Summary of CSO Receiving Water Quality Monitoring in Upper Mystic River/Alewife Brook and Charles River, 2004

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 2005-14

Citation: Coughlin, K. 2005 Apr. **Summary of CSO Receiving Water Quality Monitoring in Upper Mystic River/Alewife Brook and Charles River, 2004**. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2005-14. 35 p.

Summary of CSO Receiving Water Quality Monitoring in Upper Mystic River/Alewife Brook and Charles River, 2004

Summary of CSO Receiving Water Quality Monitoring in Upper Mystic River/Alewife Brook and Charles River, 2004

Prepared by:

Kelly Coughlin
Environmental Quality Department, Operations Division
Massachusetts Water Resources Authority
100 First Avenue, Boston, MA 02129

April 2005

Environmental Quality Department Technical Report 2005-14

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Introduction

This report presents a summary of data collected as part of MWRA's ongoing combined sewer overflow (CSO) receiving water monitoring program, conducted in support of the extended "Variance for Combined Sewer Overflow (CSO) Discharges to the Alewife Brook/Upper Mystic River" dated September 1, 2004 and the extended "Variance for Combined Sewer Overflow (CSO) Disharges to the Lower Charles River Basin" dated October 1, 2004. The goal of this monitoring is to identify the water quality impacts of CSO flows on water bodies, and to assess whether water bodies impacted by CSO flows meet Massachusetts water quality standards.

As of the end of 2004, 63 CSOs remain active in the Boston Harbor and its tributaries, 21 have been closed since the early 1990s. In the Charles, 12 CSOs remain active and 7 have been closed. In the Mystic River, eight CSOs remain active in Alewife Brook, five have been closed, and one treated CSO (MWR205A) remains active in the lower Mystic.

System improvements such as increased pumping capacity at Deer Island Treatment Plant have reduced the frequency and volume of CSO flows over the period of the monitoring program. Figure 1-1 shows the estimated CSO flow reduction system-wide since 1987 according to MWRA's CSO control plan. The increase in pumping capacity at Deer Island in the early 1990's and the introduction of secondary treatment in 1998 at Deer Island Treatment Plant also served to reduce CSO overflows system-wide. For purposes of this report, receiving water quality data from 1998 to the present is considered representative of current conditions.

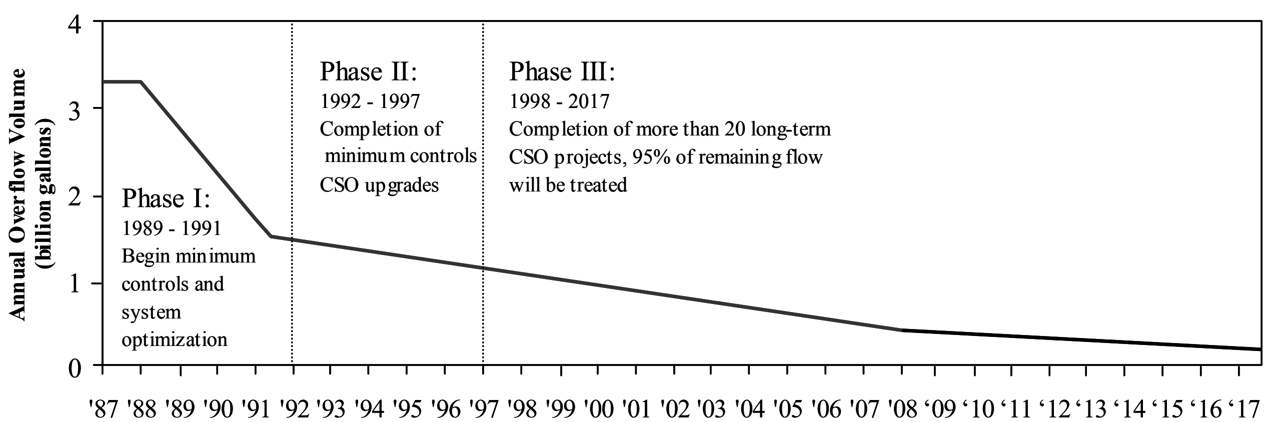

Figure 1-1. Estimated CSO flow reductions, 1987 – 2017

Source: MWRA Annual CSO Progress Report 2005

1.1 Overview of the monitoring program

MWRA's CSO receiving water quality monitoring program has been ongoing since 1989, with occasional changes in sampling frequency and intensity. All harbor and tributary areas impacted by CSOs in Boston, Chelsea, Cambridge, and Somerville have been included in the monitoring program. For most sampling locations included in this report, at least 20 samples have been collected each year for at least five years.

1.2 Organization and purpose of the report

Chapter 2 presents the materials and methods used in monitoring. Chapters 3 and 4 of this report discuss the results of the CSO receiving water quality monitoring program in the Charles River and Mystic River/Alewife Brook. Water quality parameters examined for each region include: bacterial indicators (fecal coliform, *E. coli* and *Enterococcus*), dissolved oxygen, water clarity (Secchi depth, total suspended solids), and nutrients (phosphate, ammonium, nitrate/nitrite) and chlorophyll. The purpose of the report is to summarize water quality in the Charles and Alewife Brook/Mystic River as described in the variance requirements. The report compiles sampling results to water quality standards, and shows spatial and temporal variations in water quality, and differences between wet and dry weather. Data from 1998 – 2004 are analyzed together, and data for 2004 is also shown separately.

2 Materials and Methods

2.1 Field and laboratory methods

2.1.1 Selection of sampling locations

Some sampling locations were chosen for their proximity to CSO discharges and others were chosen to provide representative water quality measurements for a given area. A complete list of stations, with descriptions for the Charles and Mystic Rivers appear in Section 3.1 and 4.1, respectively.

2.1.2 Sampling schedule

Approximately 20 station visits or more were made to each location each year. Sampling was random with respect to weather, however efforts were made to collect additional samples during wet weather, if an inadequate number of station visits occurred following rainfall events. In some cases, stations with known contamination problems were specifically targeted for wet weather sampling.

2.1.3 Sample collection

At all locations, water samples and water quality measurements were collected near-surface (approximately 0.1 meters below surface). Surface samples were collected by grab, directly into rinsed sample containers. Bottom samples were collected with a Kemmerer sampler at 0.5 meters above the sediment surface at locations deeper than approximately 4 meters. Beginning in 2000, bottom water quality measurements were made at most locations regardless of depth. Separate sampling containers were used for bacteria, nutrient, and TSS analyses.

2.1.4 Field measurements

Field measurements were made with different instruments over the course of the monitoring program. Table 2-2 lists the instruments used and the variables measured.

Table 2-1. Field measurements.

Variable	Instruments used
Temperature, conductivity/salinity, dissolved oxygen, turbidity, pH	YSI model 3800 Water Quality Logger (1994 - 2001) Hydrolab Datasonde 4 (1997-2004) Hydrolab Datasonde 5 (2003 - 2004) YSI 600XL for temperature, conductivity, dissolved oxygen (1999 – 2004)
Secchi Depth	Wildco 8-inch limnological secchi disk (above dams) Marine: Wildco 8-inch oceanographic secchi disk

2.1.5 Rainfall measurements

Rainfall measurements were taken from the National Weather Service rain gauge located at Logan Airport in East Boston, as this was considered the most representative location for the entire monitoring area. Results from the gauge are reported in one-day intervals. Data are downloaded from the NWS website and stored in MWRA's EM&MS database.

2.1.6 Laboratory analyses

Samples were analyzed either at the MWRA Central Laboratory. For enumeration of bacteria, nutrients, and TSS, MWRA Department of Laboratory Services Standard Operating Procedures was followed.

Detailed laboratory methods with quality assurance and quality control procedures are described in the Central Laboratory Standard Operating Procedure (MWRA 1999).

Table 2-3 lists the analytes measured and methods used in the monitoring program.

Table 2-2. Laboratory measurements.

Analyte	Method
Enterococcus	Standard Methods 9230C 2c, membrane filtration (for samples collected 1996 – 1998) EPA Method 1600 (for samples collected 1999–2004)
E. coli (measured from 2001 – 2004)	Modified EPA 1103.1, membrane filtration
Fecal coliform (limited measurements after 2001)	Standard Methods 9222D, membrane filtration
Total suspended solids	Clesceri et al. (1998, Method 2540D), using nucleopore filters
Total phosphorus	TP and/or TDP: Solarzano and Sharp (1980a); PP: Solarzano and Sharp (1980a), Whatman GF/F
Phosphate	Murphy and Riley (1962), modified as in Clesceri et al (1998, Method 4500-P F) Skalar SAN^{plus} autoanalyzer, Whatman GF/F filters
Total Nitrogen	TN and/or TDN: Solarzano and Sharp (1980b), Whatman G/F filters; PN: Perkin Elmer CHN analyzer, Whatman GF/F
Ammonium	Fiore and O'Brien (1962), modified as in Clesceri et al (1998, Method 4500-NH3 H), Skalar SAN^{plus} autoanalyzer, Whatman GF/F filters
Nitrate+nitrite	Bendshneider and Robinson (1952), modified as in Clesceri et al (1998, Method 4500-NO3 F), Skalar SAN^{plus} autoanalyzer, Whatman GF/F filters
Chlorophyll *a*	Acid-corrected (Holm Hansen 1965) as described in EPA (1992). Sequoia Turner Model 450 fluorometer, GF/F filters

2.2 *Data analysis*

Descriptive Analyses. Indicator bacteria counts are typically log-normally distributed, and therefore a proper measure of central tendency for these data is the geometric mean. Geometric means and their associated 95% confidence intervals were calculated for the measurements made at each station over the sampling period.

Many results are plotted as percentile plots, as shown in Figure 2-1.

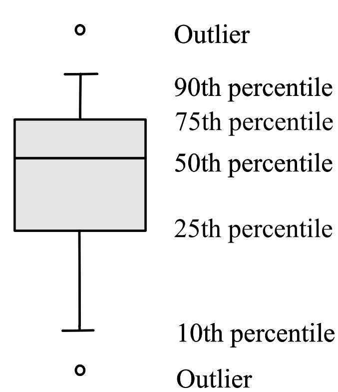

Figure 2-1. Percentile distributions indicated on percentile plots

These plots present a frequency distribution of a group of measurements. Each box comprises measurements from a single beach or sampling location. Values are shown in Figure 2-1 for the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles. Single measurements beyond these ranges (outliers) are displayed as dots.

The plots display the range and central tendencies of the data to be seen and allow for easy comparison of the results among stations. Since part of the Massachusetts standard is a percentile, these plots are particularly appropriate (see Section 2.3 for a description of these guidelines). When box plots are displayed on a logarithmic scale, the 50^{th} percentile is equivalent to the geometric mean.

Statistical Analyses. *Enterococcus* and fecal coliform were evaluated for temporal differences between each year 1998 - 2004 using an analysis of variance (ANOVA) with post hoc analysis performed by Fisher's protected least significant difference test for multiple comparisons.

Graphic and statistical analyses were performed using Excel (Microsoft Corp., Redmond, WA) and Statview (SAS, Inc., Cary, NC). Figures were generated using Statview, Excel and PowerPoint (Microsoft Corp., Redmond, WA).

2.3 Water Quality Standards used in this report

Standards are shown in Table 2-6, and include standards and guidelines from the Massachusetts Department of Environmental Protection (MADEP), Environmental Protection Agency (EPA), Massachusetts Department of Public Health (MADPH), and the Massachusetts Division of Marine Fisheries (MADMF). The EP standard for Class SB waters (fishable swimmable) are based on fecal coliform counts, while the USEPA recommends using *Enterococcus* in marine waters (USEPA 1986). The Massachusetts Department of Public Health has issued regulations for beach management based on the USEPA criteria.

Table 2-3. Water quality standards for Class B and Class SB waters[1].

Designated Use/Standard	Parameter	Support
Inland waters, Class B, warm water fishery Massachusetts waters, MADEP	Dissolved Oxygen	≥ 5.0 mg/l ≥ 60% saturation unless background conditions lower
	Temperature	≤ 28.3ºC (83ºF)
	pH	6.0 to 8.3 S.U.
Coastal/marine waters, Class SB Massachusetts waters, MADEP	Dissolved Oxygen	≥ 5.0 mg/L ≥ 60% saturation unless background conditions lower
	Temperature	< 26.7ºC (80ºF)
	pH	6.5 to 8.5 S.U.
Primary contact recreation (designated swimming area), EPA and MADPH guidelines	*Enterococcus*	Single sample limit 61colonies/100 ml (freshwater), 104 colonies/100 ml (marine); geometric mean 33 colonies/100 ml (freshwater), 35 colonies/100 ml (marine)
Primary contact recreation (designated swimming area), EPA and MADPH guidelines	*E. coli*	Single sample limit 235 colonies/100 ml (freshwater only); geometric mean 126 colonies/100 ml (freshwater only)
Primary contact recreation, Massachusetts MADEP	Fecal coliform	Geometric mean ≤ 200 colonies/100 ml, no more than 10% of samples above 400 colonies/100 ml
Restricted shellfishing, Massachusetts MADMF	Fecal coliform	Geometric mean ≤ 88 colonies/100 ml

[1] **All receiving water areas discussed in this report are either Class B or SB according to MADEP standards. From MADEP 1996:**

Inland Water Class B: These waters are designated as a 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.

Coastal and Marine Class SB: These waters are designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfishing Areas). These waters shall have consistently good aesthetic value.

3 Charles River

3.1 Sampling area

MWRA's sampling area in the Charles River includes the river segment from the Watertown Dam in Watertown downstream to the New Charles River Dam in Boston, near the river mouth. This area, for purposes of this report called the Charles Basin, is freshwater and designated Class B with a variance for Combined Sewer Overflows by MADEP (MADEP 2000). The river segment is approximately 10.3 km (8.6 mi) long. Flow is usually slow because the New Charles Dam and locks limit river flow and tidal exchange at the river mouth. MWRA monitoring locations are primarily located midstream, bracketing CSO outfalls. Locations were also selected near to or downstream of outfalls where accessible by boat: at Stony Brook outlet and CSO (MWR023), Faneuil Brook outlet and CSO (BOS032, closed in Nov. 97), and downstream of the Cottage Farm CSO outfall diffusers (MWR201).

For purposes of this report, MWRA's monitoring area in the lower Charles is divided into three smaller segments or reaches. Table 3-1 describes the reaches, sampling locations and CSOs within each reach. Sampling locations and CSOs appear in Figure 3-1.

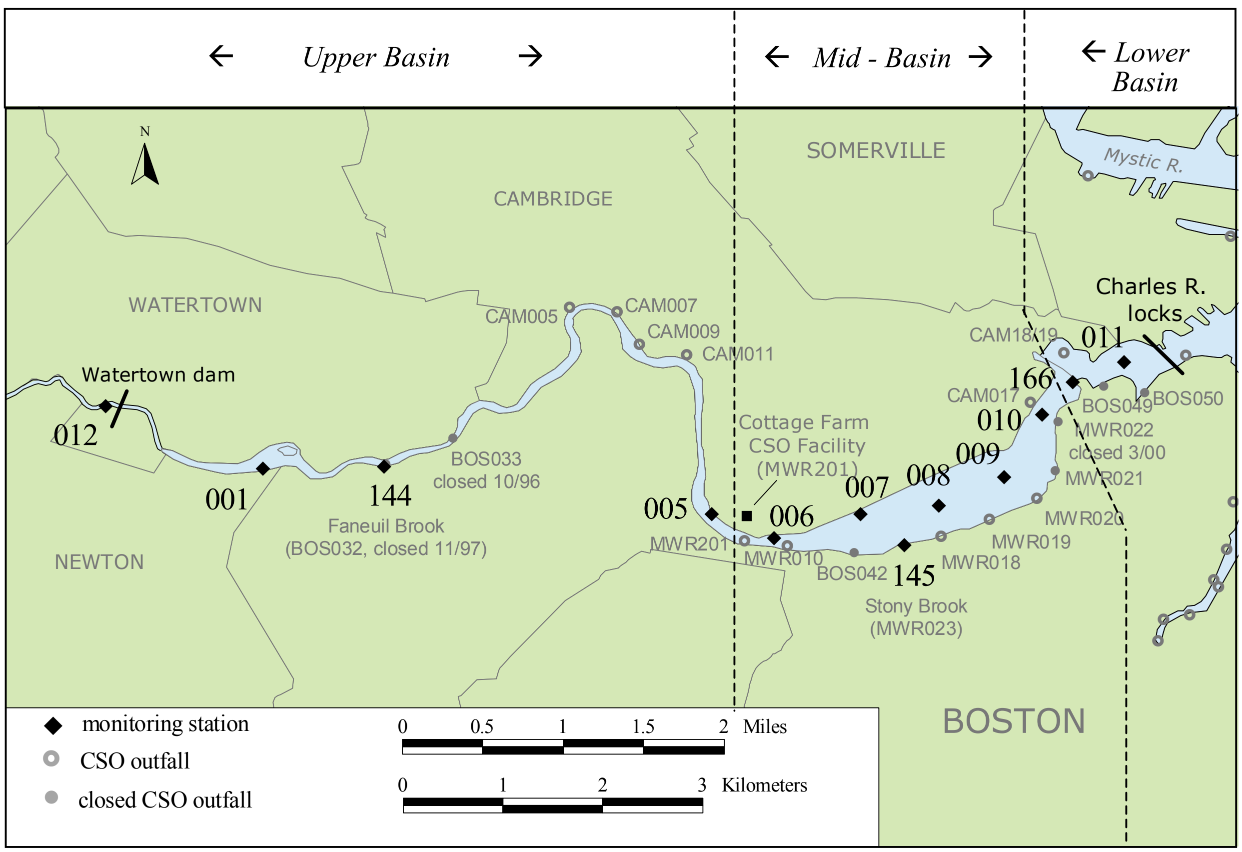

Figure 3-1. Map of MWRA Charles River sampling locations

Table 3-1. MWRA monitoring locations, Charles River Basin.

Reach	Description of Reach	Sampling location	Location Description
Upper Basin (Class B/Variance, warm water fishery)	Watertown dam in Watertown, downstream to Magazine Beach (near BU Bridge) in Cambridge	012, Watertown	Watertown Dam at footbridge (upstream of all CSOs)
		001, Newton	Downstream of Newton Yacht Club (upstream of all CSOs)
		144, Allston	Faneuil Brook outlet (at BOS032, closed 11/97)
		005, Cambridge	10 m off of Magazine Beach
Mid-Basin (Class B/Variance, warm water fishery)	BU Bridge on Boston/Cambridge line to downstream of Longfellow Bridge	006, Cambridge/Boston	BU Bridge, downstream side (downstream of MWR201)
		007, Cambridge	MIT Boathouse, Cambridge side
		145, Boston	Stony Brook outlet, Boston side (at MWR203)
		008, Cambridge/Boston	Mass. Ave bridge, downstream side (downstream of MWR203, MWR018)
		009, Cambridge/Boston	Longfellow Bridge, upstream side (downstream of MWR021, closed 3/00)
		010, Boston	Longfellow Bridge, downstream side (downstream of MWR022, closed 3/00)
Lower Basin (Class B/Variance, warm water fishery)	Science Museum to North Station railroad bridge, near Charlestown.	166, Boston	Science Museum, upstream of old dam (downstream of all lower basin CSOs)
		011, Boston	Between Science Museum and New Charles Dam/locks (downstream of all Charles CSOs)

Sampling locations are midstream unless otherwise noted.

3.2 Pollution sources

Known pollution sources to the Charles River are shown in Table 3-2. As of December 2004, the river was affected by 12 CSOs in Cambridge and Boston (1 CSO, BOS049, is scheduled for closure). Contamination upstream of the Watertown Dam has been evident since MWRA's monitoring program began in 1989 (MWRA, in prep). MWRA's Cottage Farm CSO treatment facility, located upstream of the BU Bridge, screens, chlorinates and dechlorinates CSO flow before discharge and is the only source of treated CSO discharge to the river. With increases in sewer system capacity, the number of activations at Cottage Farm has decreased in recent years – from 26 activations in 1996 to 13 activations per year, on average, since 1999 (MWRA, 2003). The Stony Brook/Muddy River outlet near Kenmore Square is a source of contaminated brook flow and large volumes of untreated CSO flows to the basin area. Numerous illicit connections in the river basin and upstream of the basin have been identified and eliminated during the monitoring period, an improvement reflected in the dry weather bacterial monitoring results shown later in this report.

Table 3-2. Charles River Basin pollution sources.

Source	Upper Basin	Mid-Basin	Lower Basin
CSOs (untreated)	4 active, 2 closed CAM005, CAM007, CAM009, CAM011 BOS032 closed 11/97 BOS033 closed 10/96	6 active, 3 closed MWR010, MWR023, MWR018, MWR019, MWR20, CAM017 BOS042 closed 5/96 MWR021 closed 3/00 MWR022 closed 3/00	1 active BOS049 (to be closed)
CSO treatment facility (settling and detention; screened, chlorinated and dechlorinated CSO discharge)	✗	✓ Cottage Farm (MWR201)	✗
Storm drains	✓	✓	✓
Upstream inputs (elevated bacteria counts upstream)	✓	✓	✓
Dry weather inputs (elevated bacteria counts in dry weather)	✓	✓	✓
Brook or stream flow	✓	✓	✓

3.3 Summary of water quality, 1998-2004

Because no significant differences were detected year-to-year among water quality variables since 1998 (ANCOVA controlling for rainfall, $p > 0.05$, data not shown), and 1998 was the beginning of Phase III of MWRA's CSO Control Plan (i.e. implementation of CSO Plan projects), Table 3-3 groups these years together to provide a more complete picture of existing water quality.

In general, bacterial water quality and water clarity is poorer in upstream portions of the monitoring area, whereas nutrient water quality is poorer in the downstream portions. The Mid-Basin area of the river, its bottom-water characteristics and stratification due to saltwater intrusion from the harbor, had the lowest dissolved oxygen levels of the three reaches.

Table 3-3. Summary of water quality, Charles River Basin 1998 – 2004.

Parameter		MA DEP Water Quality Guideline	Upper Basin				Mid-Basin				Lower Basin			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n
Surface Temperature (°C)[1]	Summer	<28.3	20.8 ± 4.5	99.9	7.2 - 28.5	810	21.1 ± 3.9	99.7	10.4 - 29.2	994	21.4 ± 4.2	97.4	11.2 - 29.9	459
	Winter		2.7 ± 3.1	100.0	-1.1 - 15.6	145	ND	ND	ND	0	3.2 ± 2.7	100.0	-1.5 - 13.7	136
Bottom water dissolved oxygen (mg/L)[1]	Summer	5.0	7.5 ± 1.9	92.2	0.2 - 13.6	785	5.7 ± 3	69.1	0 - 11.5	955	6.7 ± 2.4	79.8	0.3 - 12.8	451
	Winter	5.0	13.4 ± 1.5	100.0	5.5 - 16.1	144	ND	ND	ND	0	12.5 ± 1	100.0	10.1 - 15.8	134
pH (S.U.)		6.5-8.3	7.2 ± 0.4	95.3	5.3 – 8.7	1215	7.2 ± 0.5	95.4	6 – 8.8	1519	7.3 ± 0.5	92.0	5.1 – 8.9	747
Water clarity	Total Suspended Solids (mg/L)	NS	5.2 ± 2.9	-	0.7 - 19.3	299	ND	-	ND	0	4.3 ± 2	-	0.7 - 12.8	301
	Secchi depth (m)	NS	0.8 ± 0.2	-	0.3 - 2	449	1 ± 0.3	-	0.3 - 6	878	1.2 ± 0.3	-	0.5 - 2.2	172
	Turbidity (NTU)	NS	5.7 ± 4.9	-	0 - 36.1	743	7.6 ± 5.6	-	0 - 42.5	998	4 ± 4.2	-	0 - 45.2	542

Table 3-3. Summary of water quality, Charles River Basin 1998 – 2004, continued.

Parameter		MA DEP Water Quality Guideline	Upper Basin				Mid- Basin				Lower Basin			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n
Bacteria (col/100mL)[2]	Fecal coliform (1998 – 2000)	200 / 400[3]	228 (203-257)	69.5	0 - 158000	688	80 (71-90)	83.4	0 - 43300	876	49 (42-58)	91.4	0 - 18200	407
	E. coli (2001- 2004)	126 / 235[3,4]	239 (193-297)	50.4	0 - 12300	248	71 (60-83)	74.4	0 - 34400	590	32 (26-39)	92.0	0 - 10500	225
	Enterococcus	33 / 61[3]	81 (71-92)	44.6	0 - 17600	928	15 (13-17)	73.8	0 - 6720	1459	12 (10-14)	80.9	0 - 4000	629
Nutrients (µmol/L)	Phosphate	NS	0.76 ± 0.45	-	0.11 - 3.01	298	ND	-	ND	0	0.75 ± 0.55	-	0.07 - 3.63	295
	Ammonium	NS	6 ± 4.6	-	0.2 - 42.9	299	ND	-	ND	0	9.6 ± 6.9	-	0 - 32.1	296
	Nitrate+nitrite	NS	38.3 ± 19.9	-	0 - 99.3	297	ND	-	ND	0	36.1 ± 20.5	-	0.2 - 107.1	294
Algae (µg/L)	Chlorophyll	25[5]	8 ± 7.5	94.4	0.6 - 37.6	284	ND	ND	ND	0	15 ± 13.2	80.5	0.7 - 87.6	282

NS: no standard or guideline. ND: No data. [1]: Summer (June-September), Winter (December-March).

[2]: For bacterial data, 95% confidence intervals are provided in lieu of standard deviations.

[3]: First number is the all samples geometric mean limit - compare to the "Mean±SD" column; the second number is the single sample limit - compare to the "% meeting guideline" column. For fecal coliform, MADEP has an additional limit in that more than 90% of single samples must meet the single sample limit of 400 colonies/100mL.

[4]: *E. coli* standard is the Massachusetts Department of Public Health standard for swimming in fresh water.

[5]: NOAA guideline.

3.4 Trends in water quality, 2004

This section provides an analysis of spatial trends for each water quality parameter measured in the lower Charles in the 2004 monitoring year. While only 2004 data is shown in this section, there were not significant differences in water quality year-to-year after 1998 (ANCOVA, controlling for rainfall, analysis not shown). Changes in water quality prior to 1998 are discussed in a separate report (MWRA, in prep).

3.4.1 Physical measurements

Temperature. Summer mean temperatures for 2004 are shown for each sampling location in the top graph in Figure 3-2. Temperature profiles are relatively consistent upstream to downstream, with bottom-water temperatures relatively low in the deepest stations, 009 and 010, where depths average 6 to 7 meters (20 to 23 feet). Station 166 is collected in a shallow location in the basin near the Science Museum, so differences in surface and bottom temperatures at this location are negligible.

Dissolved Oxygen. The spatial trend in dissolved oxygen (DO) in the Charles Basin differs dramatically for surface and bottom waters, shown in the center graph of Figure 3-2. Mean surface DO meets the State standard of 5.0 mg/L at all locations at the surface, but mean bottom water DO consistently meets the standard at only the upper basin locations. Stratification (due to salt water intrusion through the river locks, as well as low bottom temperatures) results in very low bottom-water dissolved oxygen in the lower basin area. Station 166, downstream of the lower basin, is collected at a relatively shallow near-shore location and does not reflect the low levels of deeper water. Station 011 has the highest bottom water salinity of any of the locations (data not shown), but does have slightly higher dissolved oxygen levels than basin locations located further upstream – likely reflecting the influence of more oxygenated ocean water infiltrating the river locks.

Water clarity. Water clarity is indicated by Secchi disk depth, these results shown for individual sampling locations in the bottom graph in Figure 3-2. In general, there is a pattern of increasing water clarity from upstream to downstream, as the river widens and slows in the lower Basin. Most Secchi depths average approximately 1.0 meter in the summer months, which fails to meet the State guideline of 1.2 meters.

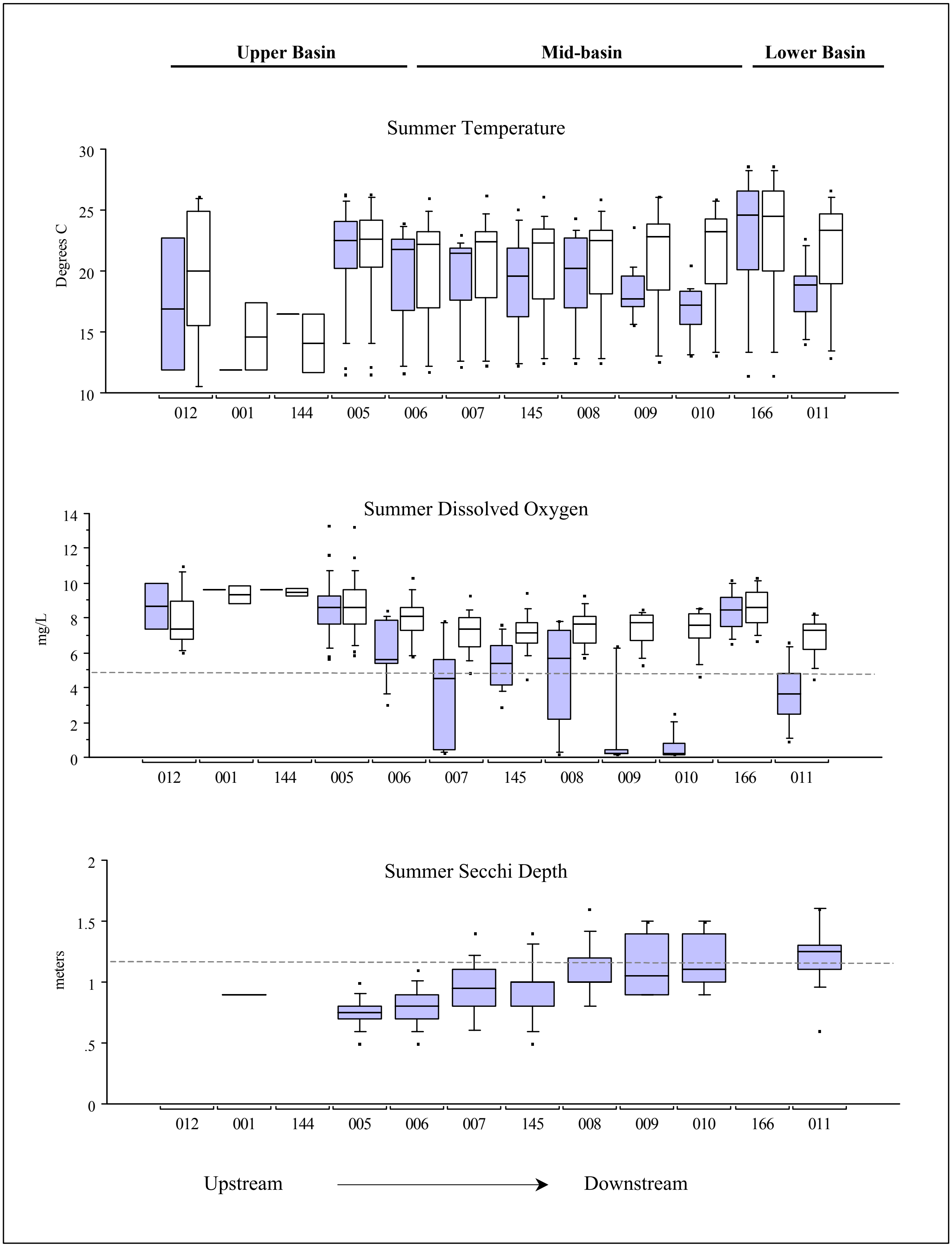

Figure 3-2. Summer temperature, dissolved oxygen, and Secchi depth, Charles River Basin, 2004.

Dashed lines are State standards.

3.4.2 Nutrients, TSS and chlorophyll

Trends in total nitrogen, ammonium, nitrate/nitrite, total phosphorus, orthophosphate, total suspended solids, and chlorophyll *a* at the upstream (166) and downstream (012) locations in the Basin are shown in Figure 3-3. Because routine nutrient monitoring in the Charles began in 1997, it is difficult to draw any conclusions about long-term trends, but to date there is no evidence of one (data not shown).

In the short term, however, the results do show strong seasonal trends. Seasonal signals are most evident with nitrate+nitrite, total phosphorus/orthophosphate, and chlorophyll *a*. While the two locations show similar concentrations for most parameters, there are marked differences between the two stations for ammonium, total suspended solids and chlorophyll *a*. Total suspended solids increases markedly in the spring months at Station 012, but there is a less dramatic increase downstream of the lower basin at Station 166.

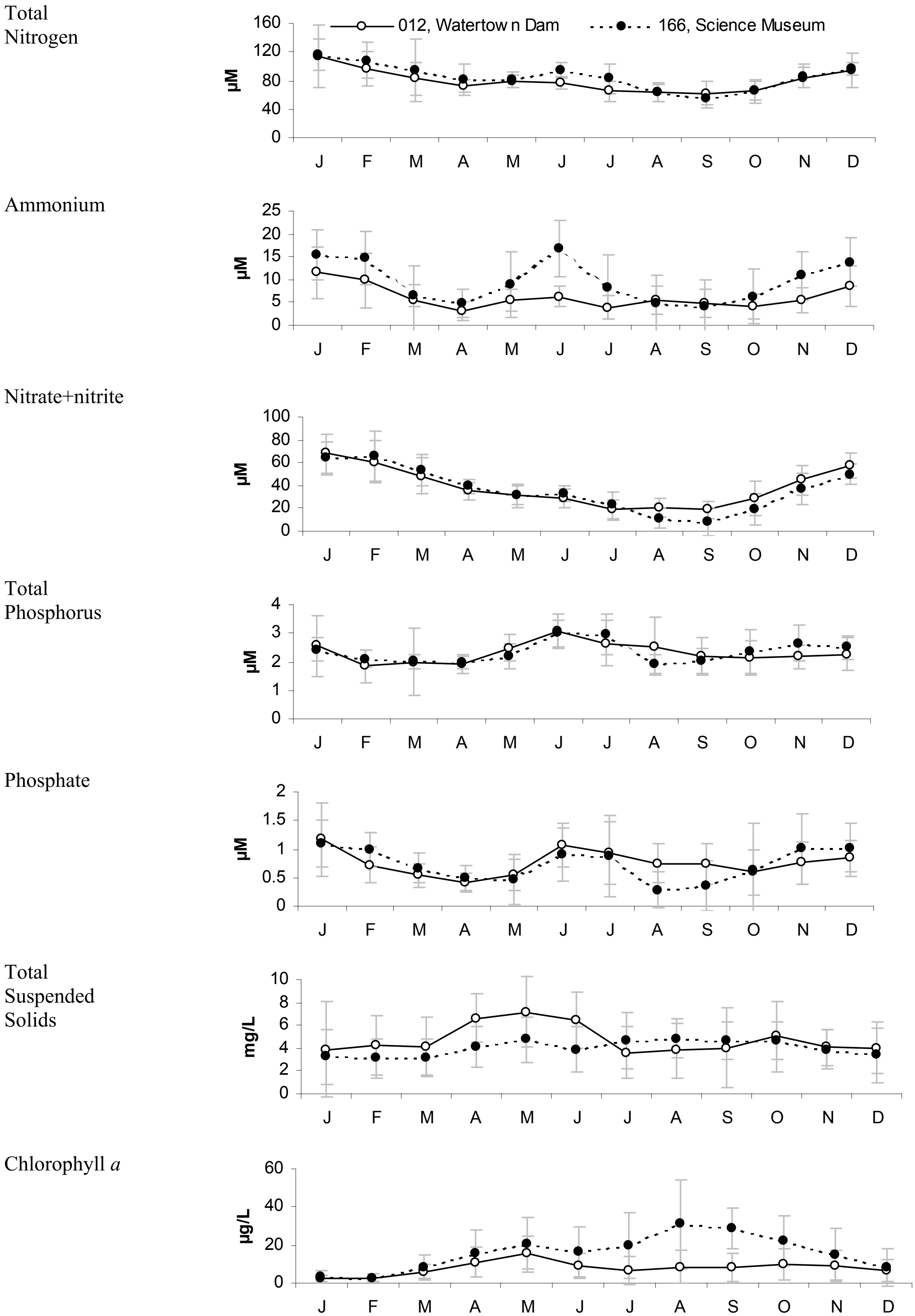

Figure 3-3. Monthly average nutrients, TSS and Chlorophyll 1998 – 2004, Charles River.

3.4.3 Bacterial water quality

Figure 3-4 shows the current bacterial water quality at each location sampled in the Charles for 2004. As in past years, bacterial water quality in the Charles varies upstream to downstream, with upstream reaches having generally higher bacteria counts than downstream locations.

Geometric means for all locations for 1998 – 2004 appear in Table 3-4. All years were grouped together for greater representativeness because no significant change was detected in bacterial water quality over this period, and 1998 marks the beginning of Phase III of MWRA's CSO Control Plan.

Enterococcus. The uppermost graph in Figure 3-4 shows percentile plots of *Enterococcus* counts arranged from upstream to downstream locations for 2004. Figure 3-5 shows the impact of rainfall on the three river reaches on *Enterococcus* densities, along with the change at locations near CSO outfalls. (With the switch in coliform indicators in 2001, wet weather data associated with *E. coli* or fecal coliform are insufficient to show results in this format). The median counts for the upstream locations fail to meet geometric mean EPA guidelines. For the lower basin locations, most meet the standard in dry weather, but fail to meet standards in wet weather. All reaches show a similar pattern, with wet weather mean counts generally higher than in dry weather.

E. coli. The center graph in Figure 3-4 shows percentile plots of *Enterococcus* counts arranged from upstream to downstream locations for 2004. Generally, *E. coli* shows the same trend as *Enterococcus*.

Fecal coliform. Fecal coliform monitoring was reduced, replaced with *E. coli* beginning in mid-2001, so there are fewer samples collected in 2004 than for the other two bacterial indicators. Fecal coliform appears in the bottom graph in Figure 3-4.

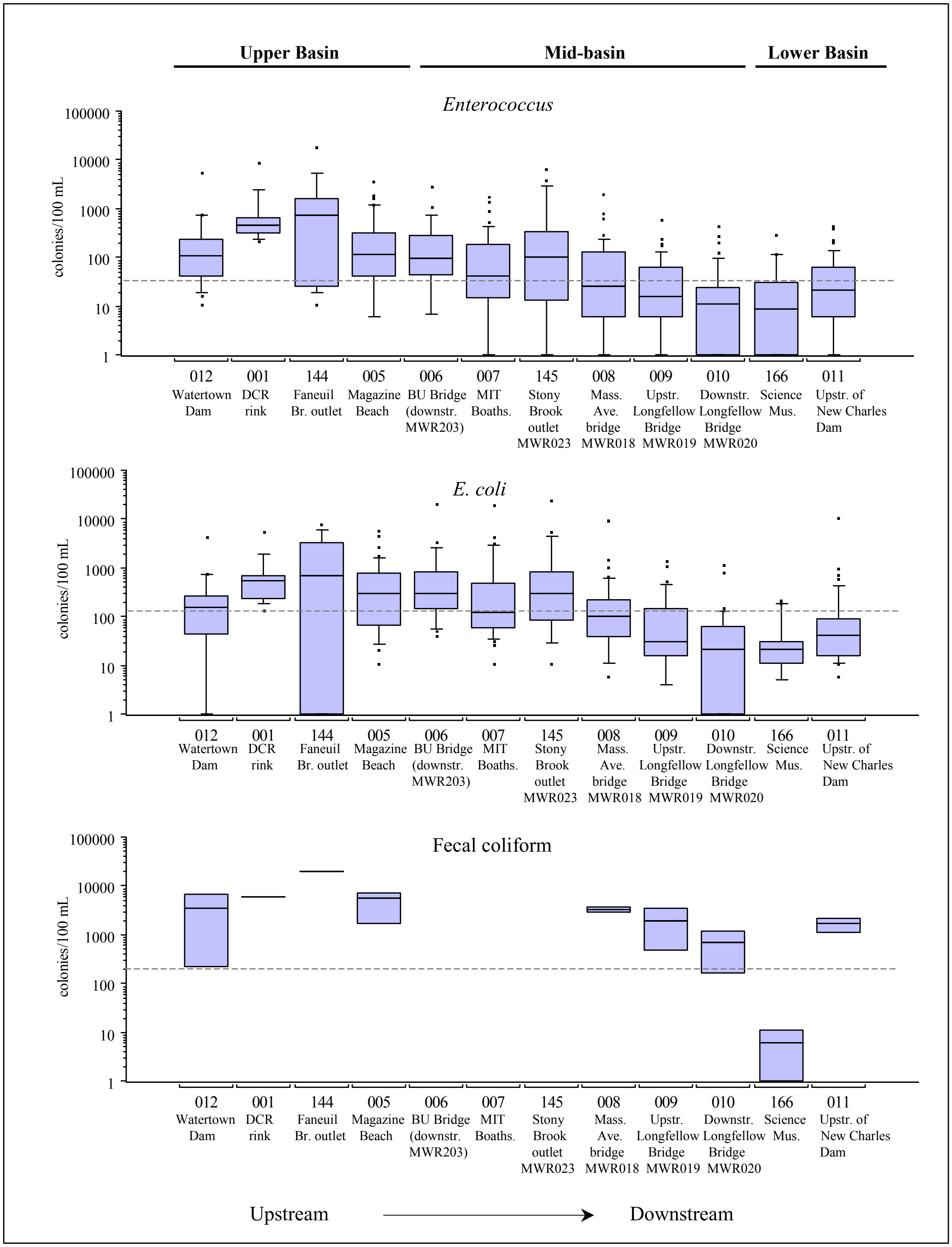

Figure 3-4. Indicator bacteria concentrations, Charles River Basin, 2004.

Dotted lines show EPA geometric mean guideline and MADEP fecal coliform standard.
Fecal coliform is being phased out from the monitoring program, replaced by *E. coli*.

Table 3-4. Geometric mean indicator bacteria, Charles River Basin, 1998 – 2004.

Station	Location	Surface or Bottom	Number of samples[1]	*Enterococcus* (95% CI)	Fecal coliform (95% CI)	*E. coli* (95% CI)
012	Newtown/Watertown, footbridge upstream of Watertown Dam	S	325/225/101	114 (97-134)	232 (198-271)	155 (119-204)
001	Newton, near Nonantum Rd., rear of DCR skating rink	S	90/83/8	169 (112-256)	468 (343-637)	1503 (471-4796)
144	Brighton, downstream of N. Beacon St. bridge, Faneuil Brook outlet, BOS-032 (closed 1999)	S	53/36/19	370 (221-619)	784 (417-1470)	264 (57-1220)
005	Cambridge, near Magazine Beach, upstream of Cottage Farm	S	152/85/68	41 (30-55)	156 (110-222)	313 (222-442)
006	Cambridge/Boston, midstream, downstream of Cottage Farm, BU bridge	S	145/87/59	52 (40-69)	219 (166-287)	400 (290-550)
007	Cambridge, near Memorial Dr., MIT Boathouse	S	146/87/59	17 (12-24)	90 (61-132)	129 (83-201)
		B	145/87/58	33 (22-48)	151 (104-218)	160 (102-252)
145	Boston (Charlesgate), Muddy River/Stony Brook outlet	S	146/87/59	34 (23-50)	175 (121-252)	220 (140-346)
008	Cambridge/Boston, midstream, downstream of Harvard Bridge	S	146/88/59	11 (8-17)	78 (52-118)	59 (36-95)
		B	145/88/58	19 (13-28)	102 (69-148)	110 (75-160)
009	Cambridge/Boston, midstream, upstream of Longfellow Bridge near Community Sailing	S	147/88/60	7 (5-10)	48 (34-69)	42 (27-64)
		B	146/88/59	9 (6-12)	59 (44-81)	22 (14-34)
010	Boston, downstream of Longfellow Bridge, MWR-022	S	147/88/60	6 (4-9)	39 (28-53)	33 (22-50)
		B	146/88/59	5 (4-7)	22 (16-32)	8 (5-13)
166	Boston, old Charles River dam, rear of Science Museum	S	333/229/104	12 (10-16)	61 (48-77)	29 (21-41)
011	Boston, upstream of river locks (New Charles River Dam) and I-93, near Nashua St.	S	148/89/61	8 (5-10)	38 (28-50)	30 (21-43)
		B	148/89/60	16 (12-20)	38 (29-49)	40 (28-56)

[1]N values for *Enterococcus*, fecal coliform, and *E. coli*, respectively.

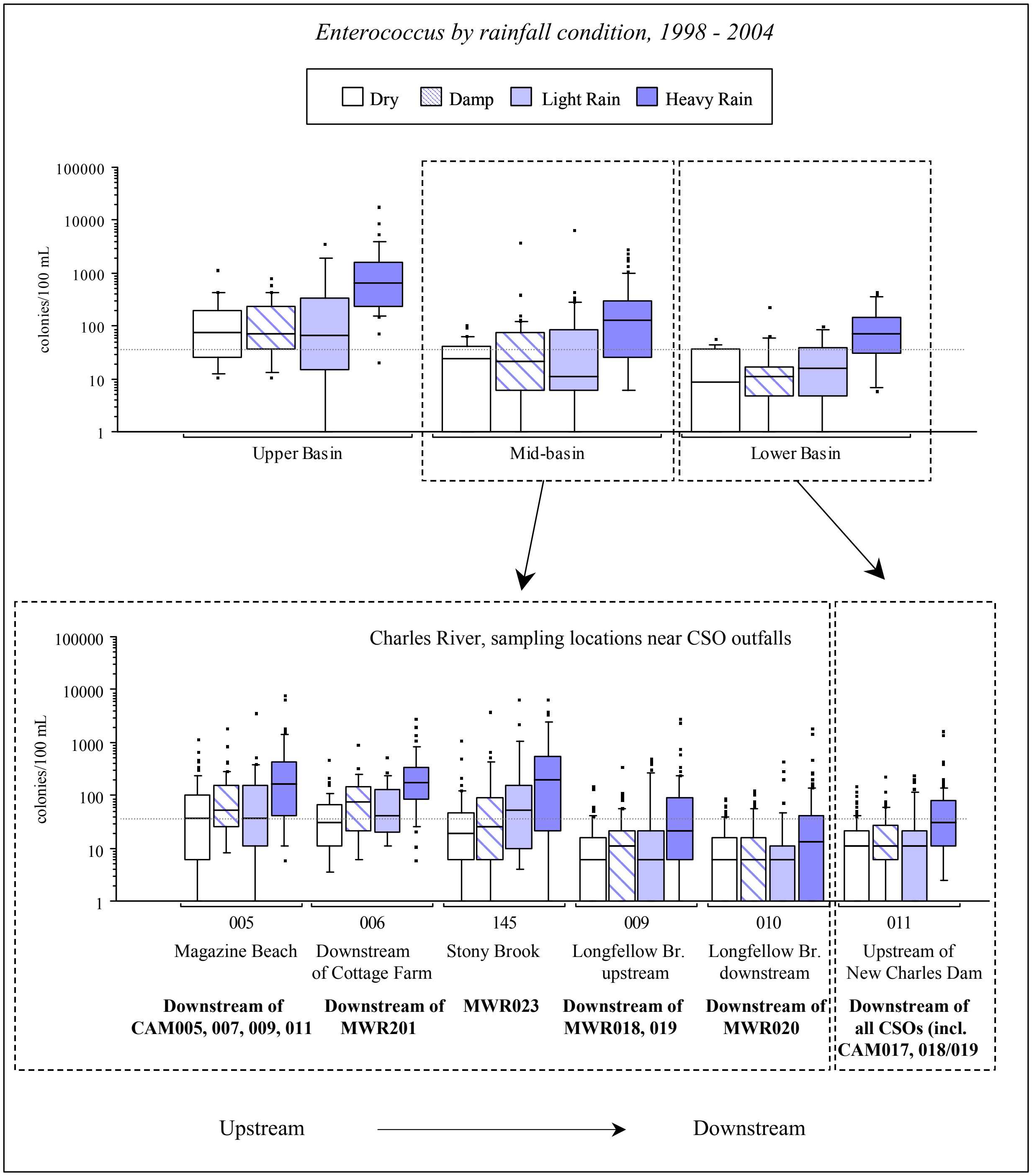

Figure 3-5. *Enterococcus* by rainfall condition, Charles Basin, 1998 - 2004.

Dotted line shows State standard. Rainfall is NOAA rainfall from Logan airport. “Dry”: no rainfall for previous 3 days; “Heavy”: more than 0.5 inches in previous 3 days; “Damp” and/or rain distant in time: any rain < 0.15 inches at least two or three days previous to sampling and/or 0.1 inches in previous day; “Light rain”: between 0.1 and 0.5 inches in previous day and/or between 0.15 and 0.5 in two previous days.

3.5 Summary of Charles River water quality

In general, water quality in the Charles River basin meets water quality standards except for the upper Basin, which fails to meet bacterial standards in all weather conditions. However, rainfall events result in the failure to meet EPA and/or MADEP bacterial standards at all but the most downstream locations, due to wet weather discharges including CSO overflows and stormwater runoff.

Water quality in the Charles is poorer at upstream locations, and improves as the river widens and slows near the New Charles Dam. An exception to this trend is bottom-water dissolved oxygen, which worsens considerably in the lower Charles basin. As in previous years, the lower basin locations were stratified in summer, resulting in relatively low bottom water temperatures and extremely low bottom water dissolved oxygen. Seawater leaking through the Charles locks in summer contributes to stratification of the basin, limiting exchange with surface waters.

Nutrients and chlorophyll exhibited strong seasonal signals, with chlorophyll *a* and ammonium more elevated downstream than upstream in summer months, and total suspended solids more elevated upstream than downstream in spring months. Total nitrogen and total phosphorus are similar in both upstream and downstream locations.

4 Mystic River and Alewife Brook

4.1 Sampling area

Monitoring results of the Mystic River are divided into four sub-regions. Table 3-1 describes the sub-regions and the sampling locations within each sub-region. Locations are shown on the map in Figure 3-1.

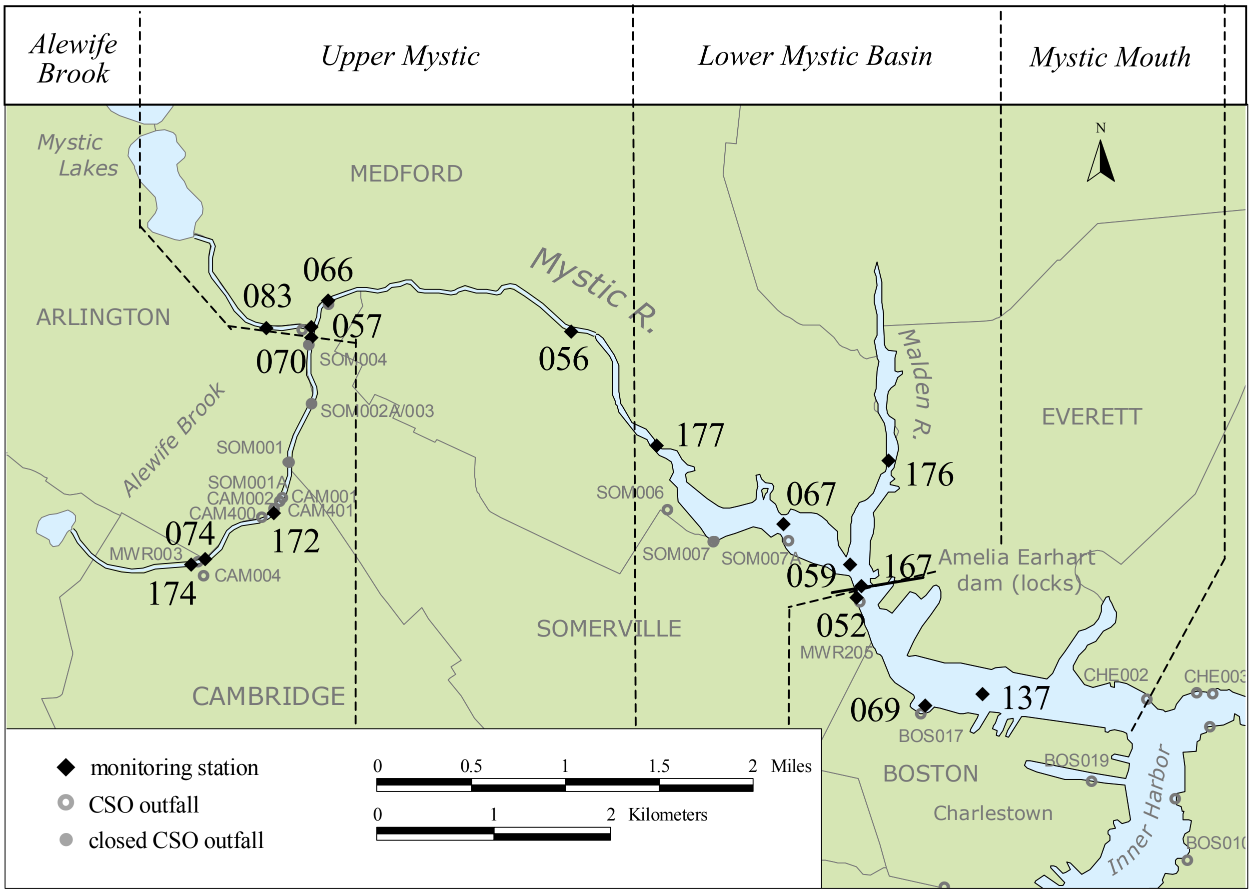

Figure 4-1. Map of Mystic River sampling locations

Table 4-1. MWRA monitoring locations, Mystic River and Alewife Brook.

Reach	Description of Reach	Sampling location	Location Description
Alewife Brook (Class B/Variance, warm water fishery)	Tributary to Mystic River. From confluence at Little River in Cambridge/Arlington to confluence with Mystic River in Arlington/Somerville	174, Cambridge/Arlington	Little River, upstream of Rt. 2 and offramp to Alewife T station. Upstream of all CSOs.
		074, Cambridge/Arlington	Downstream of CAM001A, CAM004, MWR003
		172, Cambridge/Arlington	Downstream of CAM001, CAM002, CAM400, CAM401B, SOM001A
		070, Arlington/Somerville	Mystic Valley Parkway bridge. Downstream of all Alewife CSOs
Upper Mystic River (Class B/Variance, warm water fishery)	Downstream of Lower MysticLake in Arlington/Medford to Route 28 bridge in Medford	083, Arlington/Medford	Upstream of confluence of Mystic River and Alewife Brook
		057, Medford	Confluence of Mystic River and Alewife Brook
		066, Medford	Boston Ave bridge, downstream side
		056, Medford	Upstream of I-93 bridge, near Medford Square offramp
Lower Mystic River basin (Class B/Variance, warm water fishery)	Route 28 bridge in Medford to Amelia Earhart Dam in Somerville/Everett	177, Medford	Downstream of Rt. 16 bridge
		067, Medford	Rt. 28 bridge, downstream side, near Somerville Marginal MWR205A outfall
		176, Medford/Everett	Malden River, upstream of Rt. 16 bridge
		059, Somerville/Everett	Confluence of Mystic and Malden Rivers, downstream of MWR205A
		167, Somerville/Everett	Amelia Earhart Dam, upstream side
Mystic River mouth (Class SB/CSO, marine)	Downstream of Amelia Earhart Dam in Somerville/Everett to Tobin Bridge, Chelsea R. confluence in Chelsea/East Boston	052, Somerville	Downstream of Amelia Earhart dam, near Somerville Marginal CSO facility outfall (MWR205)
		069, Charlestown	Rear of Schraffts Building at BOS-017 outfall
		137, Charlestown/Everett	Upstream of Tobin Bridge near confluence of Mystic, Chelsea Rivers and upper inner harbor

Sampling locations are midstream unless otherwise noted.

4.2 Pollution sources

Known pollution sources to the Mystic River/Alewife Brook are shown in Table 4-2. The river is affected by 9 CSOs in Cambridge and Somerville, with 8 active CSOs in Alewife Brook, and one treated CSO in the Lower Mystic basin, which discharges only during an activation at high tide. MWRA's Somerville Marginal CSO treatment facility discharges downstream of the Amelia Earhart dam at low tide, screening and chlorinating CSO flow before discharge. It is the only source of treated CSO discharge to the river. The

Alewife Brook is the primary source of contaminated brook flow and significant untreated CSO flows to the lower Mystic River.

Table 4-2. Mystic River/Alewife Brook pollution sources.

Source	Alewife Brook	Upper Mystic River	Lower Mystic River	Mystic River mouth
CSOs (untreated)	8 active, 5 closed CAM401A, MWR003, CAM001, CAM401B, CAM002, SOM001A *CAM004, CAM400 to be closed* SOM001 closed 12/96 SOM002 closed 1994 SOM002A closed 8/95 SOM003 closed 8/95 SOM004 closed 12/95	2 closed SOM006 closed 12/96 SOM007 closed 12/96	None	1 active BOS017
CSO treatment facility (screened, chlorinated and dechlorinated CSO discharge)	✗	✗	✓ Somerville Marginal (MWR205A, high tide only)	✓ Somerville Marginal (MWR205)
Storm drains	✓	✓	✓	✓
Upstream inputs (elevated bacteria counts upstream)	✓	✓	✓	✓
Dry weather inputs (elevated bacteria counts in dry weather)	✓	✓	✓	✓
Brook or stream flow	✓	✓	✓	✓

4.3 Summary of water quality, 1998-2004

A detailed summary of water quality results collected from 1998 through 2004 is shown in Table 4-3. Because no significant differences were detected year-to-year among water quality variables since 1998 (the beginning of Phase III CSO Control Plan), the years are grouped together.

Table 4-3. Summary of water quality, Mystic River/Alewife Brook 1998 – 2004.

Parameter		Water Quality Guideline	Alewife Brook				Upper Mystic				Lower Mystic Basin				Mystic Mouth			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n
Surface Temperature (°C)[1]	Summer	<28.3	18.2 ± 4.3	100.0	6.3 - 26.4	316	20.5 ± 4.6	100.0	7.2 - 27.9	643	20 ± 4.6	100.0	8.1 - 27.8	616	16.9 ± 2.8	100.0	9.5 - 24.8	468
	Winter		4.6 ± 2	100.0	1.7 - 8.1	23	3 ± 2.1	100.0	-0.2 - 9.5	103	4.0 ± 2.5	100.0	-0.3 - 14.3	132	3.6 ± 2.1	100.0	-0.7 - 8.5	87
Bottom water dissolved oxygen (mg/L)[1]	Summer	5.0	5.0 ± 1.7	51.4	1.2 - 8.9	311	6.8 ± 1.4	91.6	0.5 - 10	634	7.8 ± 2.6	85.7	0 - 13.8	608	6.5 ± 1.1	93.4	3.5 - 10.7	458
	Winter	5.0	10.4 ± 1.2	100.0	7.6 - 12	23	11.6 ± 1.5	99.0	4.1 - 14.4	102	11.4 ± 1.4	100.0	5 - 14.7	128	10.1 ± 1.1	100.0	7.5 - 13.7	87
pH (S.U.)		6.5-8.3	7.1 ± 0.3	93.7	5.9 - 8.8	413	7.4 ± 0.4	94.7	5.4 - 8.9	924	7.6 ± 0.8	74.2	5 – 9.7	952	7.7 ± 0.3	98.1	5.2 - 9.5	755
Water clarity	Total Suspended Solids (mg/L)	NS	ND	-	ND	0	6.3 ± 3.7	-	1.1 - 26.7	236	8.3 ± 4	-	0.5 - 26.3	281	4.3 ± 6.3	-	0.3 - 115	490
	Secchi depth (m)	NS	0.5 ± 0.2	-	0.2 - 1	55	1.0 ± 0.3	-	0.4 - 1.9	212	0.7 ± 0.2	-	0.2 - 2.5	300	2.2 ± 0.8	-	0.3 - 5.3	379
	Turbidity (NTU)	NS	10.1 ± 8.1	-	0 - 58.5	269	6.1 ± 4.4	-	0 - 31.3	642	10.4 ± 6.7	-	0 - 52	645	5.0 ± 5.9	-	0 - 59.9	483

Table 4-3. Summary of water quality, Mystic River/Alewife Brook 1998 – 2004, continued.

Parameter		Water Quality Guideline	Alewife Brook				Upper Mystic				Lower Mystic Basin				Mystic Mouth			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n
Bacteria (col/100mL)[2]	Fecal coliform	200 / 400[3]	1210 (1067-1372)	16.9	0 - 156000	437	190 (167-216)	73.9	0 - 95100	536	68 (59-79)	89.4	0 - 30400	483	38 (31-47)	83.7	0 - 252000	582
	E. coli	126 / 235[3,4]	701 (614-801)	7.7	0 - 146000	246	106 (87-128)	75.0	0 - 42200	276	23 (18-29)	88.4	0 - 2820	242	22 (16-30)	81.2	0 - 180000	293
	Enterococcus	33 / 61[3]	455 (404-511)	7.2	0 - 24800	555	67 (58-77)	48.8	0 - 9600	660	9 (7-10)	85.1	0 - 11400	610	7 (6-8)	84.0	0 - 58800	833
Nutrients (µmol/L)	Phosphate	NS	ND	-	ND	0	0.36 ± 0.25	-	0.07 - 1.96	234	0.29 ± 0.22	-	0.04 - 1.53	281	1.07 ± 0.45	-	0 - 2.52	492
	Ammonium	NS	ND	-	ND	0	19.8 ± 14.1	-	0.2 - 60.8	234	13.6 ± 13.9	-	0.1 - 51.8	281	7.4 ± 6.1	-	0 - 27.8	492
	Nitrate+nitrite	NS	ND	-	ND	0	54.9 ± 22.7	-	7.5 - 177.9	233	36.6 ± 26.5	-	0 - 168.6	279	6.9 ± 6.9	-	0.1 - 62.4	489
Algae (µg/L)	Chlorophyll *a*	25[5]	ND	ND	ND	0	14.6 ± 8.5	86.8	1.7 - 56.8	234	30.3 ± 21.8	46.6	1.8 - 131	266	4.1 ± 5.4	98.8	0.2 - 49.6	496

NS: no standard or guideline. ND: No data. [1]: Summer (June-September), Winter (December-March).

[2]: For bacterial data, 95% confidence intervals are provided in lieu of standard deviations.

[3]: First number is the all samples geometric mean limit - compare to the "Mean±SD" column; the second number is the single sample limit - compare to the "% meeting guideline" column. For fecal coliform, Massachusetts has an additional limit in that more than 90% of single samples must meet the single sample limit of 400 colonies/100mL.

[4]: *E. coli* standard is the Massachusetts Department of Public Health standard for swimming in fresh water.

[5]: NOAA standard.

4.4 Trends in water quality, 2004

This section provides an analysis of spatial trends for water quality parameters measured in the Mystic River in the 2004 monitoring year. While only 2004 data is shown in this section, there were not significant differences in water quality year-to-year after 1998 (ANCOVA, controlling for rainfall, $p > 0.05$). Changes in water quality prior to 1998 are discussed in a separate report (MWRA, in prep).

4.4.1 Physical measurements

Temperature. Summer mean temperatures for 2004 are shown for each sampling location in the top graph of Figure 4-2. Temperatures are lowest in the Alewife Brook and at the river mouth, where the river meets Boston Harbor. Surface and bottom temperatures are similar, except in the downstream reach near the dam where the river deepens, with depths averaging more than 6 meters (19 feet).

Dissolved Oxygen. The spatial trend in dissolved oxygen in the Mystic Basin is similar for surface and bottom waters, shown in the center graph of Figure 4-2. Mean surface and bottom dissolved oxygen are well above the State standard of 5.0 mg/L in much of the river, but fail to meet the standard in the downstream bottom-water portions of Alewife Brook, Malden River, and upstream of the Amelia Earhart dam. Bottom-water dissolved oxygen is lowest at the Malden River location, Station 176. Unlike the Charles River, there is little evidence of stratification in the lower portion of the Mystic.

Water clarity. Water clarity is indicated by Secchi disk depth; shown for individual sampling locations in the bottom graph of Figure 4-2. In general water clarity is quite poor, with nearly all stations failing to meet the guideline of 1.2 meters. (Alewife Brook is too shallow to collect Secchi depth readings.) Clarity downstream of the Amelia Earhart dam increases dramatically as the river flows into Boston Harbor.

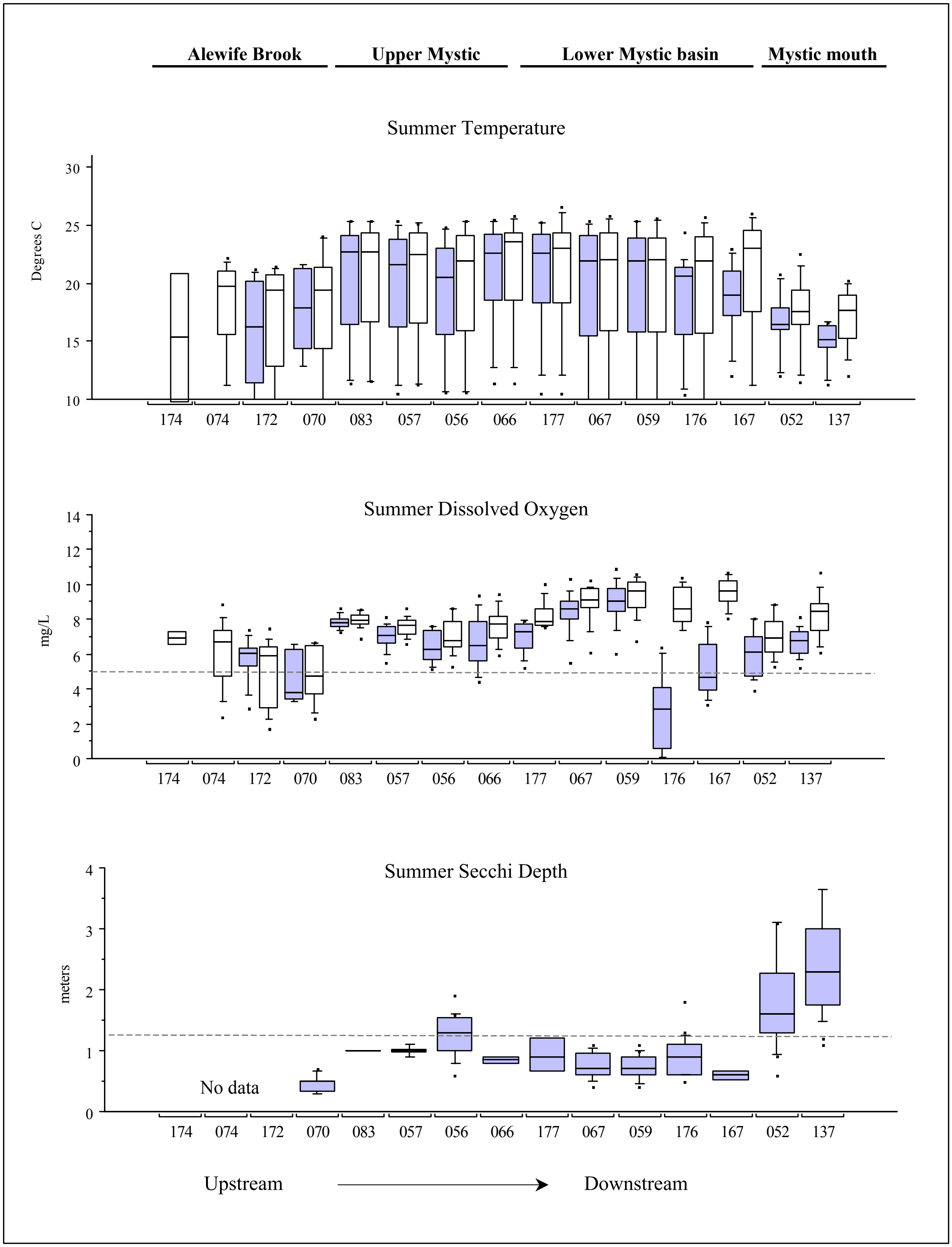

Figure 4-2. Summer temperature, dissolved oxygen, and Secchi depth, Lower Mystic, 2004.

Dashed lines are State standards.

4.4.2 Nutrients, TSS and chlorophyll

Monthly average total nitrogen, ammonium, nitrate/nitrite, total phosphorus, orthophosphate, total suspended solids, and chlorophyll *a* at the upstream (066), downstream (167) and river mouth (137) locations are shown in Figure 4-3. These results show strong seasonal trends. The nitrogen parameters drop substantially in summer months, and chlorophyll *a* and TSS increase. Station 167, immediately upstream of the dam, is more highly eutrophic than either upstream or at the mouth of the river, with dramatic increases in chlorophyll *a* in the warm weather months.

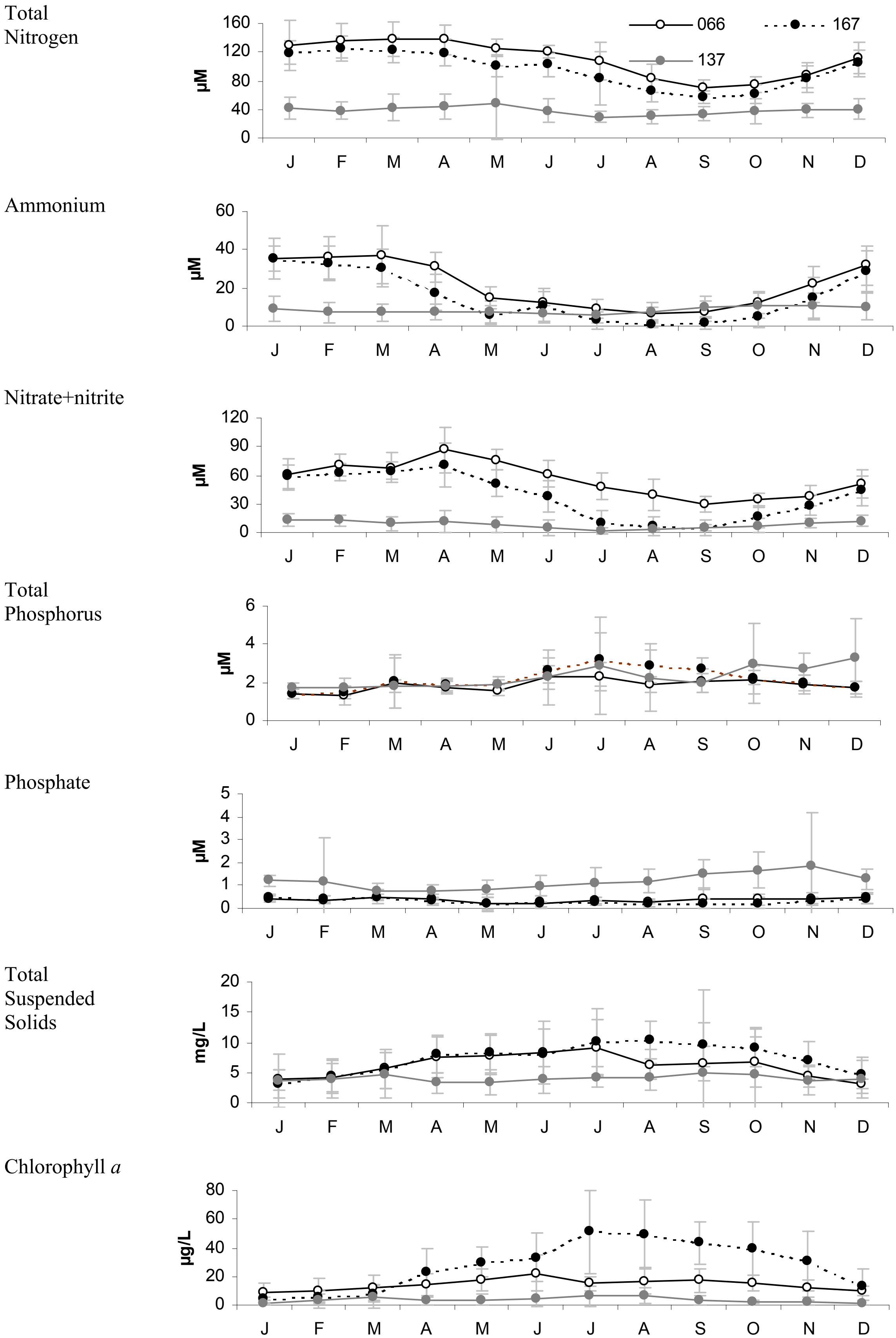

Figure 4-3. Monthly average nutrients, TSS and Chlorophyll 1998 – 2004, Mystic River.

4.4.3 Bacterial water quality

Figure 4-4 shows the current bacterial water quality at each location sampled in the Mystic River and Alewife Brook for 2004. As in past years, Alewife Brook has the highest bacteria counts, and counts gradually decrease downstream to the river mouth.

Geometric means for each indicator for all locations for 1998 – 2004 appear in Table 4-4. All years were grouped together for greater representativeness because no significant change was detected in bacterial water quality over this period, and 1998 marks the beginning of Phase III of MWRA's CSO Control Plan.

Enterococcus. The uppermost graph in Figure 4-4 shows percentile plots of *Enterococcus* counts for each location, arranged from upstream to downstream for 2004. Figure 4-5 shows the impact of rainfall on the three river reaches on *Enterococcus* densities, along with the change at locations near CSO outfalls. (With the switch in coliform indicators in 2001, wet weather data associated with *E. coli* and fecal coliform are insufficient to show results in this format). Alewife Brook locations consistently fail to meet standards, in both dry and wet weather, though conditions improve dramatically moving downstream to the river mouth.

As is evident in Figure 4-5, there is little change in water quality from the most upstream location in the Alewife (upstream of all CSOs) to the most downstream location near Mystic Valley Parkway in both wet and dry weather, indicating the influence of non-CSO, dry weather sources of contamination. However, following heavy rain, the highest counts in the Alewife are found at the two downstream locations.

E. coli. The center graph in Figure 4-4 shows percentile plots of *Enterococcus* counts arranged from upstream to downstream locations for 2004. *E. coli* shows a similar trend to *Enterococcus*.

Fecal coliform. Fecal coliform monitoring was reduced and replaced with *E. coli* beginning in mid-2001, so there are fewer samples collected in 2004 than for the other two bacterial indicators. Fecal coliform appears in the bottom graph in Figure 4-4.

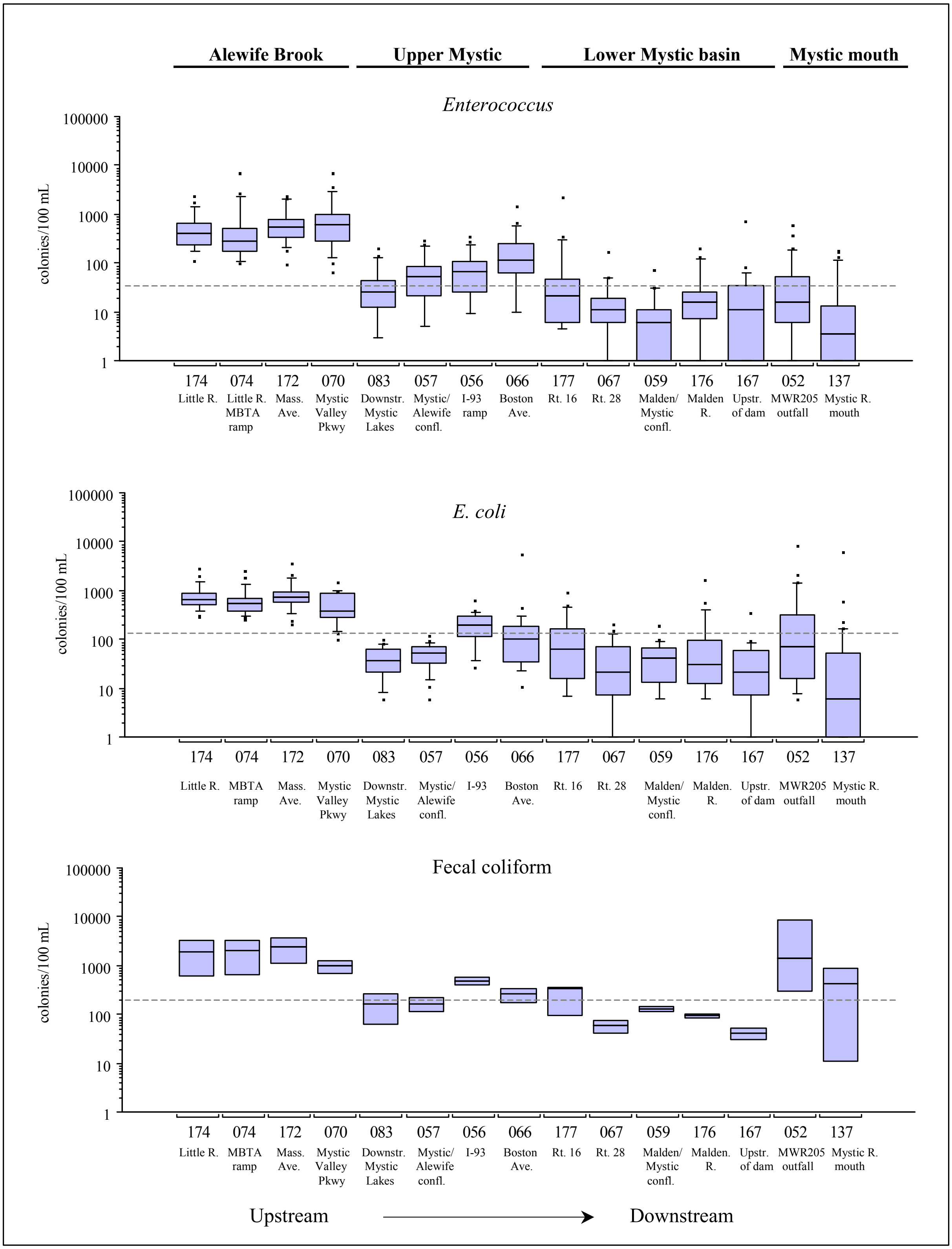

Figure 4-4. Indicator bacteria concentrations, Mystic River/Alewife Brook, 2004.

Dotted lines show EPA geometric mean guideline and MADEP fecal coliform standard. Fecal coliform is being phased out from the monitoring program, replaced by *E. coli.*

Table 4-4. Geometric mean indicator bacteria, Mystic River, 1998 – 2004.

Station	Location	Surface or Bottom	Number of samples[1]	*Enterococcus* (95% CI)	Fecal coliform (95% CI)	*E. coli* (95% CI)
174	Cambridge, Little River, upstream of Rt. 2 and offramp to Alewife T station	S	129/101/60	513 (399-660)	1506 (1179-1923)	842 (682-1040)
074	Cambridge, Little River, at offramp to Alewife T station	S	130/101/61	353 (279-446)	1230 (948-1594)	632 (488-819)
172	Arlington, Alewife Brook, upstream of Massachusetts Ave bridge, midchannel	S	147/118/62	601 (493-733)	1451 (1156-1821)	807 (668-974)
070	Arlington, Alewife Brook, off Mystic Valley Parkway bridge	S	149/117/63	387 (304-493)	823 (635-1066)	567 (395-813)
083	Medford, upstream of confluence of Mystic River and Alewife Brook	S	146/117/60	42 (31-58)	84 (63-110)	54 (38-77)
057	Medford, confluence of Mystic River and Alewife Brook	S	120/91/60	52 (41-74)	147 (108-200)	81 (56-117)
056	Medford, Mystic River, upstream of I-93 bridge	S	135/110/50	52 (38-71)	355 (291-432)	204 (135-208)
066	Medford, Mystic River, Boston Ave bridge	S	259/218/106	108 (89-133)	240 (196-294)	132 (94-184)
177	Medford, Downstream of Rt. 16 bridge, mid-channel	S	61/21/60	25 (14-42)	162 (92-284)	66 (43-102)
067	Medford, Mystic River, Rt. 28 bridge	S	120/95/52	6 (4-9)	66 (49-87)	24 (15-39)
059	Everett, confluence of Mystic and Malden Rivers	S	142/117/53	7 (5-10)	65 (49-85)	28 (17-45)
176	Malden River, upstream of Rt. 16 bridge	S	49/23/49	10 (7-12)	109 (50-237)	44 (25-77)
167	Medford, Mystic River, upstream side of Amelia Earhart Dam	S	307/266/97	10 (7-12)	70 (56-88)	16 (10-24)
052	Somerville, Mystic River, near Somerville Marginal CSO facility (MWR205)	S	195/154/67	29 (20-43)	205 (130-324)	210 (106-413)
		B	140/105/55	11 (8-15)	55 (40-75)	42 (25-72)
069	Charlestown, Mystic River, near Schraffts Building and BOS-017	S	7/6/1	34 (6-161)	161 (39-646)	1300
137	Mystic River, upstream of Tobin Bridge	S	247/160/85	6 (5-8)	50 (37-67)	22 (14-36)
		B	244/157/85	1 (1-2)	4 (3-5)	2 (1-2)

[1]N values for *Enterococcus*, fecal coliform, and *E. coli*, respectively.

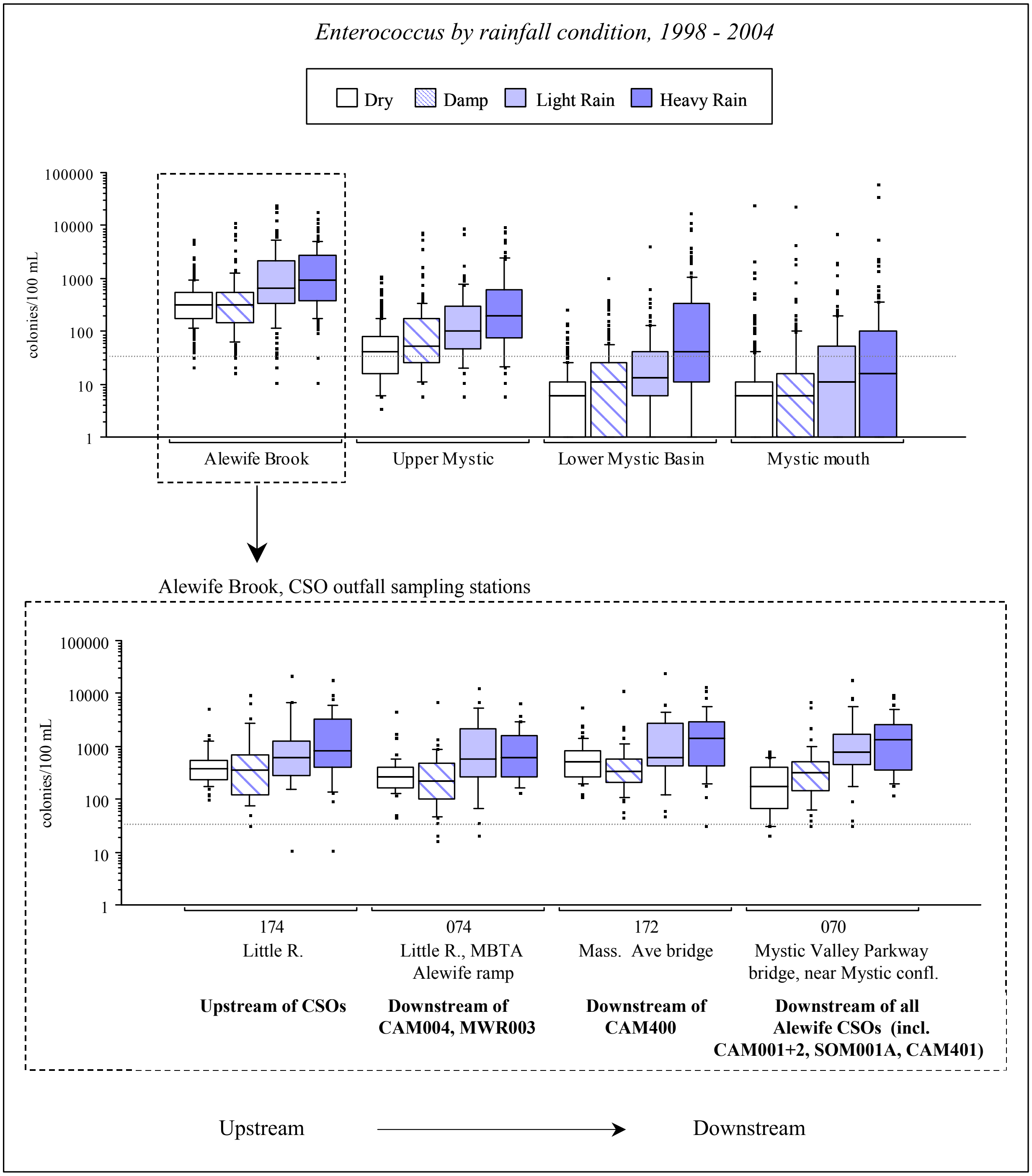

Figure 4-5. *Enterococcus* by rainfall condition, Mystic River/Alewife Brook, 1998 - 2004.

Dotted line shows State standard. Rainfall is NOAA rainfall from Logan airport. “Dry”: no rainfall for previous 3 days; “Heavy”: more than 0.5 inches in previous 3 days; “Damp” and/or rain distant in time: any rain < 0.15 inches at least two or three days previous to sampling and/or 0.1 inches in previous day; “Light rain”: between 0.1 and 0.5 inches in previous day and/or between 0.15 and 0.5 in two previous days.

4.5 Summary of Mystic River water quality

Mystic River water quality for 2004 remains similar to previous years, with bacterial water quality poorest in the Alewife Brook and improving downstream to the river mouth. Bacterial counts in the Alewife consistently fail to meet standards, and water clarity and dissolved oxygen also remain poor in this area. Conditions improve dramatically further downstream, with surface and bottom dissolved oxygen and geometric mean bacteria meeting standards.

Wet weather continues to adversely impact all locations in the Mystic River and Alewife Brook, with the highest bacteria counts occurring after heavy rain. In the lower portion of the River, geometric mean bacteria counts meet standards even in heavy rain, an improvement since the mid-1990s (MWRA, in prep).

Like the Charles River, nutrients and chlorophyll show seasonal fluctuations. Station 167, near the Amelia Earhart dam, was the most eutrophic, having the highest chlorophyll a and dramatic changes in seasonal nitrogen concentrations.

REFERENCES

Bendschneider, K. and Robinson, R. J. 1952. A new spectrophotometric determination of nitrate in seawater. Journal of Marine Research 11: 87-96.

Clesceri, L. S., A. E. Greenberg, and A. D. Eaton. 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation.

Ellis B., Rosen J. 2001. Statistical Analysis of Combined Sewer Overflow Receiving Water Data, 1989 – 1999. Massachusetts Water Resources Authority. Report ENQUAD 2001-06.

Fiore, J. and O'Brien, J. E. 1962. Ammonia determination by automatic analysis. Wastes Engineering. 33: 352.

Gong G., Lieberman J., D. McLaughlin. 1998. Statistcal analysis of combined sewer overflow receiving water data, 1989-1996. Boston: Massachusetts Water Resources Authority. Report ENQUAD 98-09.

Holm-Hanson. O, Lorenzen, C. J, Holmes, R. W, and Strickland, J. D. H. 1965. Fluorometric determination of chlorophyll. J. Cons. Int. Explor. Mer. 30: 3-15.

Murphy, J. and Riley, J. 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31.

MADEP. 1996. (Revision of 1995 report). Massachusetts surface water quality standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA (Revision of 314 CMR 4.00, effective June 23, 1996).

MA DEP. 2002. Boston Harbor 1999 Water Quality Assessment Report. Massachusetts Department of Environmental Protection, Division of Watershed Management. Worcester, MA. Report 70-AC-1.

Solarzano, L, and Sharp, J. H. 1980a. Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnology and Oceanography, 25, 754-758.

Solarzano, L, and Sharp, J. H. 1980b. Determination of total dissolved nitrogen in natural waters. Limnology and Oceanography, 25, 750-754.

USEPA, Office of Water. 1986. Ambient Water Quality for Bacteria – 1986. Washington, D.C. Office of Water. EPA 440/5-84-002.

Wu D. 2003. NPDES compliance summary report, fiscal year 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-11.

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
http://www.mwra.state.ma.us