the bacteria counts in stormwater would reduce the hours of exceedance of water quality criteria for bacteria attributable to stormwater but would still leave over 3,300 hours of exceedance of the *E. coli* criterion based on stormwater loadings only.

5. Summary and Next Steps

5.1 Summary

Hydrodynamic and water quality models for the Lower Charles River and Alewife Brook/Upper Mystic River were used to assess the water quality impacts of CSOs and other discharges to these water bodies. The Charles River model is two-dimensional (based on Delft3D) and the Alewife Brook/Upper Mystic River model is one-dimensional (based on InfoWorks ICM). These models receive flows derived from USGS gauges and from separate collection system models. The models were calibrated using extensive monitoring data primarily collected by MWRA from receiving waters, storm drains, and CSO outfalls.

The models were applied to the Typical Year annual rainfall series developed as part of previous CSO planning activities. The Typical Year was based on the 1992 year with several storms replaced to improve the match with the long-term record. The Typical Year included the 1-year storm used for the previous assessments and a storm very similar to the 3-month storm previously used. The 1-year and 3-month storms were used in previous CSO planning (1997 FP/EIR, *2003 Final Variance Report for Alewife Brook/Upper Mystic River*) to estimate annual attainment with water quality criteria because the models used then were not capable of running an entire year. The models used in the present assessment are capable of running the entire Typical Year but some results for the 1-year and 3-month storms are also presented for completeness. The MWRA's collection system hydraulic model that was the basis of generating CSO flows was based on 2019 system conditions (see *Semiannual CSO Discharge Report No. 4*, April 30, 2020, for further details on 2019 system conditions).

The water quality parameters simulated by the models were *E. coli* and *Enterococcus* and the model results, in terms of #/100 mL, were compared to the Single Sample Maximum water quality criteria for bacteria in the current Massachusetts Water Quality Standards. Since the model could generate significantly more data points than could reasonably be sampled in the real world, calculating a geometric mean from the model output was not considered to be consistent with the intent of the criteria. Use of the single-sample maximum criterion was considered to be a more appropriate approach for assessing water quality impacts. MADEP indicated this was the preferred approach.

Model runs were conducted for the different sources separately and together. Simulations were conducted for the following conditions:

- All sources;
- Non-CSO sources only
- Stormwater only;
- Dry weather discharges only (infiltration flow from storm drains or groundwater flow directly to a waterbody; can also include flow from illicit sanitary connections to storm drains); and;
- Boundaries only; and
- CSO only

For each of these conditions, the number of hours of exceedance of the single sample maximum criteria were calculated during the Typical Year. These exceedance hours were calculated for each of the two water bodies as a whole and also as a function of location within these water bodies. From these hours of exceedance, percent annual compliance with the criteria were calculated. Results were presented in tables and plots (2-dimensional contour plots for the Charles River and 1-dimensional plots for the Alewife Brook/Upper Mystic River).

For both the Charles River and the Alewife Brook/Upper Mystic River the following general observations were made:

- Loadings due to stormwater and upstream boundaries were the two largest sources of *E. coli* and *Enterococcus* in both the 1-year and 3-month design storms and for the Typical Year.
- CSOs contribute loadings only during the larger storms, 8 times during the Typical Year for the Charles and 10 times for the Alewife/Upper Mystic, respectively.
- For CSOs only, single sample maximum criteria compliance for the Typical Year over the entire water bodies is summarized in Table 5-1. Note that at fixed points, compliance is even greater than the entire water body values given in this table, but this approach allows comparison with previous assessments. These numbers are consistent with those predicted during CSO planning 1997 FP/EIR for the Charles River, and in the *2003 Final Variance Report for Alewife Brook/Upper Mystic River*.
- For CSOs only, the annual compliance percentage is greater in the Alewife Brook than in the Mystic River, although there are no direct untreated CSO discharges to the Mystic River. The reason for this apparent discrepancy is that the elevated bacterial counts due to the CSO discharges to the Alewife Brook quickly move to the Mystic River where they take some time to decay below the standard.

Table 5-1. Summary of Annual Compliance with *E. coli* Single-Sample Maximum Criteria, Typical Year, CSO Sources Only

Waterbody	Annual Compliance with Single-Sample Maximum Criterion, Typical Year, CSO Sources Only
	E. coli
Charles River	99.6%
Alewife Brook	98.7%
Upper Mystic River	95.8%

Sensitivity analyses were conducted in which the stormwater loadings were decreased by factors of 2 and 5 and CSO loadings were increased by a factor of 2. The stormwater loading reductions increased the percent compliance with the criteria, but considerable non-compliance remained (approximately 1,500 hours for the Charles River, and 3,300 hours for the Alewife Brook/Upper Mystic River). The doubled CSO loadings only marginally decreased compliance with the criteria (the Charles River remained above 99%, while Alewife Brook/Upper Mystic River remained in the 95-96% range).

5.2 Next Steps

The models will next be applied to assess the potential benefits of additional CSO reduction alternatives in terms of improvement in attainment of water quality standards. Alternatives based on specific system improvements will be simulated, and additional sensitivity runs may be conducted. MWRA intends to coordinate with EPA and MADEP to identify the additional evaluations to be conducted as part of the alternatives evaluations.

6. References

AECOM. 2020. *CSO Post Construction Monitoring and Performance Assessment: Task 5.2 Receiving Water Quality Model Development and Calibration Report.* Prepared for MWRA. Boston: Massachusetts Water Resources Authority. Report 2020-15. 180 p.

Massachusetts DEP 2019. *Massachusetts Year 2016 Integrated List of Waters Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act.*

Metcalf & Eddy. 1997. *Final Combined Sewer Overflow Facilities Plan and Environmental Impact Report.* (EOEA 10335) (Vols. 1-5). Prepared for the MWRA. Wakefield, Massachusetts: Metcalf & Eddy.

Metcalf & Eddy. 2003. *Final Variance Report for Alewife Brook and the Upper Mystic River*. (EOEA 10335) Prepared for the MWRA Wakefield, Massachusetts: Metcalf & Eddy.

Metcalf & Eddy. 2004. *Cottage Farm CSO Facility Assessment Report.* CSO Facilities Planning – Phase II Contract 5716. (EOEA 10335) Prepared for the MWRA Wakefield, Massachusetts: Metcalf & Eddy.

USEPA. 1999. *Combined Sewer Overflows Guidance For Monitoring And Modeling*. EPA 832-B-99-002.

USEPA. 2012. *Post Construction Compliance Monitoring Guidance*. EPA-833-K-11-001

USGS. 2002a. Zariello, P.J. and Barlow, L.K. *Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999 – September 2000*. Water Resources Investigations Report 02-4129.

USGS (Zarriello, PJ, Breault, RF, and Weiskel PK.) USGS. 2002b. *Potential Effects of Structural Control and Street Sweeping on Stormwater Loads to the Lower Charles River, Massachusetts.* Northborough, Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 02-4220. http://water.usgs.gov/pubs/wri/wri024220/.

Appendix A

Mystic River *Enterococcus* Model Recalibration

AECOM
250 Apollo Drive
Chelmsford, MA 01824
aecom.com

Project name:
CSO Post Construction Monitoring and Performance
MWRA Contract No. 7572

Subject:
Mystic River Enterococcus Model Recalibration

To:
File

From:
Dominique Brocard

Date:
July 27, 2021

Memo

When the Alewife Brook/Upper Mystic River model was run with the Typical Year, the hours of exceedance of the single sample maximum criterion for *Enterococcus* were found to be higher than anticipated based on sampling data collected for the Upper Mystic River. A review of the model found that the higher than anticipated hours of exceedance were attributed to the high "soil store" count specified upstream of MWRA Monitoring Station 083. Soil store simulates the effect of dry weather sources. High *Enterococcus* counts were specified upstream of 083 for soil store, as well as stormwater runoff, to simulate the effect of upstream boundary sources. Station 083 is located upstream of the Alewife Brook confluence, approximately half a mile downstream of the Lower Mystic Lake, which is the upstream boundary of the water quality model, see Figure 1.

Model calibration was conducted by comparing model predictions with monitoring data for 2018. The calibration plots at Station 083 and Station 066, located on the Upper Mystic River a short distance downstream of the Alewife confluence indicated that the relatively high soil store and stormwater inputs upstream of station 083 allowed the best match to wet weather peak bacteria values in the calibration period. However, for the Typical Year, the model yielded a compliance percentage (percent time the calculated *Enterococcus* count was below the single sample maximum criterion of 61 #/100 mL) at Station 083 of 11% whereas monitoring data yielded percent compliance factors of 47% for 2018 and 40% for 2019. The original calibration plots for Stations 083 and 066 are shown in the top panels of Figures 2 through 5.

The soil store *Enterococcus* count in the original calibration was 10,000 #/100 mL. Two additional calibration runs were done with soil store *Enterococcus* counts of 2,000 #/100 mL and 3,000 #/100 mL in that order. The second value was selected as the first one appeared to be too low. The calibration plots at Stations 083 and 066 for the reduced soil store counts are included in Figures 2 to 5 for comparison with the original calibration. Visually, the two model runs with the reduced soil store counts, which are very similar to each other, appear to yield slightly better calibration with the measured data. The main effect of the reduced soil store counts is lower *Enterococcus* counts during dry weather, which sometimes better compare with the measured data, such as in the period between July 6 and 11, 2018. This period was just following a storm.

Some of the very low *Enterococcus* counts measured, for instance at the end of April, are not matched by any of the simulations, but these occurred during wet weather when elevated bacterial counts would be expected. These low counts cannot be matched by the model, whatever parameter values are assumed.

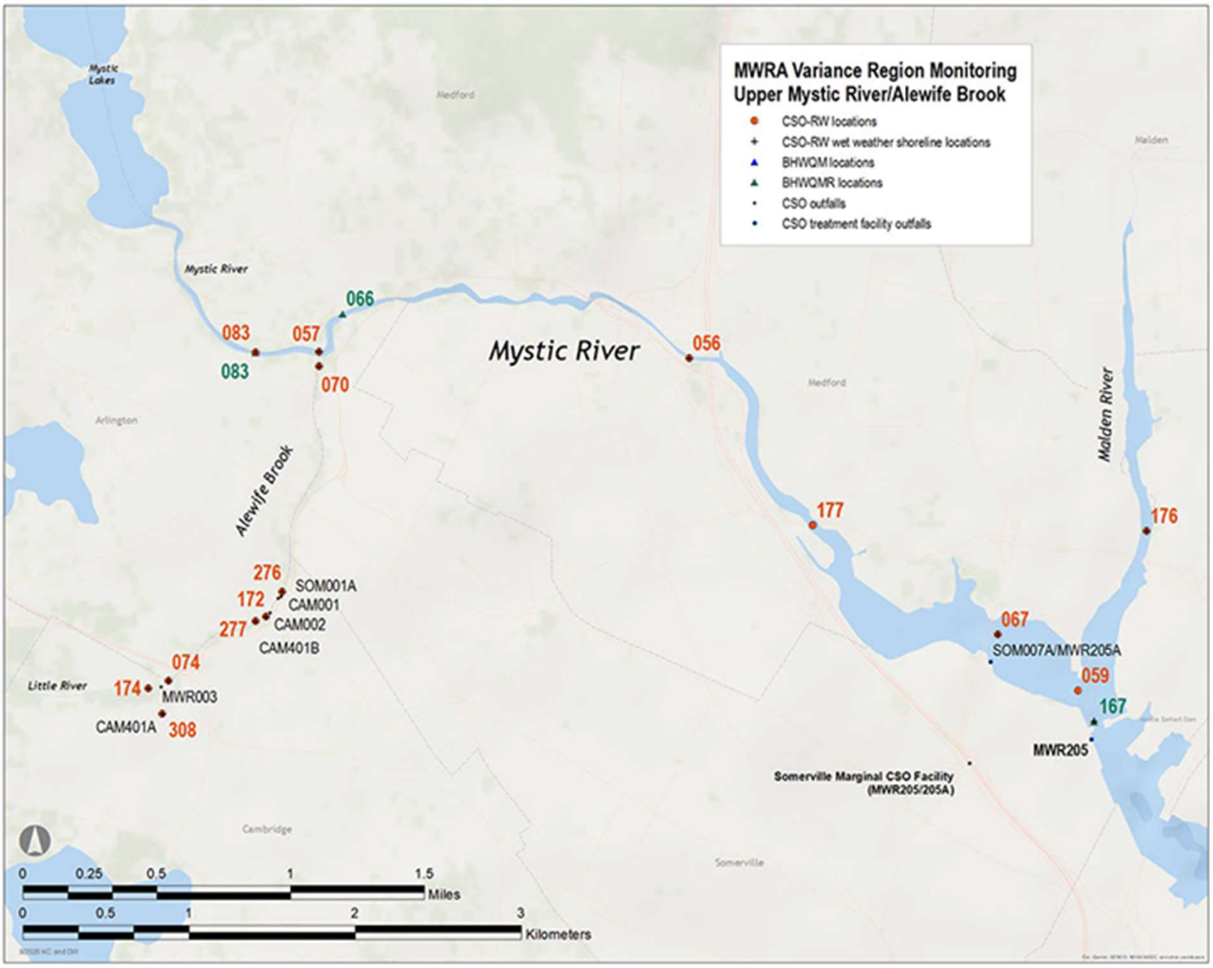


Figure 1. Alewife Brook/Upper Mystic River Map showing CSO Locations and MWRA Monitoring Stations

Compliance statistics are summarized in Table 1 for these three simulations. Model percent compliance is for the entire Typical Year. For the Upper Mystic River, the hours of exceedance are for the stretch of the river downstream of Station 083. The reasons for this selection are that i) the stormwater and soil store discharges upstream of 083 are meant to simulate upstream boundary sources by matching measured bacterial counts at 083 and counts upstream of 083 are not representative of actual conditions and ii) there are no CSOs upstream of 083, therefore this section is of lesser interest.

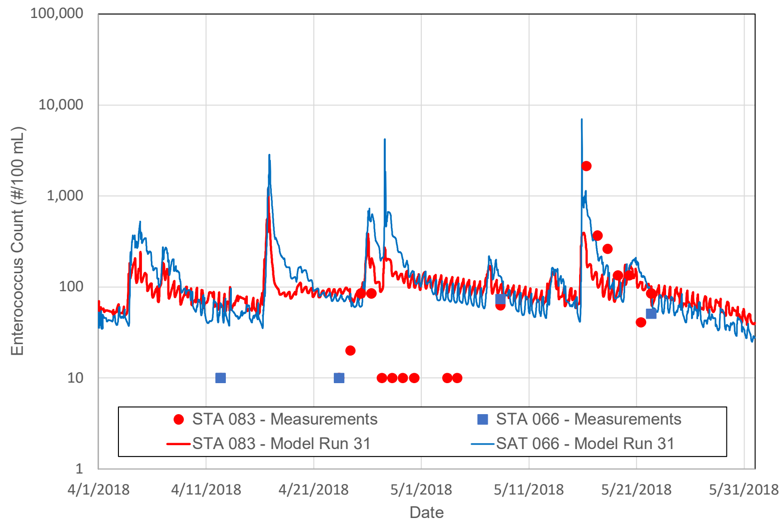
Percent compliance values are also listed for Station 083 itself. For both recalibration runs, the percent compliance values at Station 083 are higher than the percent compliance computed from the measured *Enterococcus* counts. However, the percent compliance computed from the measured counts would be conservatively low as many of the samples were collected during and following wet weather events when bacterial counts would be elevated. (The monitoring program during those years emphasized sampling during and after storms.) At Station 083 the percent compliance obtained for the model run with soil store *Enterococcus* count of 3,000 #/100 mL is closer to the measured values and, therefore, this value was selected for the revised *Enterococcus* model runs.

Table 1. Compliance Statistics for the Upper Mystic River *Enterococcus* Recalibration

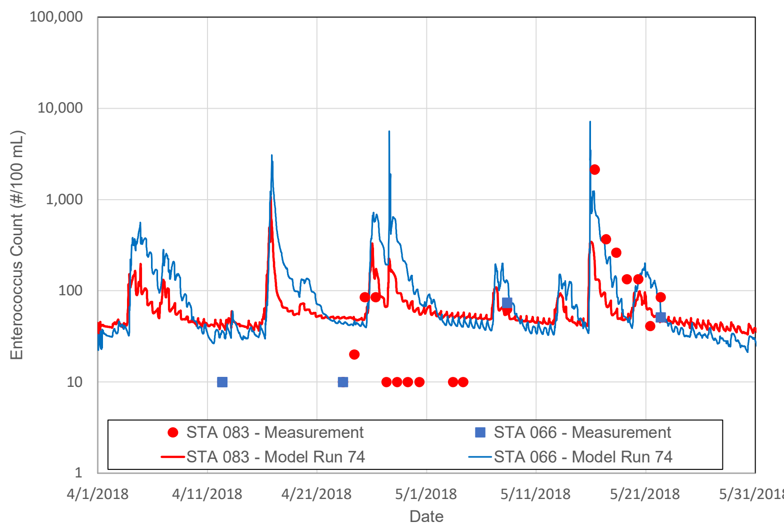
Enterococcus	**Percent Compliance with the 61 #/ 100 mL Criterion**	
MWRA Monitoring	**Year**	**Station 083**
	2018	47%
	2019	40%
Model[1]	**Upper Mystic** [2]	**Station 083**
All Sources		
Original model (10,000 #/ 100 mL)	11%	11%
New Model (2,000 #/100 mL)	51%	66%
New Model (3,000 #/100 mL)	43%	53%
Boundary Conditions Only		
Original model (10,000 #/ 100 mL)	18%	18%
New Model (2,000 #/100 mL)	69%	70%
New Model (3,000 #/100 mL)	61%	62%

(1) The model percent compliance values are for the Typical Year
(2) Downstream of Station 083

Original Calibration



Soil Store *Enterococcus* = 2,000#/100 mL



Soil Store *Enterococcus* =3,000#/100 mL

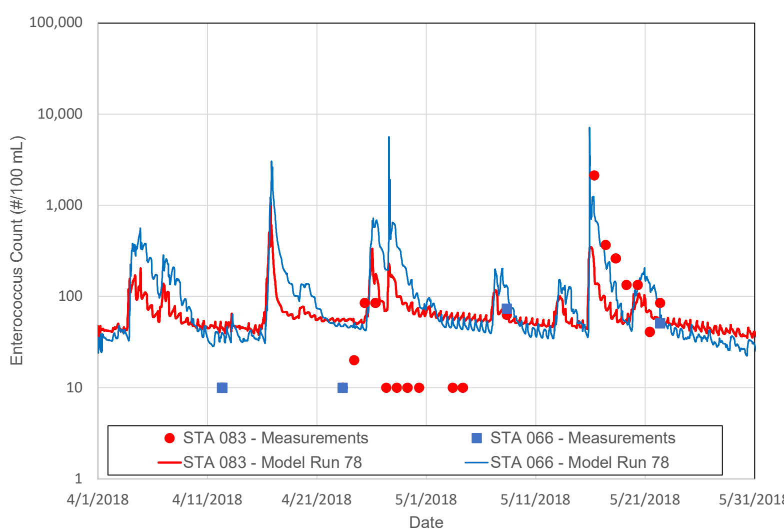
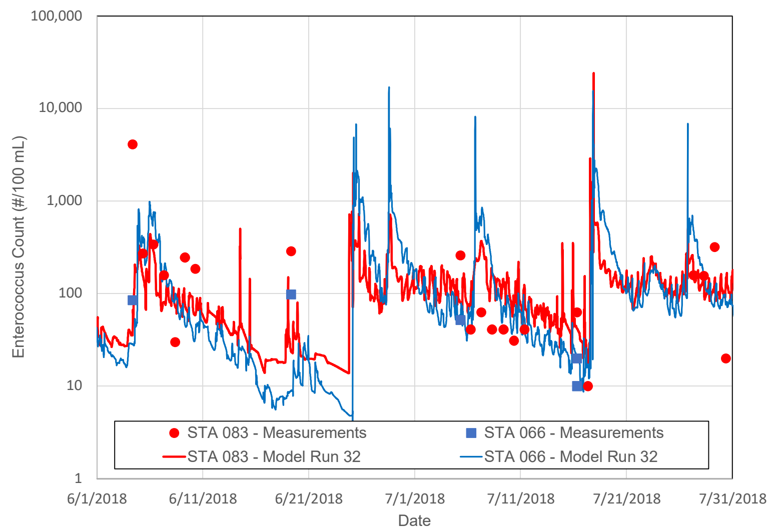
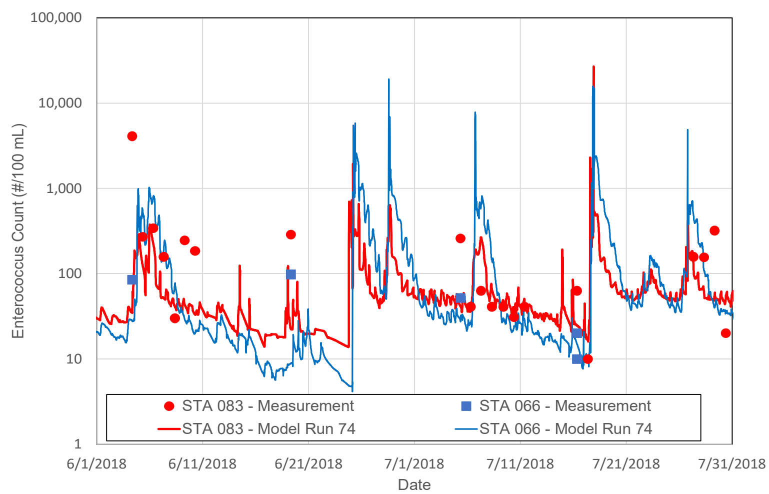


Figure 2. Calibration Plots for April-May 2018

Original Calibration



Soil Store
Enterococcus =
2,000#/100 mL



Soil Store
Enterococcus
=3,000#/100 mL

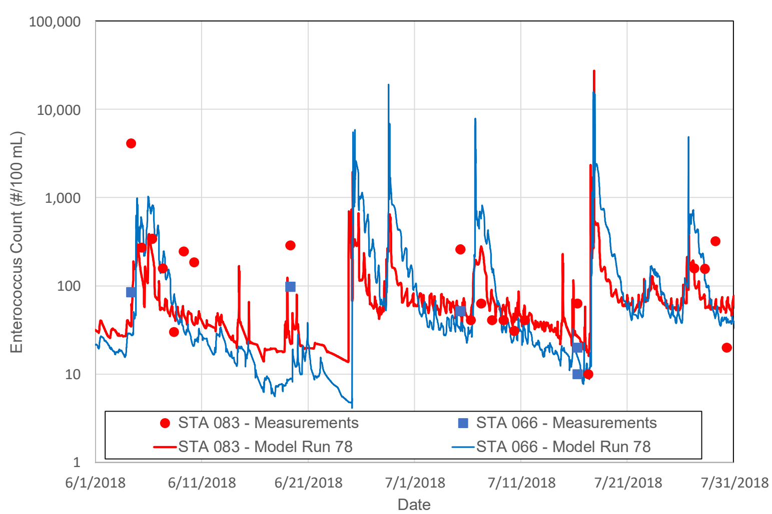
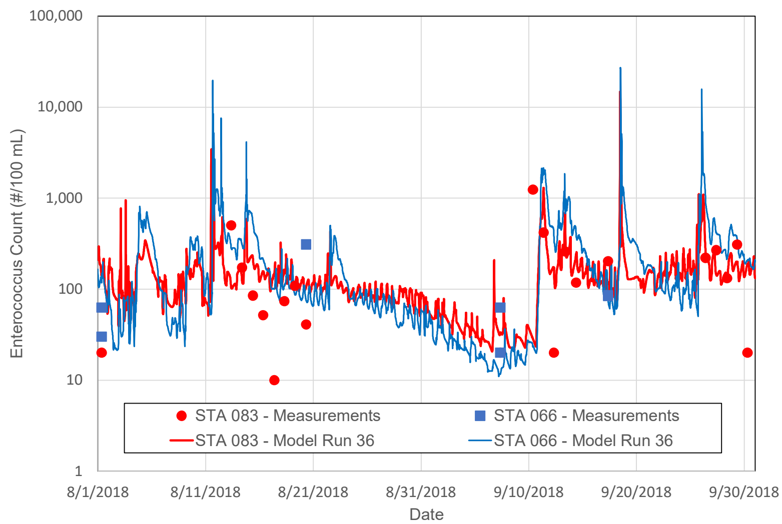
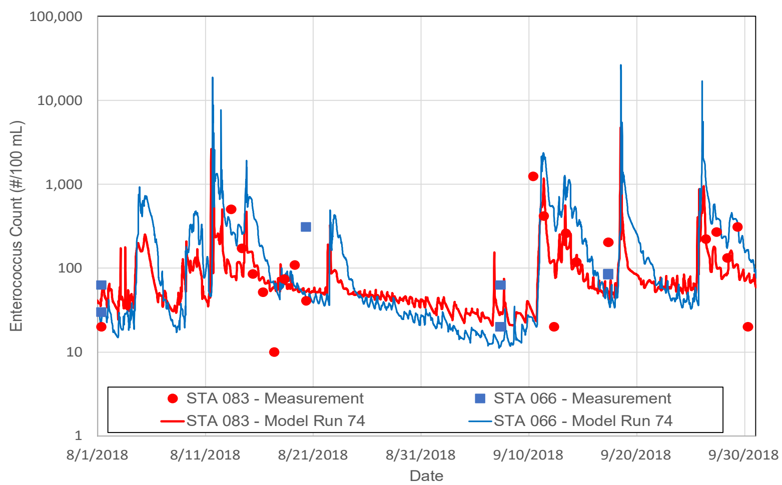


Figure 3. Calibration Plots for June-July 2018

Original Calibration



Soil Store
Enterococcus =
2,000#/100 mL



Soil Store
Enterococcus
=3,000#/100 mL

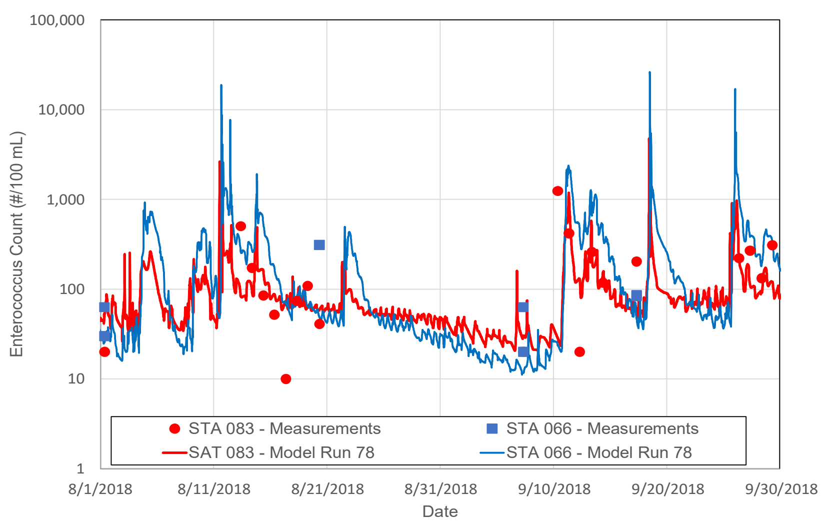
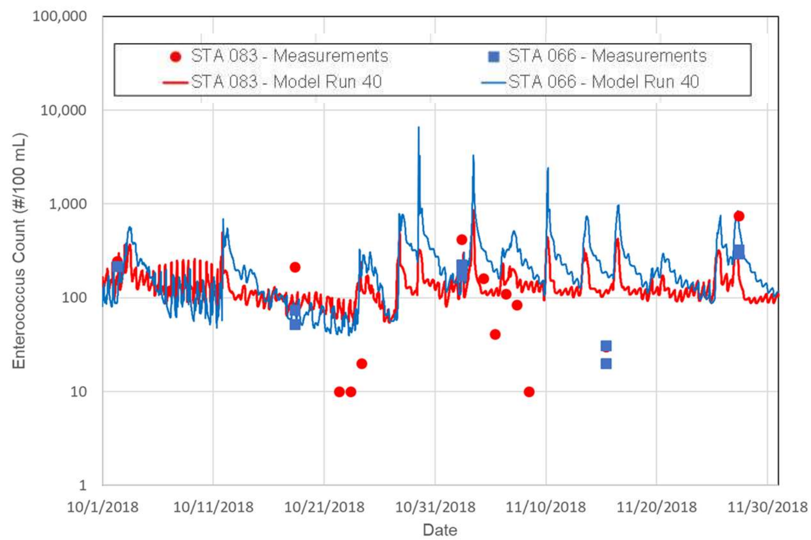
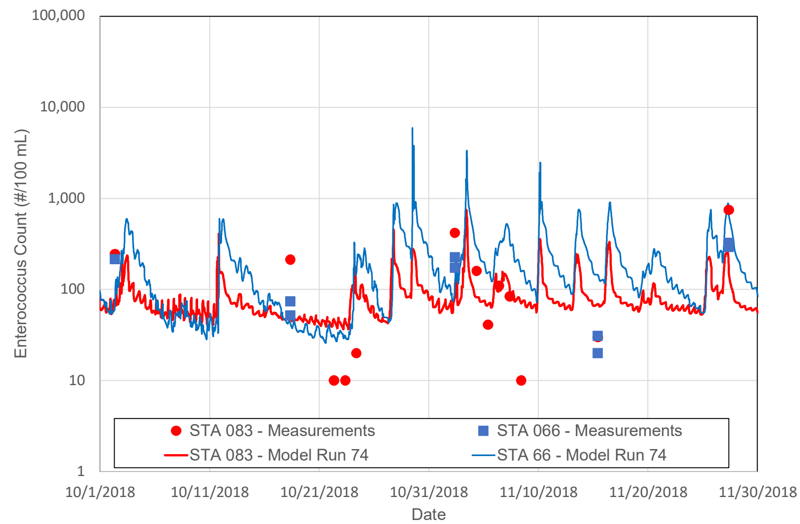


Figure 4. Calibration Plots for August-September 2018

Original Calibration



Soil Store
Enterococcus =
2,000#/100 mL



Soil Store
Enterococcus
=3,000#/100 mL

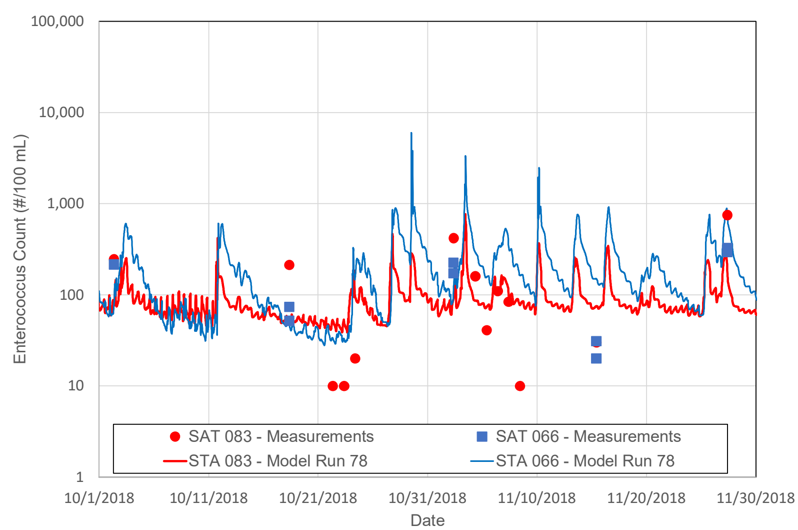


Figure 5. Calibration Plots for October-November 2018

Appendix B

Enterococcus Results

B.1 Charles River

B.1.1 Bacterial Loadings

The *Enterococcus* loadings to the Charles River during the 3-month and 1-year storms and during the Typical Year are summarized in Table B-1.

Table B-1. *Enterococcus* Loadings to the Charles River

Source	*Enterococcus* Loadings					
	3-Month Storm		1-Year Storm		Typical Year	
	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total
Untreated CSOs(1)						
Sanitary Component	0.00		0.32		0.59	
Non-Sanitary Component	0.00		0.54		1.37	
Total	0.00	0%	0.86	0.4%	1.96	<0.01%
Treated CSOs(1)	0.00	0%	0.07	0.02%	0.10	<0.01%
Stormwater	101	86%	160	67%	2,417	70%
Dry Weather	0.11	0.09%	0.06	0.02%	16	0.5%
Boundary	17	14%	77	32%	1,018	29%
Total	118	100%	238	100%	3,455	100%

Notes:

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

As for *E. coli*, *Enterococcus* loadings from untreated CSOs are small fractions of the loadings due to the other sources. CSOs contribute no loadings for the 3-month storm. For the 1-year storm, the untreated CSO loadings are 0.4% of the total loadings for *Enterococcus*. For the typical year this fraction decreases to 0.1%.

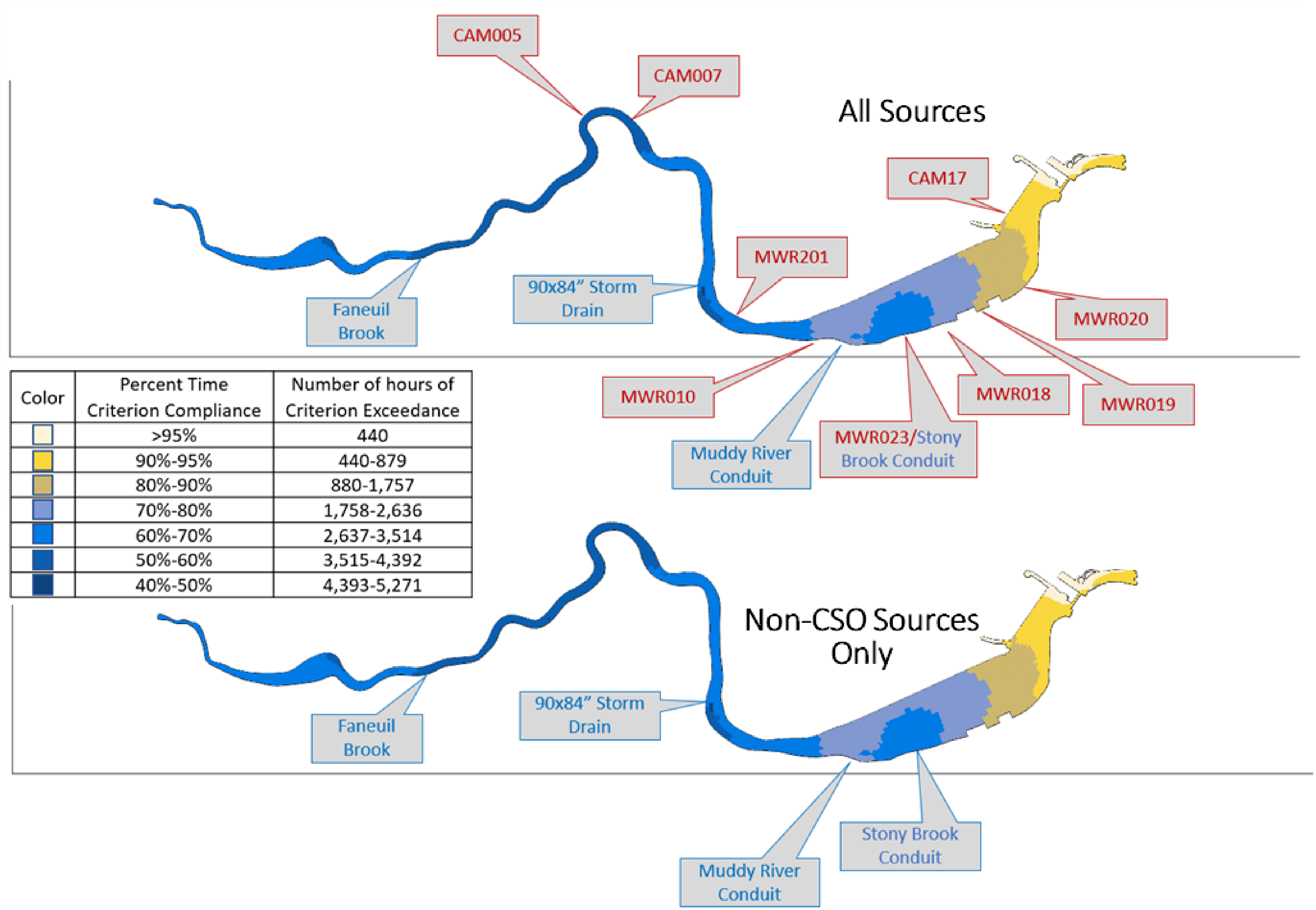
B.1.2 Criteria Exceedances

The hours of exceedance and percent annual compliance for *Enterococcus* criteria are presented in Table B-2 for the six different simulation conditions that were listed in Section 3.3.3. The hours shown in Table B-2 are the number of hours the *Enterococcus* bacterial counts exceed the criteria anywhere in the model area.

Table B-2. Hours of the Single Sample Maximum Criterion Exceedance at any point in the Lower Charles River During the Typical Year

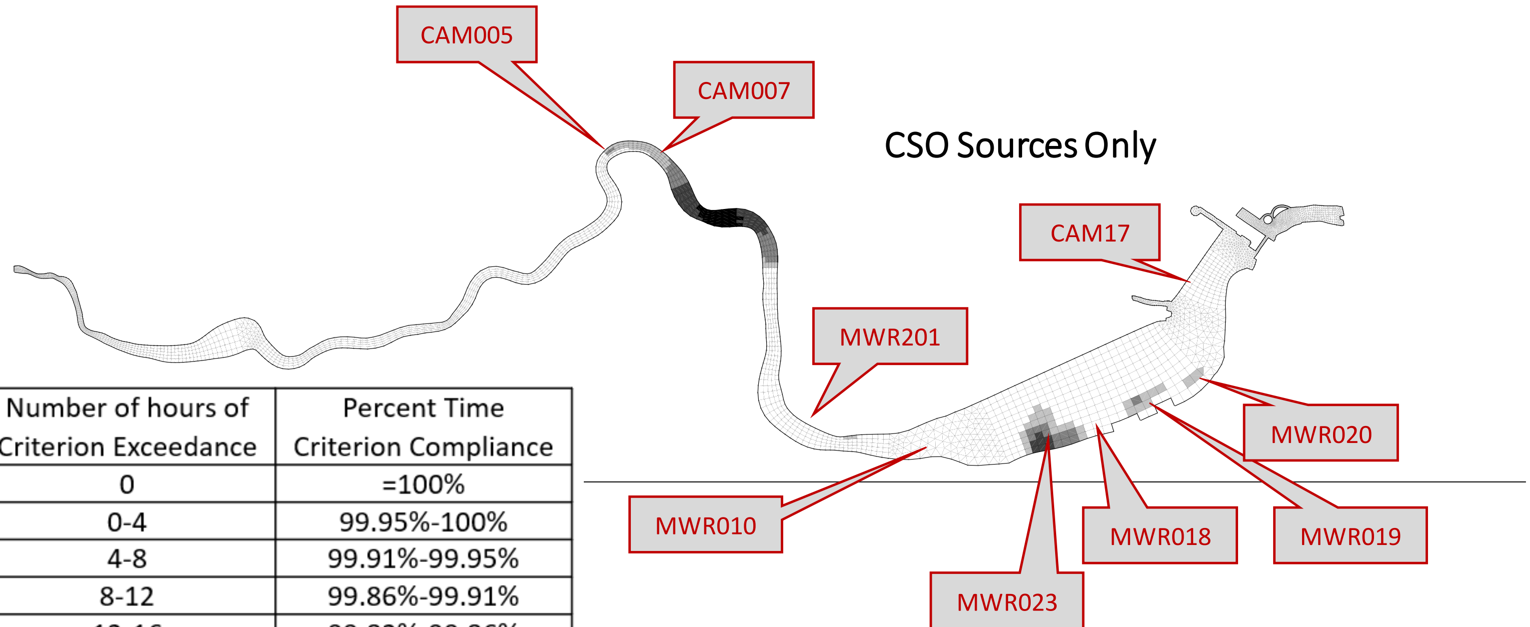
Charles River		
	Enterococcus Single Sample Maximum Criterion (61 #/100 mL)	
	Hours of Exceedance	**Percent Annual Compliance**
All Sources	6,285	28%
Non-CSO Sources Only	6,285	28%
Stormwater Only	5,062	42%
Dry Weather Sources Only	0	100%
Boundary Only	4,233	52%
CSOs Only	42	99.5%

Figure B-1 presents isopleths of the hours of exceedance of the *Enterococcus* single sample maximum criterion over the Typical Year for “All Sources” and “Non-CSO Sources Only”. Figure B-2 presents the results for “CSO only”.



Color	Percent Time Criterion Compliance	Number of hours of Criterion Exceedance
	>95%	440
	90%-95%	440-879
	80%-90%	880-1,757
	70%-80%	1,758-2,636
	60%-70%	2,637-3,514
	50%-60%	3,515-4,392
	40%-50%	4,393-5,271

Figure B-1. Hours of Exceedance and % Compliance with 61#/100mL *Enterococcus* Single-Sample Max. Criterion for the Typical Year



Color	Number of hours of Criterion Exceedance	Percent Time Criterion Compliance
(white)	0	=100%
(light gray)	0-4	99.95%-100%
(gray)	4-8	99.91%-99.95%
(dark gray)	8-12	99.86%-99.91%
(black)	12-16	99.82%-99.86%

Figure B-2. Hours of Exceedance and % Compliance with 61#/100mL *Enterococcus* Single-Sample Max. Criterion for the Typical Year for CSO Sources Only

B.1.3 Sensitivity Analysis

As was done for *E. coli* in the main body of the report, a sensitivity analysis was conducted for *Enterococcus* to assess the effect of possible departures from the bacterial counts assigned to the different sources. Stormwater *Enterococcus* counts were decreased by factors of 2 and 5 (possibly representing stormwater quality improvements), CSO counts were increased by a factor of 2 (to gauge the robustness of the CSO impact assessment) and boundary counts were multiplied by 0.5 and 0.2. Results are summarized in Table B-3.

Table B-3. Single Sample Maximum Sensitivity Analysis

Charles River				
	Source Count Multiplier	***Enterococcus* Value (#/100 mL)**	***Enterococcus* Single Sample Maximum Criterion (61 #/100 mL)**	
			Hours of Exceedance	**Percent Compliance**
Stormwater Only	1.0	10,000	5,062	42%
	0.5	5,000	3,492	60%
	0.2	2,000	2,298	74%
	25th Percentile	1,154	1,790	80%
CSO Only	1.0	Time varying Computed by Mass Balance	42	99.5%
	2.0	2x Time varying Computed by Mass Balance	79	99.1%
Boundary Only	1.0	Time varying Computed by Boundary Condition Model	4,233	52%
	0.5	0.5 x Time varying Computed by Boundary Condition Model	3,434	61%
	0.2	0.2 x Time varying Computed by Boundary Condition Model	2,287	84%

As expected, the sensitivity analysis shows that decreasing *Enterococcus* counts in sources increases percent compliance and, conversely, increasing counts decreases compliance. Bringing stormwater *Enterococcus* to the 25% percentile of the values measured in the stormwater monitoring would increase compliance from 42% to 80% for the stormwater-only condition, and decreasing boundary counts by a factor of 5 would increase compliance from 52% to 84% for the boundary loads-only condition. Noting that these compliance percentages are maxima over the entire river, these compliance improvements are significant.

Increasing the *Enterococcus* counts in untreated CSOs by a factor of 2 decreases compliance for the CSO-only case, but only minimally, from 99.5% to 99.1%

B.1.4 Summary

Salient *Enterococcus* results of the Charles River water quality impact assessment are summarized below:

- Stormwater contributes bacterial loadings each time it rains, over 90 times/year on average, and is the largest source of bacterial loading for both the design storms and on an annual basis

- The upstream boundary at Watertown Dam contributes bacterial loadings 24/7, and is the second-largest source of bacterial loading.

- CSOs contribute loadings only during the larger storms during a Typical Year, on average 8 times/year (at CAM005, less often at the other CSOs, and Cottage Farm discharge is treated)

- In a 1-year storm, CSOs contribute less than 1 percent of the total bacterial load.

- Typical Year performance:
  - With CSO loadings only, the single sample maximum criterion for *Enterococcus* is met everywhere in the Lower Charles River Basin approximately 99.6% of the time.
  - Even if the modeled CSO concentrations were doubled, attainment of the single sample maximum criterion for *Enterococcus* would still be 99.2%.
  - These results are consistent with the findings from the WQ modeling conducted for the 1997 LTCP (99-100% of time <200 colonies/100mL fecal coliform for CSO loads, only).
  - An 80 percent reduction in the bacteria counts in stormwater would reduce the hours of exceedance of water quality criteria for bacteria attributable to stormwater but would still leave approximately 2,300 hours of exceedance of the *Enterococcus* criterion based on stormwater loadings only.

B.2 Alewife/Mystic

B.2.1 Bacterial Loadings

The *Enterococcus* loadings to the Alewife Brook and Upper Mystic River during the 3-month and 1-year storms and during the Typical Year are summarized in Table B-4.

B.2.2 Criteria Exceedances

To assess compliance with the current water quality criteria for bacteria, the model was used to compute the total duration that the bacteria count in each segment along the linear model was predicted to exceed the single-sample maximum criteria for *Enterococcus* over the course of the Typical Year. The resulting values for percent annual attainment of the criteria would be generally analogous to the values for annual percent attainment presented in the 1997 FP/EIR. The hours of exceedance and percent annual compliance for the *Enterococcus* criterion in Alewife Brook is presented in Table B-5 for the six different simulation conditions that were simulated. Similar output is provided for the Mystic River in Table B-6. For the Mystic, only points downstream of Monitoring Station 083 were considered, as the stormwater and soil store discharges upstream of 083 were adjusted to simulate the boundary condition by matching measurements at 083. Therefore, *Enterococcus* values upstream of 083 are not reliable.

Table B-4. *Enterococcus* Loadings to the Alewife Brook/Upper Mystic River

Source	*Enterococcus* Loadings											
	Alewife Brook						Upper Mystic River					
	3-Month Storm		1-Year Storm		Typical Year		3-Month Storm		1-Year Storm		Typical Year	
	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total	counts (x 10^{12})	Percent of Total
Untreated CSOs(1)							N/A	N/A	N/A	N/A	N/A	N/A
Sanitary Component	0.001		2.13		6.01							
Non-Sanitary Component	0.22		0.71		6.59							
Total	0.22	5%	2.84	32%	12.6	11%						
Treated CSOs(1)	N/A	N/A	N/A	N/A	N/A	N/A	0.0006	<0.01%	0.0012	<0.01%	0.015	<0.01%
Stormwater	4.0	94%	6.0	68%	97	87%	13	88%	15	90%	340	80%
Dry Weather	0.024	0.6%	0.021	0.2%	2.0	1.8%	0.08	0.5%	0.075	0.5%	8.0	1.9%
Boundary	N/A	N/A	N/A	N/A	N/A	N/A	1.69	11%	1.68	10%	75.0	18%
Total	4 (100%)	100%	9 (100%)	100%	112 (100%)	100%	15 (100%)	100%	17 (100%)	100%	423 (100%)	100%

Notes:

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

Table B-5. Hours of the Single Sample Maximum Standard Criterion at any point in the Alewife Brook During the Typical Year

Alewife Brook		
	Enterococcus Single Sample Maximum Criterion (61 colonies/100 mL)	
	Hours of Exceedance	**Percent Annual Compliance**
All Sources	5,458	38%
Non-CSO Sources Only	5,458	38%
Stormwater Only	5,221	40%
Dry Weather sources Only	0	100%
Boundaries Only	N/A(1)	N/A(1)
CSOs Only	119	98.6%

Notes:

(1) Separate boundary flows/loads distinct from stormwater runoff are not generated by the model for the upstream end of Alewife Brook.

Table B-6. Hours of the Single Sample Maximum Criterion Exceedance at any point in the Upper Mystic RIver During the Typical Year

Upper Mystic River		
	Enterococcus Single Sample Maximum Criterion (61 colonies/100 mL)	
	Hours of Exceedance	**Percent Annual Compliance**
All Sources	4,996	46%
Non-CSO Sources Only	4,996	46%
Stormwater Only	4,665	47%
Dry Weather sources Only	0	100%
Boundaries Only	3,400	61%
CSOs Only	297	96.6%

Plots of hours of criteria exceedances over the Typical Year along Alewife Brook and Upper Mystic River for all sources are presented in Figure B-3, and for “CSOs only” in Figure B-4. Plots of criteria exceedances over the Typical Year for the condition of all sources except CSO were identical to the “All Sources” plots, so the plots are not repeated here.

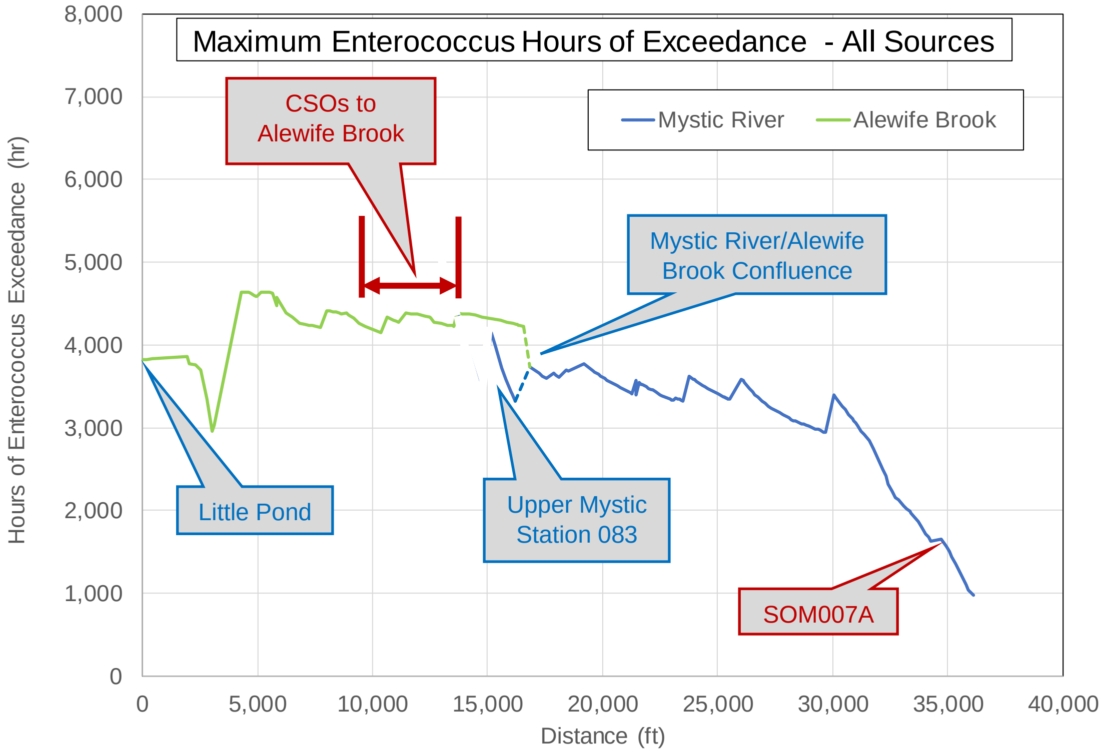


Figure B-3. Hours of Exceedance of Single Sample Max Criterion *Enterococcus*, All Sources, Typical Year.

Figure B-3 shows that for "All Sources" the location with the highest hours of exceedance in the Mystic River is at the upstream end, at MWRA Monitoring Station 083, located about 1 mile downstream of the Lower Mystic Lake outlet (at a distance of 15,144 ft on Figure B-3). The 4,147 hours of exceedance at that location results in a corresponding percent annual compliance of 53%. This is consistent with percent annual compliance values of 47% and 40% measured at Monitoring Station 083 for 2018 and 2019 respectively. The monitoring included storm-centric surveys where samples were collected during storms and for several days afterwards, which may explain the slightly lower percent annual compliance in the measurements.

Downstream of the Alewife Brook confluence, in the part of the Upper Mystic River affected by CSOs, the maximum hours of criteria exceedance for "All Sources" is 3,770, with a corresponding percent annual compliance of 57%.

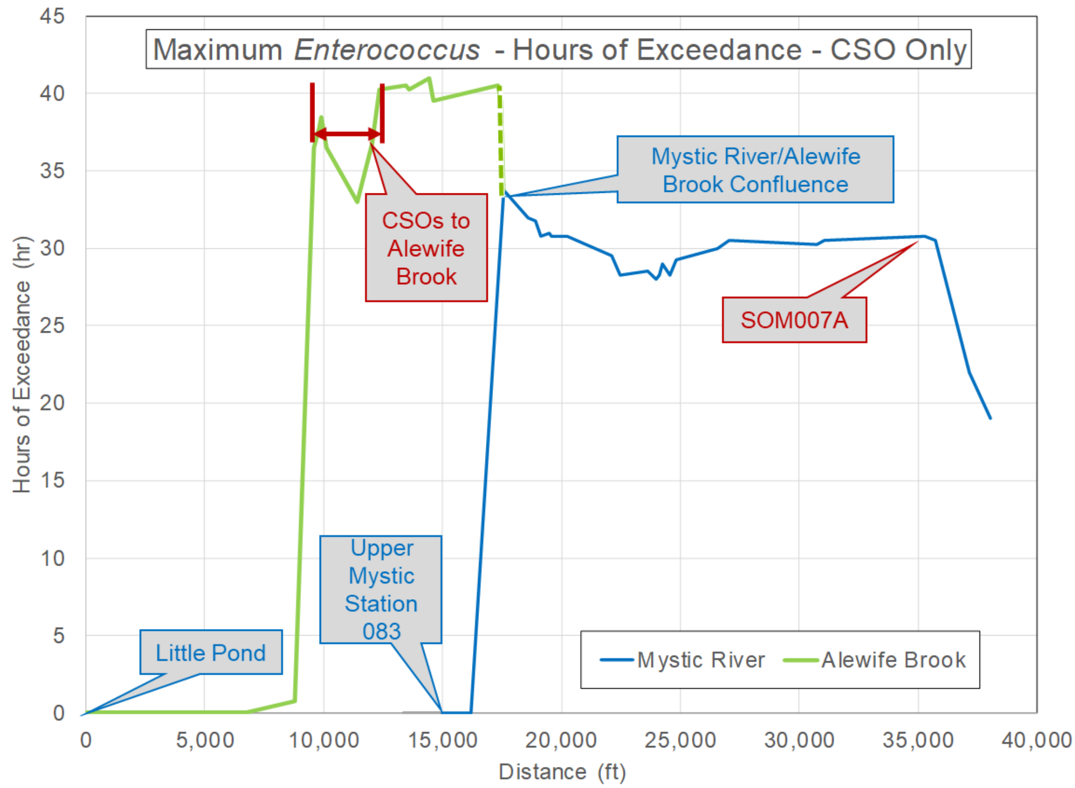


Figure B-4. Hours of Exceedance of Single Sample Max Criterion *Enterococcus*, CSOs Only, Typical Year. Note change in scale from "All Sources".

For "CSOs Only", the highest number of hours of exceedance in the Upper Mystic River downstream of the Alewife Brook confluence is 33, with a corresponding percent annual compliance of 99.6%.

B.2.3 Sensitivity Analysis

As was done for the Charles River and described in Section B.1.3, a sensitivity analysis was conducted for the Alewife Brook/Upper Mystic River. The same factors were used. Results are summarized in Table B-7.

The results of the sensitivity analysis are similar to those obtained for the Charles.

- Reducing the *Enterococcus* count in stormwater by a factor of 5 increases the percent annual compliance from 39% to 55% for the stormwater-only case.
- Reducing the boundary *Enterococcus* counts by a factor of 5 bring the percent annual compliance to 98% for the boundary conditions-only case.

- Increasing the CSO Enterococcus count by a factor of 2 has a minimal impact on the annual percent compliance for the CSO-only case.

Table B-7. Single Sample Maximum Sensitivity Analysis

Alewife Brook and Upper Mystic River Downstream of 083				
	Source Count Multiplier	*Enterococcus* Value (MPN/100 mL)	*Enterococcus* Single Sample Maximum Criterion (61 colonies/100 mL)	
			Hours of Exceedance	Percent Compliance
Stormwater Only	1.0	6,700	5,382	39%
	0.5	3,350	4,789	45%
	0.2	1,340	4,061	54%
	25th Percentile	1,154	3,959	55%
CSO Only	1.0	Time varying Computed by Mass Balance	343	96%
	2.0	2x Time varying Computed by Mass Balance	390	96%
Boundary Only	1.0	SW = 20,000(1) SS= 3,000(2)	5,394	38%
	0.5	SW = 10,000 SS = 1,500	1,099	87%
	0.2	SW = 4,000 SS = 600	212	98%

Notes:
(1) SW = Stormwater *Enterococcus* count upstream of Monitoring Station 083
(2) SS = Soil Store *Enterococcus* count upstream of Monitoring Station 083

Summary

Salient *Enterococcus* results of the Alewife Brook/Upper Mystic River water quality impact assessment are summarized below:

- Stormwater contributes bacterial loadings each time it rains, over 90 times/year on average, and is the largest source of bacterial loading for both the design storms and on an annual basis.

- The upstream boundary sources are not present for the Alewife, which is entirely covered by the runoff areas in the model. For the Upper Mystic River boundary sources are significant.

- CSOs contribute loadings directly to Alewife Brook only during the larger storms during a Typical Year, on average 10 times/year (at CAM401A, less often at the other CSOs). No untreated CSOs discharge to the Mystic River.

- In a 1-year storm, CSOs contribute approximately 30 percent of the total bacterial load to Alewife Brook, but the contribution drops to 5 percent in the 3-month storm.

- Typical Year performance:
  - With CSO loadings only, the single sample maximum criterion for *Enterococcus* is met everywhere in Alewife Brook more than 98% of the time, and everywhere in the Mystic River approximately 97% of the time.
  - Even if the modeled CSO concentrations were doubled, attainment of the single sample maximum criterion for *Enterococcus* would still be at least 95%.
  - These results are consistent with the findings from the WQ modeling conducted for the *2003 Final Variance Report for Alewife Brook/Upper Mystic River* (98.5 percent of time <200 cfu/100mL fecal coliform for CSO loads, only).
  - An 80 percent reduction in the bacteria counts in stormwater would reduce the hours of exceedance of water quality criteria for bacteria attributable to stormwater but would still leave over 4,000 hours of exceedance of the *Enterococcus* standard based on stormwater loadings only.