Summary of
CSO Receiving Water Quality Monitoring in Boston Harbor and Tributary Rivers, 1989 - 2001

DRAFT

(chapters 1 – 3 only)

Environmental Quality Department
Report ENQUAD 2003-02

Citation:

Coughlin K. 2003. Summary of CSO Receiving Water Quality Monitoring in Boston Harbor and Tributary Rivers, 1989 – 2001. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-02. 135 p.

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.

A descriptive tool used in this report for fecal coliform and *Enterococcus* results is the percentile plot, as shown in Figure 2-1.

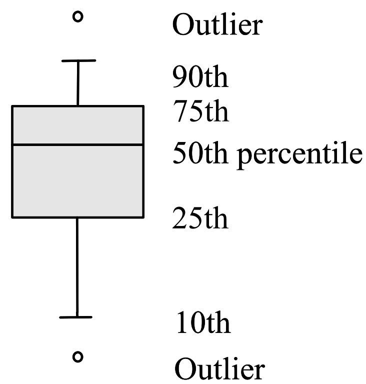


Figure 2-1. Percentile distributions indicated on percentile plots

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 boxplots are displayed on a logarithmic scale, the 50^{th} percentile is equivalent to the geometric mean.

Several parameters are presented with data summarized for the winter and summer seasons. For many of these parameters, results were collected in the fall and spring months but these data were omitted from the summaries for simplicity. Although seasonal boundaries differ somewhat for each parameter, the same time range was used for all parameters for the sake of consistency. For the purposes of this report, summer is defined as June 1 through September 30 and winter is defined as December 1 through March 31.

Statistical Analyses. The association between indicator counts and rainfall was evaluated using correlation analyses (Pearson's r and Spearman Rank Order Correlation). *Enterococcus* and fecal coliform were evaluated for temporal differences within each phase of the CSO Program 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 Criteria used in this report

Criteria are shown in Table 2-6, and are a combination of criteria 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). standards 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.

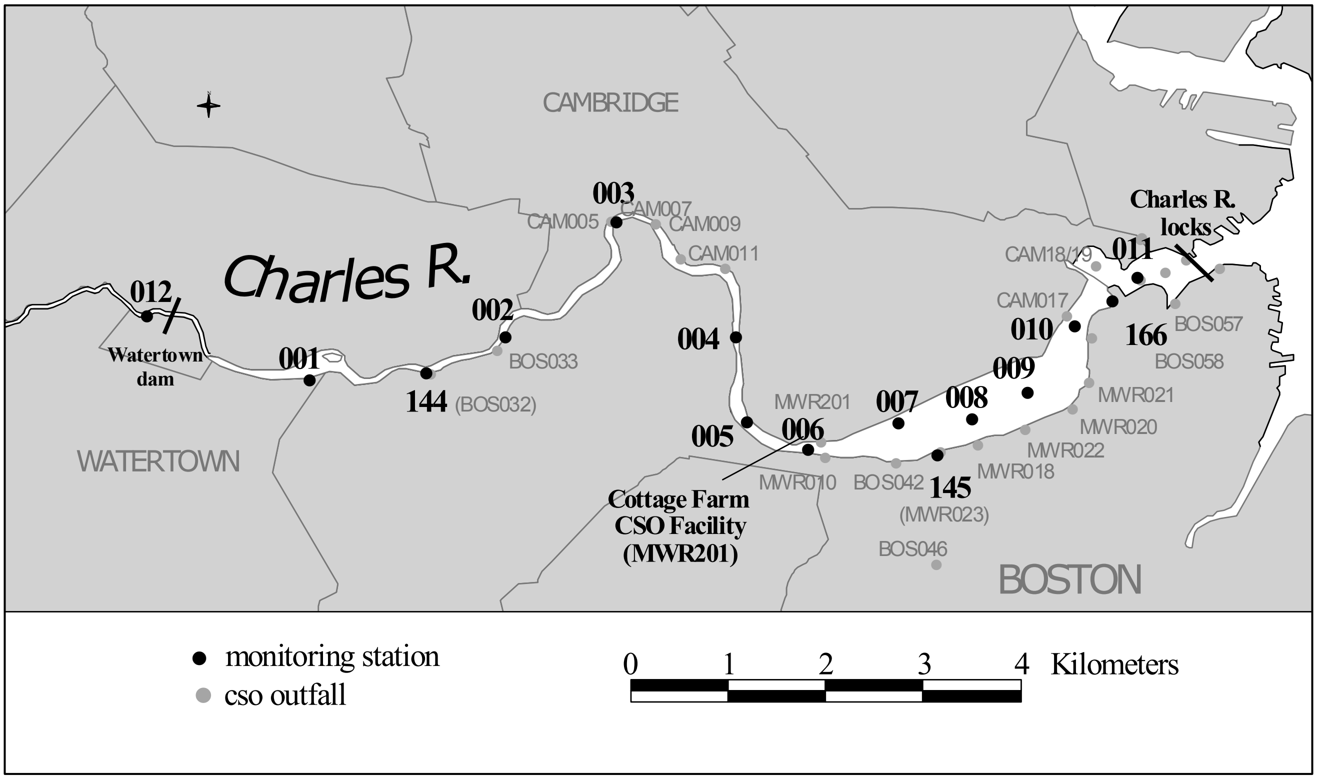
Table 2-6. Water quality criteria

Designated Use	**Parameter**	**Support**
Warmwater fisheries, Massachusetts waters, MADEP	Dissolved Oxygen	>5.0 mg/l, >=60% to <= 100% saturation
	Temperature	<20 degrees C (68 degrees F)
	pH	6.0 to 8.3 S.U.
	Ammonia (pH and temperature dependent)	<0.2 mg/L
Coldwater fisheries, Massachusetts waters, MADEP	Dissolved Oxygen	>5.0 mg/L, >=60% saturation
	Temperature	>28.3 degrees C (83 degrees F)
	pH	6.0 to 8.3 S.U.
	Ammonia	<0.2 mg/L
Primary contact recreation (designated swimming area), EPA and MADPH guidelines	*Enterococcus*	Single sample limit 61 colonies/100 ml (freshwater), 104 colonies/100 ml (marine); geometric mean 33 colonies/100 ml (freshwater), 35 colonies/100 ml (marine)
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

3 Charles River

3.1 Sampling area

Monitoring results of the Charles River are divided into three 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.



CSO outfall

Figure 3-1. Map of Charles River sampling locations

Table 3-1. Charles River sampling sub-regions

Sub-region	Description	Sampling locations
Upstream of Lower Basin	Watertown dam in Watertown to upstream of BU Bridge on Boston/Cambridge line	012, 001, 144, 002, 003, 004, 005
Lower Basin	BU Bridge on Boston/Cambridge line to Science Museum, near Leverett Circle, Boston	006, 007, 145, 008, 009, 010

Downstream of Lower Basin	Science Museum to North Station railroad bridge, near Charlestown.	166, 011

3.2 Pollution sources

Known pollution sources to the Charles River are shown in Table 3-2. The river is affected by approximately 16 CSOs in Cambridge and Boston (some are scheduled to be closed – see MWRA CSO System Master Plan). Upstream contamination above the Watertown dam has been evident since 1989. MWRA's Cottage Farm CSO facility, located upstream of the BU Bridge, screens and chlorinates 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 12 activations per year, on average, since 1999 (MWRA 2001). The Stony Brook/Muddy River outlet near Kenmore Square is a source of contaminated brook flow and significant 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, as indicated by the bacterial monitoring results shown later in this report.

Table 3-2. Charles River pollution sources

Source	**Upstream of Lower Basin**	**Lower Basin**	**Downstream of Lower Basin**
CSOs (untreated)	✔	✔	✔
CSO treatment facility (screened, chlorinated CSO discharge)	✗	✔	✗
Storm drains	✔	✔	✔
Upstream inputs	✔	✔	✔
Dry weather inputs	✔	✔	✔
Brook or stream flow	✔	✔	✗

3.3 Summary of current water quality, 1998-2001

A summary of water quality results collected from 1998 through 2001 is shown in Table 3-3. 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 lower basin area of the river, with bottom-water stratification due to saltwater intrusion from the harbor, had the lowest dissolved oxygen levels of the three sub-regions.

Table 3-3. Summary of current water quality, Charles River 1998 - 2001

Parameter		Water Quality Guideline	Upstream of Lower Basin				Lower Basin				Downstream of Lower Basin			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean	% meeting guideline	Range	n
Surface Temperature (C)	Summer	<28 (warm water fishery)	22 ± 3	100	13.9 - 27.5	320	23 ± 2	100	14.0 - 27.0	264	16	100	16.8 - 27.9	126
	Winter		6 ± 4	100	-0.3 - 15.6	138	8 ± 4	100	-0.2 - 12.5	84	5 ± 4	100	-0.2 – 13.7	88
Bottom-water Dissolved Oxygen (mg/L)*	Summer	5.0	7.0 ± 1.7	92	0.2-12.9	472	5.5 ± 2.9	69	-0.2 - 10.7		6.1 ± 2.2	78	0.3-12.6	278
	Winter	5.0	11.8 ± 2.1	99	0.5-16.1	250	9.0 ± 3.4	88	0.4-15.0		11.3 ± 2	100	1.2-14.4	173
pH		6.0 – 8.3	7.2 ± 0.4		5.8 – 9.2	811	7.3 ± 0.5		6.0 - 9.0	863	7.3 ± 0.6		5.1 – 9.5	413
Water clarity	Total Suspended Solids (mg/L)		5.3 ± 3.0	-	0.00-19.3	202	-	-	-	-	4.4 ± 2.0	-	0.7-12.8	205
	Secchi Depth (m)	1.5	0.8 ± 0.2	8	0.3-2.0	388	1.0 ± 0.3	6	0.3 - 6.0	522	1.2 ± 0.3	18	0.5 - 2.1	104

Parameter		Water Quality Guideline	Upstream of Lower Basin				Lower Basin				Downstream of Lower Basin			
			Mean ± SD	% meeting guideline	Range	n	Mean ± SD	% meeting guideline	Range	n	Mean	% meeting guideline	Range	n
	Turbidity (NTU)	NS	4.4 ± 4.0	-	0 - 22.6	358	6.0 ± 4.7	-	0 - 22.8		3.2 ± 4.1	-	0.0-45.2	189
Bacteria (col/100 mL)	Fecal coliform	200	225 ± 5	51	0 -158,000	664	90 ± 5	76	0 - 43,000	522	58 ± 5	87	0-15,800	304
	Enterococcus	33	77 ± 6	34	0 – 9,200	664	23 ± 5	70	0 - 5,220	521	20 ± 4	72	0 - 4,000	303
Nutrients (umol/l)	Phosphate	NS	0.78 ± 0.47	-	0.11 - 3.01	202	-	-	-	-	10.2 ± 7.3	-	0.07 - 3.63	200
	Ammonium	NS	6.6 ± 5.0	-	0.36 -42.9	203	-	-			10.3	-	0.1-32.1	201
	Nitrate+nitrate	NS	36.3 ± 18.4	-	3.4 - 97.1	201	-	-			33.9 ± 17.4	-	0.2 -91.4	199
Algae	Chlorophyll (ug/L)	25	8.2	95	0.9-37.6	188	-	-			15.73	78	1.0-87.6	185

Surface samples unless otherwise noted. NS: no standard or guideline. *Summer (June-Sept), Winter (Dec-March)

3.4.5 Bacterial water quality

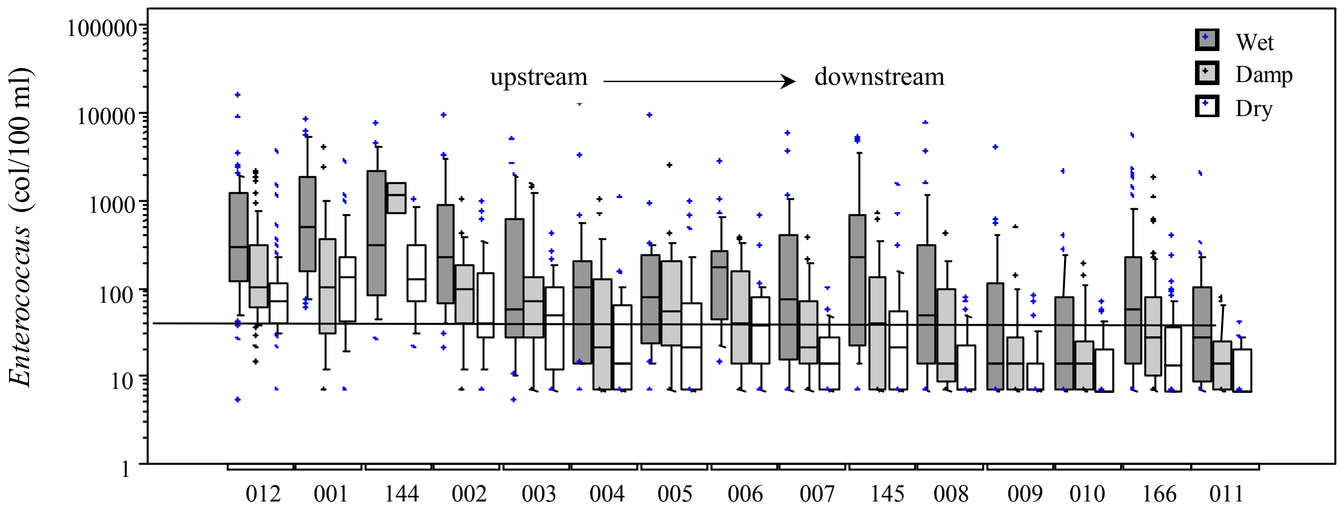
Table 3-4 shows the current bacterial water quality at locations sampled in the Charles. Results are presented graphically beginning on page 22. Bacterial water quality in the Charles varies spatially, with upstream portions more contaminated than downstream portions. There is a clear trend of improving water quality from 1989 to 2001 in all regions, in both wet and dry weather. Between 1998 and 2001, Station 144, Laundry Brook, had by far the poorest water quality of all locations sampled in the River, followed by Station 001 in Newton and Station 012 at the Watertown Dam. In the lower basin, Station 145, Stony Brook/Muddy River, had the poorest water quality, followed by station 166 located at the rear of the Science Museum.

Enterococcus. Figure 3-6 shows percentile plots of *Enterococcus* counts arranged from upstream to downstream locations and grouped by weather condition. This figure also includes line plots of annual geometric mean counts of a representative group of locations for which data exist for all twelve years (stations 012, 006, 008 and 011). The median counts for the upstream locations fail to meet the 33 col/100 ml EPA guideline in dry, damp, and wet weather. For the lower basin locations, most meet the standard in dry weather, but fail to meet standards in wet weather. With the exception of station 166, lower basin stations meet the standard in all weather. Comparison of annual means shows an improvement in bacterial water quality at all four representative stations during the twelve years of monitoring. For dry weather, all four stations failed to meet standards at the start of monitoring in 1989, but are meeting standards (at the latest) by 1998. Trends are similar for both weather categories, with wet weather mean counts generally higher than in dry weather.

Fecal coliform. Figure 3-7 shows percentile plots of fecal coliform counts grouped by weather condition and line plots of annual geometric mean counts of stations 012, 006, 008 and 001. The trends are very similar to those of *Enterococcus*. Median counts for upstream locations fail to meet the 200 col/100 ml standard for Class B waters in all weather conditions; the lower basin stations (stations 008, 009, 010, 166, and 011) are elevated but do generally meet the standard in wet weather.

Table 3-4. Geometric mean fecal coliform and *Enterococcus* counts, Charles River, 1998 - 2001

Station	Location	Surface or Bottom	Number of samples	Mean *Enterococcus* (95% CI)	Mean fecal coliform (95% CI)
012	Newton/Watertown, footbridge upstream of Watertown dam	S	204	120 (98-147)	237 (201-280)
001	Newton, near Nonantum Road, rear of MDC skating rink	S	83	146 (96-222)	468 (344-637)
144	Brighton, downstream of N. Beacon Street bridge, Laundry Brook outlet, BOS-032 (closed	S	35	318 (180-562)	716 (385-1,329)
002	Allston, downstream of Arsenal Street bridge, BOS-033	S	85	81 (55-118)	299 (224-401)
003	Allston/Cambridge, midstream, near Mt. Auburn Street, between CAM-005 and CAM-	S	85	44 (29-67)	175 (127-239)
004	Allston/Cambridge, midstream, between River Street and Western Avenue bridges	S	85	18 (11-28)	83 (58-119)
005	Cambridge, near Magazine Beach, upstream of Cottage	S	85	29 (19-43)	157 (111-223)
006	Cambridge/Boston, midstream, downstream of Cottage Farm, BU bridge	S	87	40 (29-57)	219 (167-287)
007	Cambridge, near Memorial Drive, MIT Boathouse	S B	87	29 (18-46) 15 (10-24)	151 (105-219) 91 (62-134)
145	Boston (Charlesgate), Muddy River/Stony Brook outlet	S	87	28 (17-46)	176 (123-254)
008	Cambridge/Boston, midstream, downstream of Harvard Bridge	S B	87	17 (11-27) 11 (7-18)	99 (68-144) 75 (50-113)
009	Cambridge/Boston, midstream, upstream of Longfellow Bridge near Community Sailing	S B	87	7 (4-10) 7 (4-10)	59 (43-79) 47 (33-66)
010	Boston, downstream of Longfellow Bridge, MWR-022	S B	87	6 (4-8) 6 (4-9)	23 (17-32) 38 (28-52)
166	Boston, old Charles River dam, rear of Science Museum	S	212	15 (12-20)	64 (50-81)
011	Boston, upstream of river locks (New Charles River Dam) and Rt. 93, near Nashua Street	S B	88	15 (11-21) 7 (5-11)	37 (29-47) 37 (28-48)


Enterococcus (col/100 ml)
100000
10000
1000
100
10
1
upstream
downstream
Wet
Damp
Dry
012
001
144
002
003
004
005
006
007
145
008
009
010
166
011

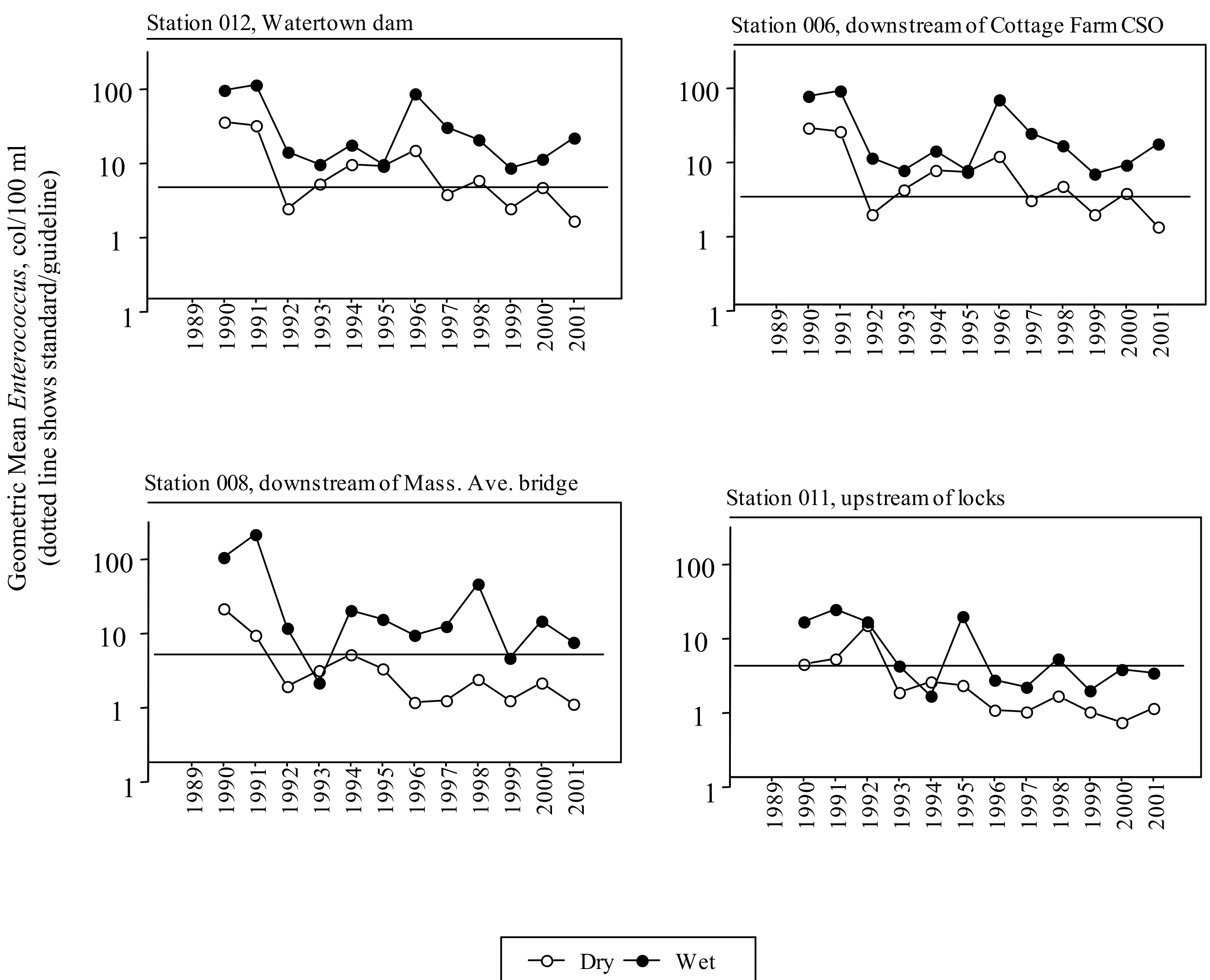
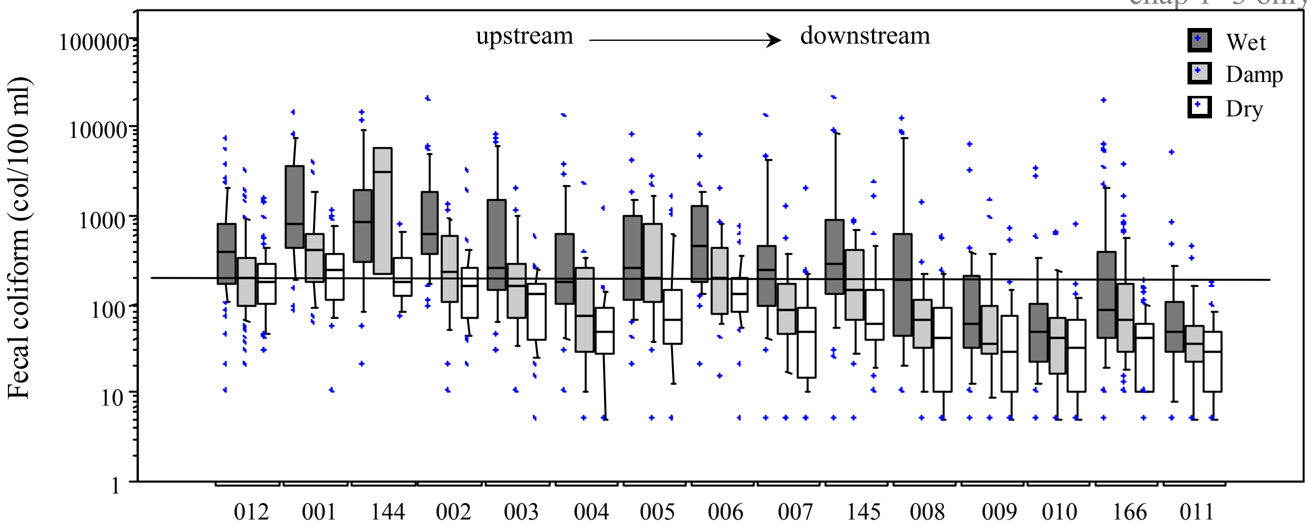

Geometric Mean Enterococcus, col/100 ml
(dotted line shows standard/guideline)
Station 012, Watertown dam
Station 006, downstream of Cottage Farm CSO
Station 008, downstream of Mass. Ave. bridge
Station 011, upstream of locks
100
10
1
1
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Dry
Wet

Figure 3-6. Current and long term trends in *Enterococcus*, Charles River

“Dry”: no rainfall for previous 3 days; “Wet”: at least 0.5 inches in previous 2 days; “Damp”: all remaining results


Fecal coliform (col/100 ml)
upstream
downstream
Wet
Damp
Dry
100000
10000
1000
100
10
1
012
001
144
002
003
004
005
006
007
145
008
009
010
166
011

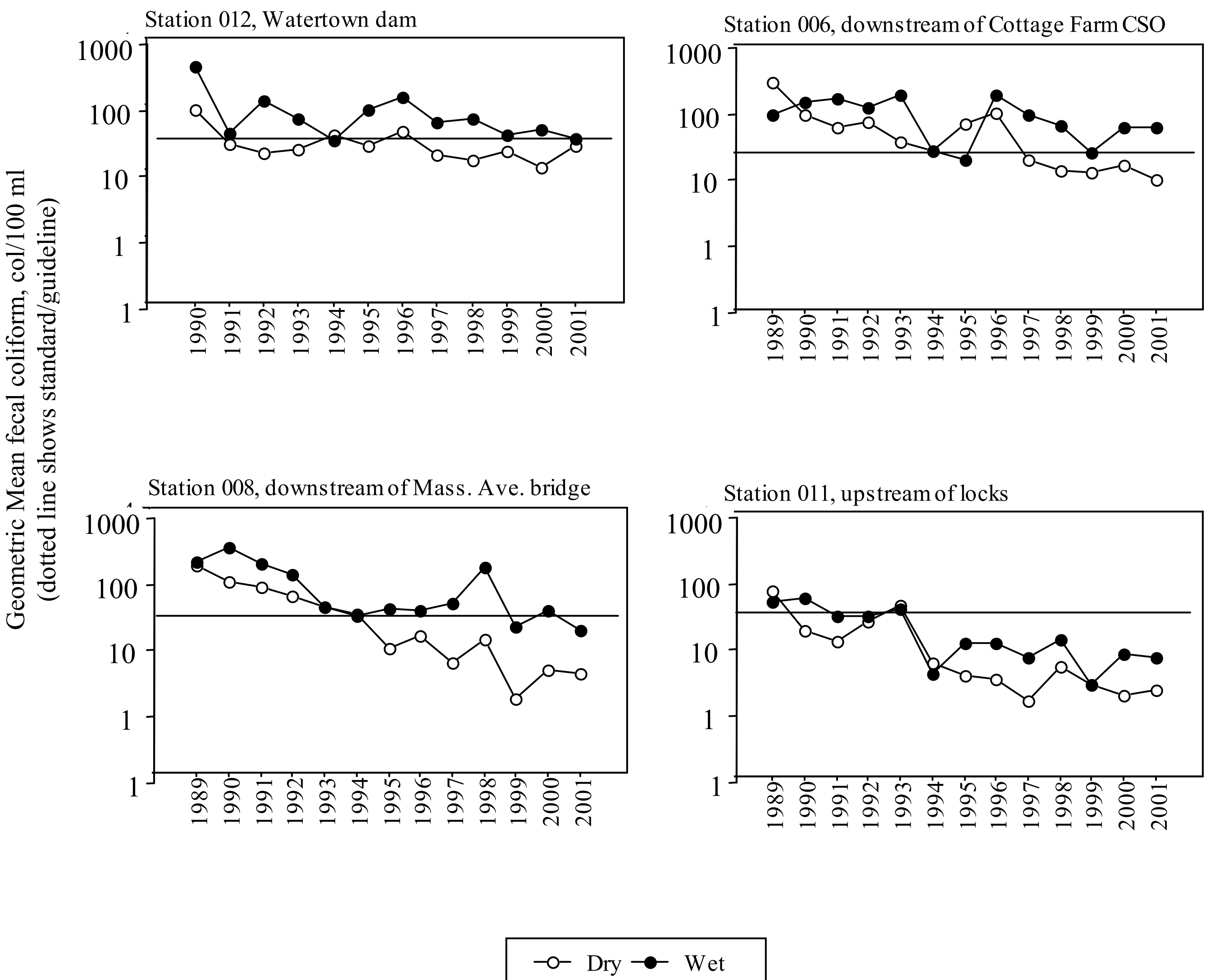

Geometric Mean fecal coliform, col/100 ml
(dotted line shows standard/guideline)
Station 012, Watertown dam
Station 006, downstream of Cottage Farm CSO
Station 008, downstream of Mass. Ave. bridge
Station 011, upstream of locks
1000
100
10
1
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Dry
Wet

Figure 3-7. Current and long-term trends in fecal coliform, Charles River

"Dry": no rainfall for previous 3 days; "Wet": at least 0.5 inches in previous 2 days; "Damp": all remaining results

3.4.6 Relationship between bacteria and rainfall, 1998 – 2001

The relationship between log-transformed indicator bacteria and rainfall are highly significant but somewhat weak. The correlation coefficients for *Enterococcus* and fecal coliform are shown in Table 3-5. Fecal coliform showed a stronger correlation with rainfall than *Enterococcus*. Of the three rainfall categories (one-day, two-day, and three-day summed rain), three-day summed rain consistently had the strongest correlation with indicator counts. Only station 145, Laundry Brook outlet, had no significant relationship to rainfall. This is likely because the sample size is relatively small and dry weather contamination obscures rain-related impacts at this location.

Spearman's rank order correlation also showed a highly significant but somewhat weak relationship between bacteria and rain, with rho of 0.41 for fecal coliform and 0.34 for *Enterococcus*, corrected for ties ($p<0.0001$).

Table 3-5. Correlation coefficients, bacteria and three-day summed rain, Charles River, 1998 – 2001

p<0.0001 unless otherwise noted. Higher r value indicates stronger correlation; generally, r values above 0.8 are considered strong, values below 0.4 are considered weak.

Station	Location	log *Enterococcus*		log fecal coliform	
		r	95% CI	r	95% CI
012	Newton/Watertown, footbridge upstream of	0.50	(0.38, 0.60)	0.41	(0.28, 0.52)
001	Newton, near Nonantum Road, rear of MDC skating	0.40 (p=0.0004)	(0.19, 0.58)	0.45	(0.25, 0.61)
144	Brighton, downstream of N. Beacon Street bridge, Laundry Brook outlet, BOS-	Not significant			
002	Allston, downstream of Arsenal Street bridge, BOS-	0.46	(0.26, 0.61)	0.46	(0.27, 0.61)
003	Allston/Cambridge, midstream, near Mt. Auburn Street, between CAM-005 and	0.40	(0.20, 0.56)	0.46	(0.27, 0.61)
004	Allston/Cambridge, midstream, between River Street and Western Avenue	0.61	(0.42, 0.74)	0.58	(0.42, 0.71)
005	Cambridge, near Magazine Beach, upstream of Cottage	0.42 (p=0.0002)	(0.21, 0.59)	0.36 (p=0.001)	(0.15, .0.53)
006	Cambridge/Boston, midstream, downstream of Cottage Farm, BU bridge	0.40 (p=0.0002)	(0.20, 0.57)	0.41	(0.22, 0.58)
007	Cambridge, near Memorial Drive, MIT Boathouse	0.41	(0.26, 0.55)	0.51	(0.39, 0.61)
145	Boston (Charlesgate), Muddy River/Stony Brook outlet	0.38	(0.15, 0.56)	0.42	(0.22, 0.58)
008	Cambridge/Boston, midstream, downstream of	0.44	(0.28, 0.57)	0.50	(0.37, 0.60)
009	Boston, downstream of Longfellow Bridge, MWR-	0.43	(0.26, 0.57)	0.48	(0.35, 0.59)
010	Cambridge/Boston, midstream, upstream of Longfellow Bridge near	0.48	(0.32, 0.62)	0.48	(0.36, 0.59)
166	Boston, old Charles River dam, rear of Science Museum	0.52	(0.39, 0.63	0.62	(0.53, 0.70)
011	Boston, upstream of river locks (New Charles River Dam) and Rt 93, near Nashua	0.54	(0.41, 0.66)	0.57	(0.46, 0.66)

3.4.7 Effects of system improvements

Bacterial results collected during the 12-year monitoring period were grouped into phases of MWRA's CSO System Master Plan, as shown in Figure 1-1. (Phase I: 1989 – 1991; Phase II: 1992 – 1997; Phase III: 1998 – 2001). Both fecal coliform and *Enterococcus* counts were significantly lower in each subsequent phase ($p<0.0001$), with geometric mean counts falling nearly an order of magnitude between Phase I and Phase III. Boxplots for both fecal coliform and *Enterococcus* are shown in Figure 3-8. This trend held for both dry and wet weather, indicating that both dry weather sources and wet weather sources were reduced over this period

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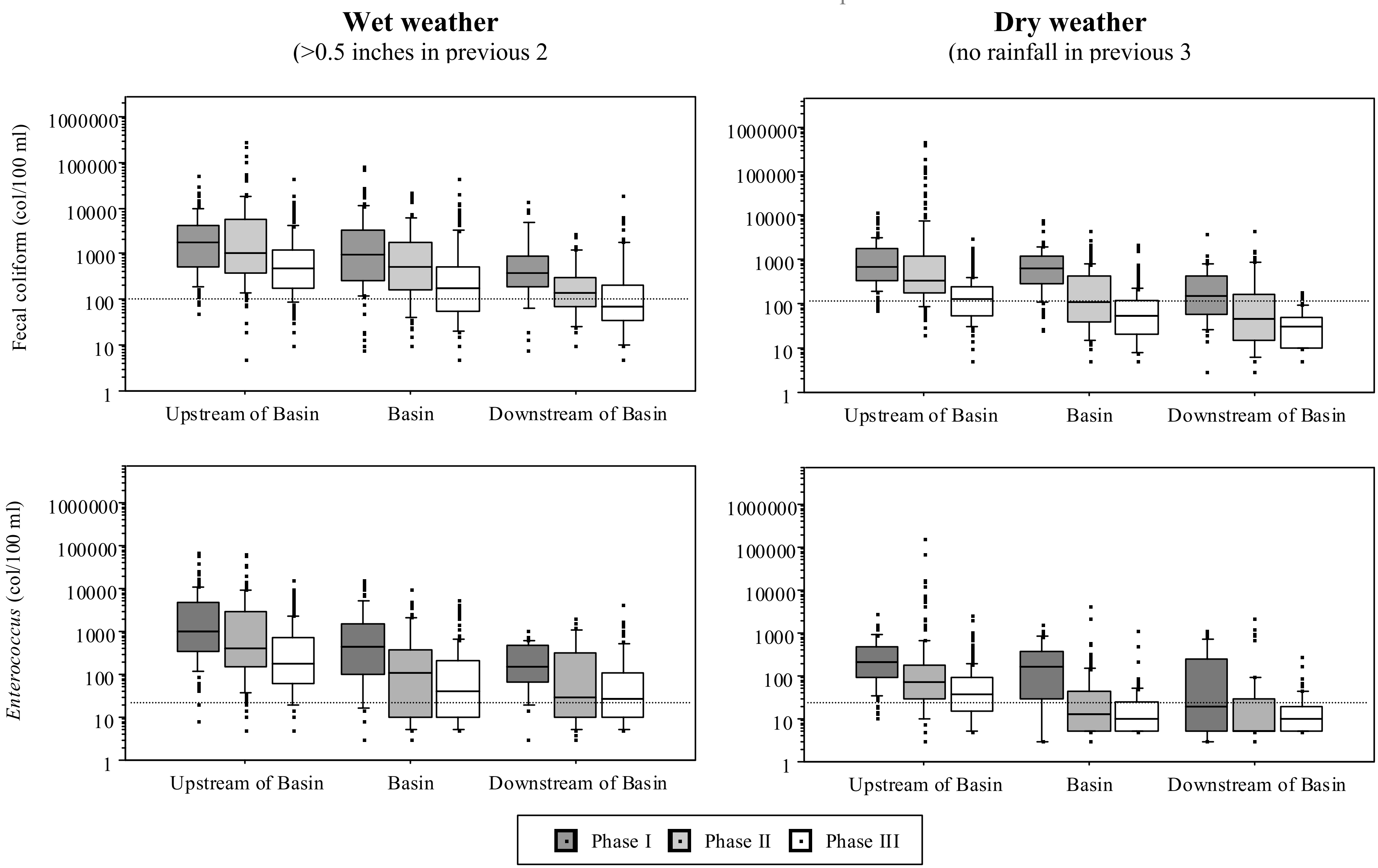

Figure 3-8. Bacterial indicator counts 1989 - 2001, grouped by phases of MWRA's CSO System Master Plan
Dotted line shows geometric mean guideline

3.5 Summary of Charles River water quality

A significant decline in bacterial concentrations is evident in Charles River receiving waters downstream of the Watertown Dam. This decline has occured in both wet and dry weather, suggesting that elimination of both dry weather and wet weather sources has had a significant impact on the water quality in the Charles. As the water quality has improved, the relationship between rainfall and water quality has grown weaker - previous analyses have indicated that the relationship between rainfall and bacteria has shown a reduction in correlation over time (MWRA, 2001). Evaluation of current conditions (1998 – 2001) confirms that the relationship between rainfall and bacteria counts in the river is somewhat weak.

While there is significant year-to-year variation due to multiple factors (e.g. environmental factors such as rainfall, temperature, sunlight intensity, river flow), change in bacterial water quality can be detected when results are grouped, as in the Phase I, II, and III time periods of the CSO System Master Plan. Trends are subtle, and results must be observed over a long period of time to detect change; it is difficult to detect effects of individual CSOs. Attempts to gauge short-term rainfall effects at individual CSOs proved logistically difficult because of inconsistent or infrequent overflows. However, impacts of viral pathogens at several CSO discharge locations (Cottage Farm and Stony Brook CSOs) are currently being evaluated and a report is in preparation (MWRA, in prep).

Physical parameters showed very little evidence of a trend over time, and any variability is likely due to short-term environmental factors (e.g., volume of rainfall and associated runoff, river flow). Dissolved oxygen, pH, temperature, and secchi depth likewise showed no obvious trend over the monitoring period. However, some of these parameters exhibited significant spatial trends, particularly salinity and dissolved oxygen. Lower basin locations showed relatively high bottom-water salinity and low dissolved oxygen levels consistently throughout the monitoring period. Nutrients and chlorophyll exhibited strong seasonal signals, however not enough data has been collected to draw any conclusions regarding long term trends.

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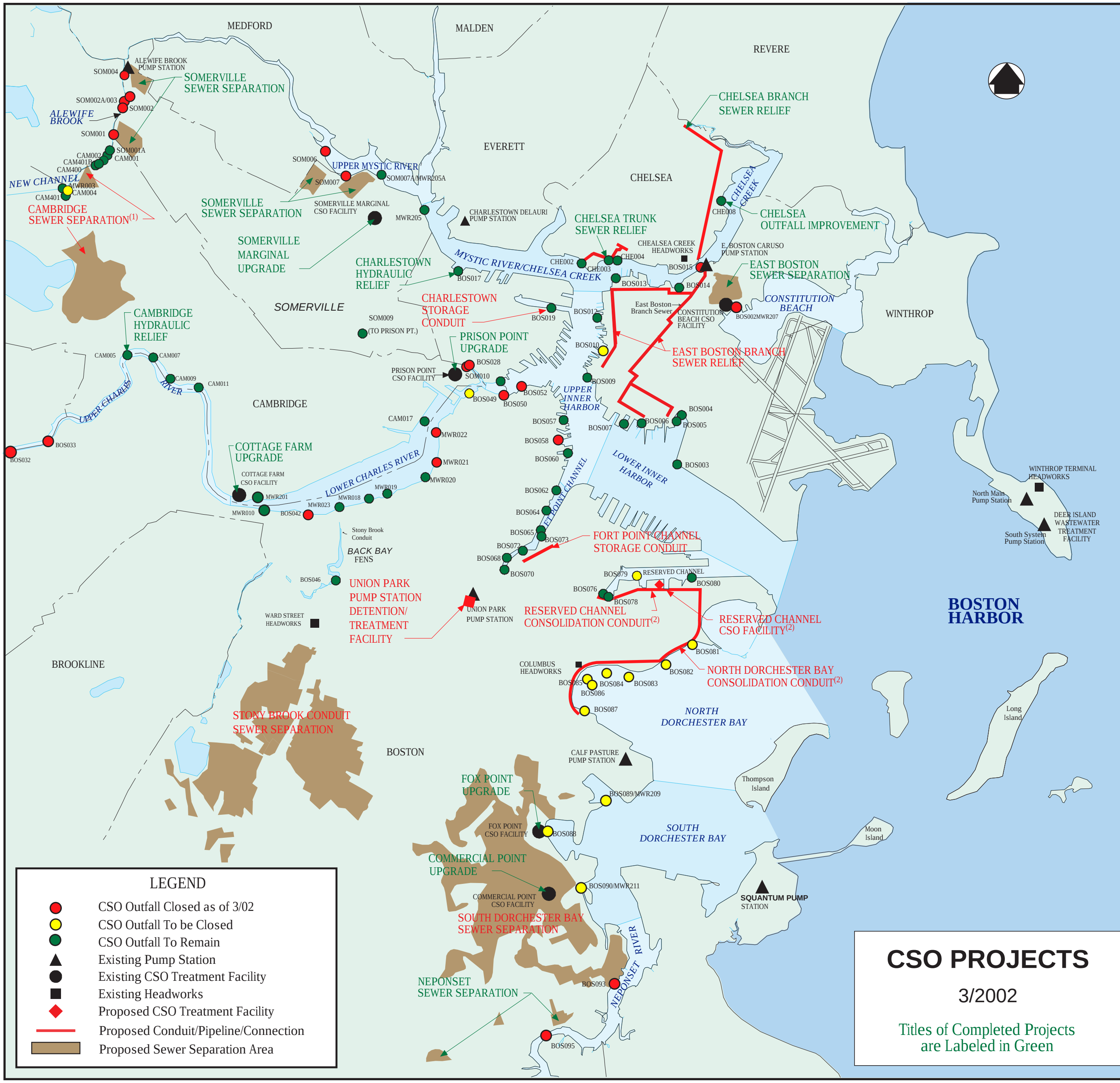

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Notes:
(1) Construction of Cambridge Sewer Separation and other Alewife Brook CSO controls is on-hold pending federal and state regulatory approval of a revised plan.
(2) A MEPA reassessment of the CSO control plan for North Dorchester Bay and the Reserved Channel is underway.

FIGURE 1. MWRA RECOMMENDED CSO CONTROL PLAN

U.S. Department of the Interior
U.S. Geological Survey

Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999–September 2000

By PHILLIP J. ZARRIELLO and LORA K. BARLOW

Water-Resources Investigations Report 02-4129

In cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY,
MASSACHUSETTS DEPARTMENT OF
ENVIRONMENTAL PROTECTION, and the
MASSACHUSETTS WATER RESOURCES AUTHORITY

Northborough, Massachusetts
2002

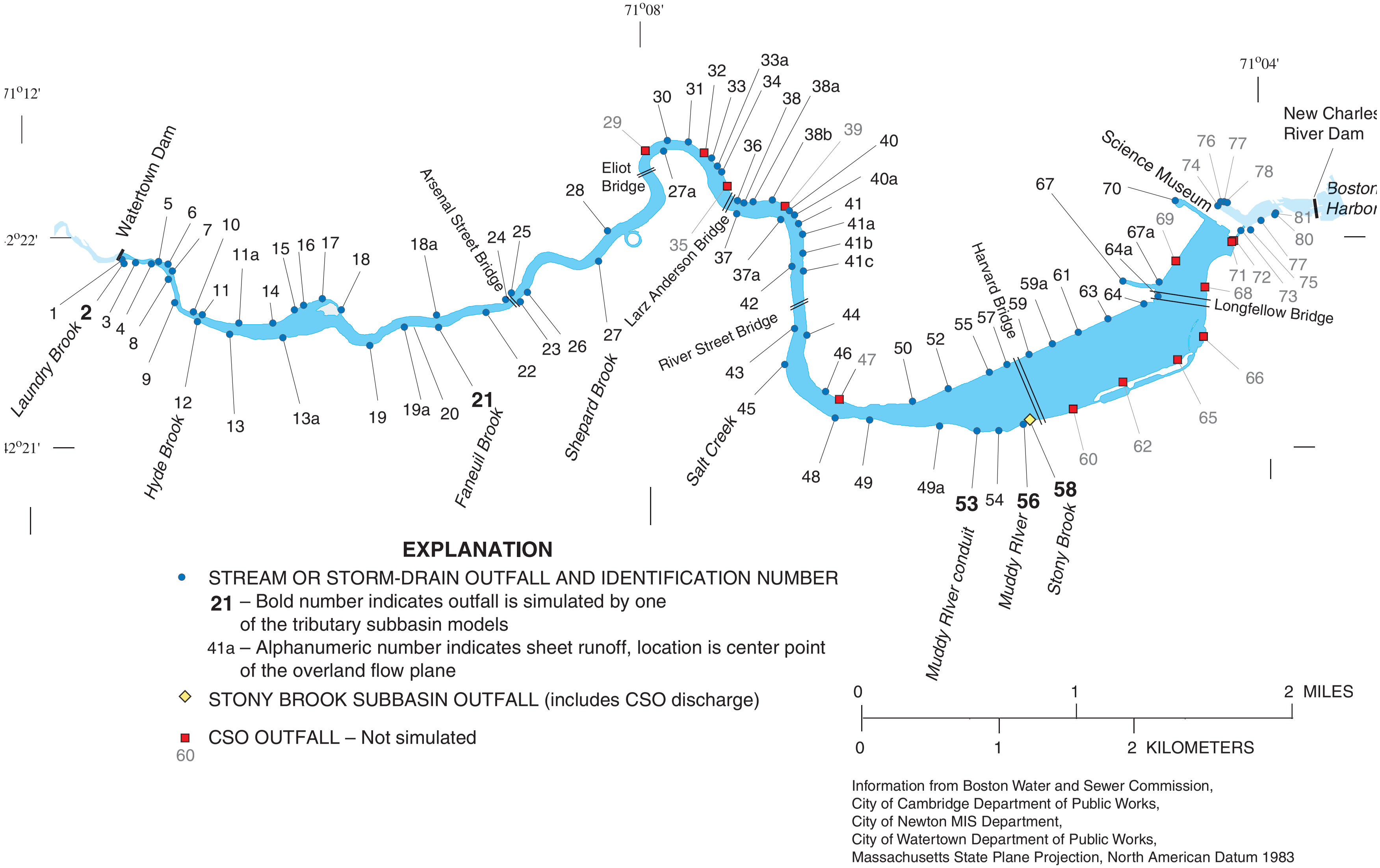

Figure 6. Outfalls to the lower Charles River, Massachusetts.