Ambient water quality monitoring of the Massachusetts Water Resources Authority effluent outfall: indicator bacteria in Massachusetts Bay 1999-2011

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Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129

Prepared by
Andrea Rex

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1.0 Introduction

The Massachusetts Water Resources Authority (MWRA) has been monitoring bacterial water quality in Massachusetts Bay since 1999 to ensure that its discharge from the Deer Island Wastewater Treatment Plant (DITP) outfall complies with water quality standards (Massachusetts SA) for primary contact recreation and for shellfishing. This report summarizes eleven years of data collected since the outfall went on-line in September 2000 for two groups of sewage indicator bacteria: fecal coliform, which is used to monitor shellfish-growing waters; and *Enterococcus,* which is used to monitor recreational water quality in marine waters. Spatial and temporal trends are discussed.

2.0 Background: Permit limits and water quality standards

The DITP effluent outfall was built with the goal of achieving as much dilution as practicable. The outfall is a 9.5-mile-long deep rock tunnel—the terminal 1.25 miles is a diffuser comprising 53 working risers topped by multi-port caps which sit on the sea floor. The water depth at the diffuser is approximately 100 feet, the minimum available dilution is 70-fold. Regulatory authorities acknowledged that there were environmental benefits to minimizing use of chlorine disinfectant and dechlorinating chemicals, and wrote DITP's National Pollutant Discharge Elimination System (NPDES) permit limits to take available dilution into account.

The bacteria limitations in the permit were based on the water quality criteria for SA waters for primary contact recreation. At the time the DITP permit was written, the state water quality criterion for primary contact recreation was a geometric mean fecal coliform density of no more than 200 per 100 ml. The 70-fold dilution factor gave an effluent limitation of a geometric mean of 14,000 fecal coliform/100 ml. (Permit No. MA0103284 Part I.1.a.).

At the time the permit was written, there was concern that the outfall should not adversely impact shellfishing resources. The shellfishing standard is more stringent than the primary contact SA recreational standard. In waters designated for shellfishing, fecal coliform shall not exceed a geometric mean of 14 organisms/100ml and no more than 10% exceed 28 organisms/100 ml. In order to ensure that the outfall does not threaten shellfishing resources, the MWRA, the Massachusetts Division of Marine Fisheries (DMF) and the US Food and Drug Administration (FDA) agreed to develop a Memorandum of Understanding (MOU) with an attached monitoring plan for classification of shellfish growing waters (MWRA NPDES permit MA0103284 Part I.1.a. Footnotes 15 and 16). The original 1999 MOU is in the Appendix. The Notification Plan and Monitoring Plan, updated in 2003, are also in the Appendix.

In brief, the present monitoring consists of monthly sampling at an agreed-upon set of 11 stations ("Conditional Zone Classification Surveys") supplemented by special responsive monitoring ("Adverse Condition Surveys") at the same 11 stations. Responsive monitoring is required should conditions occur at the treatment plant such as an upset, chlorination failure, or long period of secondary blending, that have the potential to increase the discharge of bacteria to the bay.

In addition to fecal coliform, MWRA monitored *Enterococcus* from the beginning of the program because there was an emerging regulatory initiative to change the bacterial indicator in marine recreational waters to *Enterococcus*. In 2007 Massachusetts changed the SA water quality standard to a geometric mean of 35 *Enterococcus*/100 ml and a single sample maximum of 104

Enterococcus/100 ml. (The fecal coliform shellfish-growing water standard remained the same.) (The DITP permit limitations for bacteria were not modified.)

3.0 Methods

3.1 Sampling Locations

Sampling locations were selected to assess water quality directly over the outfall, at other stations in the outfall nearfield, and near the coastline between the outfall and active shellfish beds. During stratified periods, samples are collected at two depths: surface and subpycnocline. When the water column is well-mixed, only surface samples are collected. After the first two years of sampling, DMF agreed that the sampling design should be simplified and some stations (primarily the more distant offshore stations, not shown) were dropped. For consistency in this report, only those stations that have been sampled throughout the period 1999-2011 have been included in the data analyses. Those stations are shown in Figure 1 and are listed in Table 1. For some data analyses, the stations are aggregated into three groups: Coastal, Nearfield, and Outfall as shown in Table 1. Although both the conditional zone classification surveys and the adverse condition surveys targeted sampling all these stations, sea state and other logistical circumstances occasionally precluded reaching all stations during adverse condition surveys.

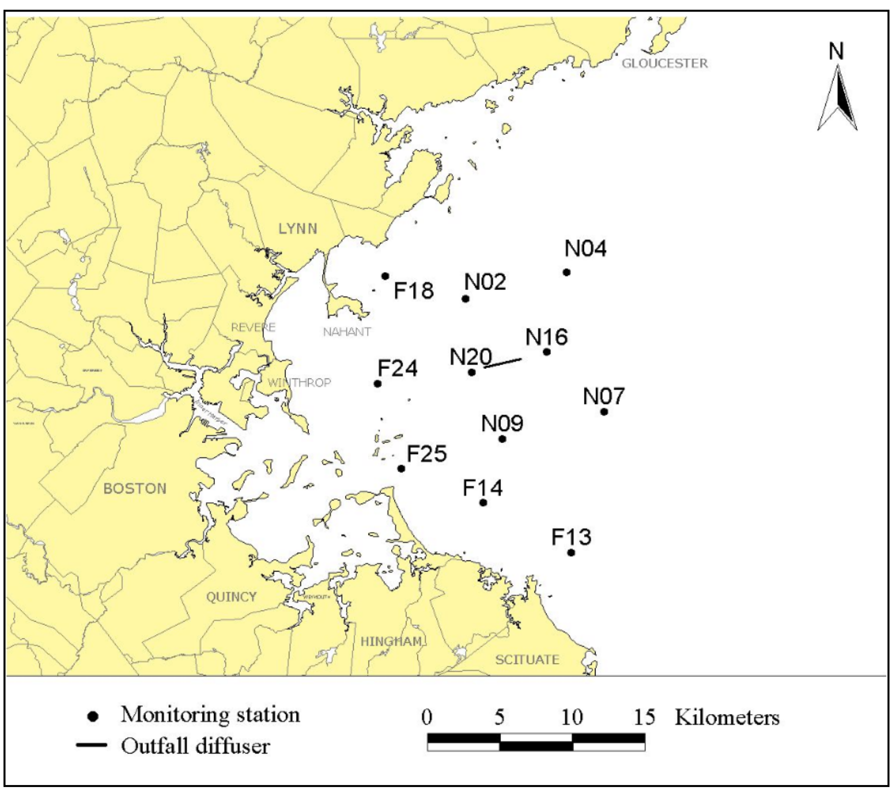

Figure 1 Map of shellfish-growing water sampling locations sampled consistently throughout the monitoring program.

Table 1 Shellfish growing water sampling stations

Area	Station ID	Location description	Average water depth (meters)	Latitude	Longitude
Coastal	F13	Mass. Bay, South of Outfall Site	25	42-16.10	70-44.10
	F14	Mass. Bay, South of Nearfield	19	42-18.00	70-48.50
	F18	Nahant Bay	25	42-26.53	70-53.30
	F24	Broad Sound	21	42-22.50	70-53.75
	F25	Near Point Allerton	15	42-19.30	70-52.58
Nearfield	N02	Northern Edge of Nearfield	39	42-25.65	70-49.31
	N09	Southern Edge of Nearfield	35	42-20.39	70-47.48
	N04	Northeastern corner of Nearfield	50	42-26.64	70-44.22
	N07	Southeastern corner of Nearfield	50	42-21.36	70-42.36
Outfall Area	N16	East End of Outfall Site	42	42-23.64	70-45.20
	N20	West End of Outfall Site	31	42-22.90	70-49.03

3.2 Sampling Schedule

3.2.1 Conditional Zone Classification Surveys

The FDA and DMF require that conditional zone classification surveys be carried out once per month in the area potentially affected by the DITP outfall to determine whether the water meets shellfish growing standards. Three baseline surveys were done (May 13-14, 1999; July 19, 1999; and August 16, 2000) before the outfall went on-line in September 2000. Monthly conditional zone classification surveys began in October 2000 and have been ongoing since then.

3.2.2 Adverse Condition Surveys

Adverse condition surveys assess the water quality under "worst case" conditions. Secondary treatment and disinfection are the phases of treatment that significantly reduce pathogens and indicator bacteria. An adverse condition survey is triggered by either (1) a reduction in secondary treatment, when the effluent consists of 60% secondary treated flows or less for more than six hours; or (2) complete loss of chlorination for more than six hours. There have been 18 adverse condition surveys; the dates are shown in Table 2 (none of these events involved failure of disinfection).

Table 2 Adverse Condition Survey Dates

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Mar 26	Oct 18	Dec 19	Aug 17	Apr 13	May 16	None	Mar 11	None	Feb 27
Jul 3			Sep 30	Sep 2					Mar 17
Oct 12				Oct 18					Mar 25
Oct 13									Apr 1
									Aug 27

3.3 Sample Collection

Details of the sample collection procedure are in the MWRA Department of Laboratory Services Standard Operating Procedure for Conditional Zone Classification Survey, DCN 4001.0.

In brief, water samples are collected by boat using a 2.5L Niskin sampler deployed by winch and line. The samples are transferred to 250-ml sterile sample bottles, placed in an ice-filled cooler maintained <10^{o} C and transported to MWRA's Department of Laboratory Services at Deer Island. Bacteria analyses are initiated within six hours of sampling. Water samples are collected at the surface (depth = 1 meter). If the water column is stratified (generally in spring and summer), a sample is also collected below the pycnocline, 2 meters above the sea floor. The presence of a pycnocline is determined from the water column profile collected by the most recent antecedent outfall ambient water quality monitoring program survey (for details of water column profiling see Libby *et al.* 2011).

3.4 Parameters

Parameters monitored are shown in Table 3. Standard physical and chemical field measurements are recorded, but will not be reported on here. Laboratory methods for enumerating fecal coliform and *Enterococcus* changed over the course of the monitoring. At present, fecal coliform bacteria are enumerated by a membrane filtration method approved by the US Food and Drug Administration (FDA) for shellfish-growing waters (mTEC). *Enterococcus* are enumerated by the defined substrate method Enterolert®. Details of the bacteria enumeration procedures are in MWRA's Department of Laboratory Services Standard Operating Procedures (Membrane Filter Method for Fecal coliforms and *Escherichia coli* in Water using mTEC medium DCN1130.2, and *Enterococci* in Source Waters, Receiving Waters, and Wastewater by the Defined Substrate Method-Enterolert ® DCN 1217.3) and will not be repeated here.

Table 3 List of parameters

Parameter	Method, Reference (Time period used)
Temperature	Field, YSI 600XL sonde/650 MDS logger
Salinity	
Depth sampled	
Water depth	
pH	
Fecal coliform	mTEC, EPA 1103.1 and SM9213D (Aug 2006-present) A-1M, 1990 AOAC International - Official Methods of Analysis, 15th Edition. (May 1999-July 2006)
Enterococcus	Enterolert,® ASTM Method D 6503-99 (Jan 2007-present) MEI, EPA Method 1600 (May 1999-Dec 2006)

The lower detection limit for fecal coliform was either 1 or 2 organisms/100 ml. The lower detection limit for *Enterococcus* was 1 or 2 organisms/100 ml until the change to Enterolert® in January 2007 at which time the method detection lower limit increased to 10 organisms/100ml. Studies done by MWRA have found that the methods yield comparable results.

4.0 Results and Discussion

4.1 Data from all stations

A total of 2,071 samples were analyzed for fecal coliform and 2,059 samples for *Enterococcus* at stations monitored consistently throughout the sampling period May 1999-July 2011. For statistical analyses, samples where no bacteria were found (non-detects, results below the detection limit) were treated as having counts of 0 organisms/100 ml.

Summary statistics are shown in Table 4. The data include all samples from the monthly conditional zone surveys and from adverse condition surveys. The majority of samples were non-detects, including at the outfall site where 90% of samples for both indicators were non-detects. Compared to water quality standards the bacteria counts are extremely low. The proportion of counts exceeding the upper thresholds of 28 fecal coliform/100 ml and 104 *Enterococcus*/100 ml is vanishingly small, well less than 1% of samples at any area. Of 2,026 samples collected after the outfall went on-line, three samples exceeded the *Enterococcus* single-sample maximum, only one of those was at the outfall site. The samples having >104 organisms/100 ml were at coastal Station F25 subpycnocline, July 11, 2011(109/100 ml); at nearfield Station N09 surface October 12, 2010 (185/100 ml); and at outfall Station N20 subpycnocline, September 24, 2003 (303/100) ml.

4.2 Data from outfall stations

Table 5 lists all the samples positive for fecal coliform since sampling began in 1999 at the outfall stations N20 and N16. Of 461 samples collected at the outfall stations post-discharge, only 40 had any fecal coliform detected. Three samples exceeded the upper detection limit of 50 organisms/100 ml and could not be further quantified. All other samples were below the 200 organism/100 ml water quality standard for primary recreation. All but 8 of 461 samples were less than 28 organisms/100 ml shellfishing standard.

Table 6 lists all the samples positive for *Enterococcus* since sampling began in 1999 at the outfall stations N20 and N16. Of the 461 samples collected at the outfall stations post-discharge, only 44 had any *Enterococcus* detected. Only one sample exceeded the 35 organisms/100 ml geometric mean standard and that same sample was the only one to exceed the single-sample maximum of 104 organisms/100 ml.

Table 4 Descriptive statistics for fecal coliform and *Enterococcus*, comparing data from pre- and post-effluent diversion and among monitoring areas.

In waters designated for shellfishing, fecal coliform shall not exceed a geometric mean of 14 organisms/100ml and no more than 10% exceed 28 organisms/100 ml. For primary contact recreation, the standard is a geometric mean of no more than 35 *Enterococcus*/100 ml and a single sample maximum of 104 *Enterococcus*/100 ml.

Indicator	Period (pre or post diver-sion)	Area	Count	Non-Detects (%)	Percent Fecal coliform > 28 /100 ml or Enterococcus >104 /100ml	Organisms/100 ml water			
						Mean	Geometric Mean	Min	Max
Fecal coliform	All	All	2071	1821 (88%)	0.009% (20/2071)	0.9	0.2	0	>50
	Pre	Outfall	12	11 (92%)	0%	0.2	0.1	0	2
		Nearfield	12	11 (92%)	0%	0.2	0.1	0	2
		Coastal	21	20 (95%)	0%	0.3	0.1	0	6
	Post	Outfall	461	421 (91%)	0.017% (8/461)	1.1	0.2	0	>50
		Nearfield	752	708 (94%)	0.005% (4/752)	0.4	0.1	0	53
		Coastal	813	650 (80%)	0.009% (8/813)	1.3	0.4	0	50
Entero-coccus	All	All	2059	1856 (90%)	0.0009% (2/2059)	0.9	0.2	0	303
	Pre	Outfall	8	8 (100%)	0%	0.0	0.0	0	0
		Nearfield	10	9 (90%)	0%	0.1	0.2	0	1
		Coastal	15	11 (73%)	0%	0.6	0.3	0	4
	Post	Outfall	461	417 (90%)	0.002% (1/461)	1.1	0.2	0	303
		Nearfield	753	703 (93%)	0.001% (1/753)	0.6	0.1	0	185
		Coastal	812	708 (87%)	0%	1.0	0.2	0	74

Table 5 List of all sample results where fecal coliform was detected at outfall stations.

Date Sampled	Station	Fecal coliform /100 ml	Time period	Depth sampled	Survey type
7/19/99	N20P	2	Pre-discharge	Sub pycnocline	Conditional
12/19/00	N20S	2	Post-discharge	Surface	Conditional
6/21/01	N16P	2	Post-discharge	Sub pycnocline	Conditional
6/21/01	N20P	>50	Post-discharge	Sub pycnocline	Conditional
6/21/01	N20S	>50	Post-discharge	Surface	Conditional
7/ 3/01	N20P	4	Post-discharge	Sub pycnocline	Adverse
10/25/01	N20P	14	Post-discharge	Sub pycnocline	Conditional
7/23/02	N16P	2	Post-discharge	Sub pycnocline	Conditional
12/10/02	N16S	18	Post-discharge	Surface	Conditional
12/10/02	N20S	11	Post-discharge	Surface	Conditional
7/17/03	N16P	2	Post-discharge	Sub pycnocline	Conditional
7/17/03	N20P	6	Post-discharge	Sub pycnocline	Conditional
8/19/03	N20P	4	Post-discharge	Sub pycnocline	Conditional
9/24/03	N16P	6	Post-discharge	Sub pycnocline	Conditional
9/24/03	N20P	>50	Post-discharge	Sub pycnocline	Conditional
9/24/03	N20S	28	Post-discharge	Surface	Conditional
10/ 7/03	N20P	4	Post-discharge	Sub pycnocline	Conditional
2/ 9/04	N16S	4	Post-discharge	Surface	Conditional
2/ 9/04	N20S	4	Post-discharge	Surface	Conditional
8/17/04	N16P	18	Post-discharge	Sub pycnocline	Adverse
8/17/04	N16S	2	Post-discharge	Surface	Adverse
8/17/04	N20P	50	Post-discharge	Sub pycnocline	Adverse
8/17/04	N20S	4	Post-discharge	Surface	Adverse
9/ 7/04	N20P	2	Post-discharge	Sub pycnocline	Conditional
10/ 4/04	N20P	36	Post-discharge	Sub pycnocline	Conditional
12/16/04	N20S	8	Post-discharge	Surface	Conditional
1/26/05	N20S	6	Post-discharge	Surface	Conditional
2/14/05	N16S	2	Post-discharge	Surface	Conditional
8/ 9/05	N20P	4	Post-discharge	Sub pycnocline	Conditional
9/ 2/05	N20P	36	Post-discharge	Sub pycnocline	Adverse
9/19/05	N16P	2	Post-discharge	Sub pycnocline	Conditional
9/19/05	N16S	2	Post-discharge	Surface	Conditional
9/19/05	N20P	4	Post-discharge	Sub pycnocline	Conditional
10/18/05	N16P	2	Post-discharge	Sub pycnocline	Adverse
1/11/06	N16S	2	Post-discharge	Surface	Conditional
8/ 9/06	N16P	1	Post-discharge	Sub pycnocline	Conditional
8/ 9/06	N20P	1	Post-discharge	Sub pycnocline	Conditional
9/ 8/06	N20S	1	Post-discharge	Surface	Conditional
10/ 8/08	N16P	1	Post-discharge	Sub pycnocline	Conditional
7/ 7/09	N16P	1	Post-discharge	Sub pycnocline	Conditional
3/17/10	N20S	47	Post-discharge	Surface	Adverse

Table 6 List of all sample results where *Enterococcus* was detected at outfall stations.

Date Sampled	Station	Enterococcus /100 ml	Time period	Depth sampled	Survey type
12/19/00	N20S	2	Post-discharge	Surface	Conditional
1/29/01	N20S	4	Post-discharge	Surface	Conditional
6/21/01	N20P	1	Post-discharge	Sub pycnocline	Conditional
6/21/01	N20S	2	Post-discharge	Surface	Conditional
8/27/01	N20S	1	Post-discharge	Surface	Conditional
10/ 4/01	N16P	1	Post-discharge	Sub pycnocline	Conditional
9/26/02	N16P	1	Post-discharge	Sub pycnocline	Conditional
12/10/02	N16S	1	Post-discharge	Surface	Conditional
12/10/02	N20S	1	Post-discharge	Surface	Conditional
9/24/03	N16P	6	Post-discharge	Sub pycnocline	Conditional
9/24/03	N16S	1	Post-discharge	Surface	Conditional
9/24/03	N20P	303	Post-discharge	Sub pycnocline	Conditional
9/24/03	N20S	10	Post-discharge	Surface	Conditional
12/16/03	N20S	1	Post-discharge	Surface	Conditional
12/19/03	N16S	10	Post-discharge	Surface	Adverse
12/19/03	N20S	5	Post-discharge	Surface	Adverse
1/21/04	N20S	1	Post-discharge	Surface	Conditional
7/ 6/04	N16S	1	Post-discharge	Surface	Conditional
7/ 6/04	N20P	1	Post-discharge	Sub pycnocline	Conditional
8/17/04	N16P	3	Post-discharge	Sub pycnocline	Adverse
9/ 7/04	N16P	1	Post-discharge	Sub pycnocline	Conditional
12/16/04	N16S	2	Post-discharge	Surface	Conditional
12/16/04	N20S	2	Post-discharge	Surface	Conditional
1/26/05	N20S	2	Post-discharge	Surface	Conditional
4/13/05	N16S	1	Post-discharge	Surface	Adverse
5/ 5/05	N20S	1	Post-discharge	Surface	Conditional
9/ 2/05	N20P	1	Post-discharge	Sub pycnocline	Adverse
10/18/05	N20P	1	Post-discharge	Sub pycnocline	Adverse
8/ 9/06	N16P	2	Post-discharge	Sub pycnocline	Conditional
10/ 4/06	N20S	1	Post-discharge	Surface	Conditional
12/11/06	N20S	1	Post-discharge	Surface	Conditional
8/10/07	N16S	10	Post-discharge	Surface	Conditional
9/20/07	N16P	10	Post-discharge	Sub pycnocline	Conditional
9/20/07	N20S	10	Post-discharge	Surface	Conditional
8/ 4/08	N16P	10	Post-discharge	Sub pycnocline	Conditional
8/ 4/08	N20P	20	Post-discharge	Sub pycnocline	Conditional
9/ 4/08	N20P	10	Post-discharge	Sub pycnocline	Conditional
8/ 3/09	N20P	10	Post-discharge	Sub pycnocline	Conditional
1/14/10	N16S	10	Post-discharge	Surface	Conditional
5/ 4/10	N16P	10	Post-discharge	Sub pycnocline	Conditional
6/14/10	N20P	10	Post-discharge	Sub pycnocline	Conditional
7/ 2/10	N20S	10	Post-discharge	Surface	Conditional
8/ 6/10	N16S	10	Post-discharge	Surface	Conditional
11/ 3/10	N20P	10	Post-discharge	Sub pycnocline	Conditional

4.3 Spatial and temporal patterns

Water quality standards are written in terms of geometric means which are appropriate measures of central tendency for log-normally distributed data. Arithmetic means are more affected by higher outliers and are therefore more conservative. Analyses in this section are based on arithmetic means, which are a conservative complement to the geometric mean data.

4.3.1 Fecal coliform

Figure 2 shows there has been some variation in fecal coliform counts from year to year, however the average counts are all extremely low, with arithmetic means less than 3 organisms/100 ml for any year or area. Generally, counts tended to be slightly higher in all areas before 2007. The outfall and coastal sites tend to be slightly higher than the (non-outfall) nearfield area. All the average counts are far below the shellfish-growing water standard of 14 organisms /100 ml.

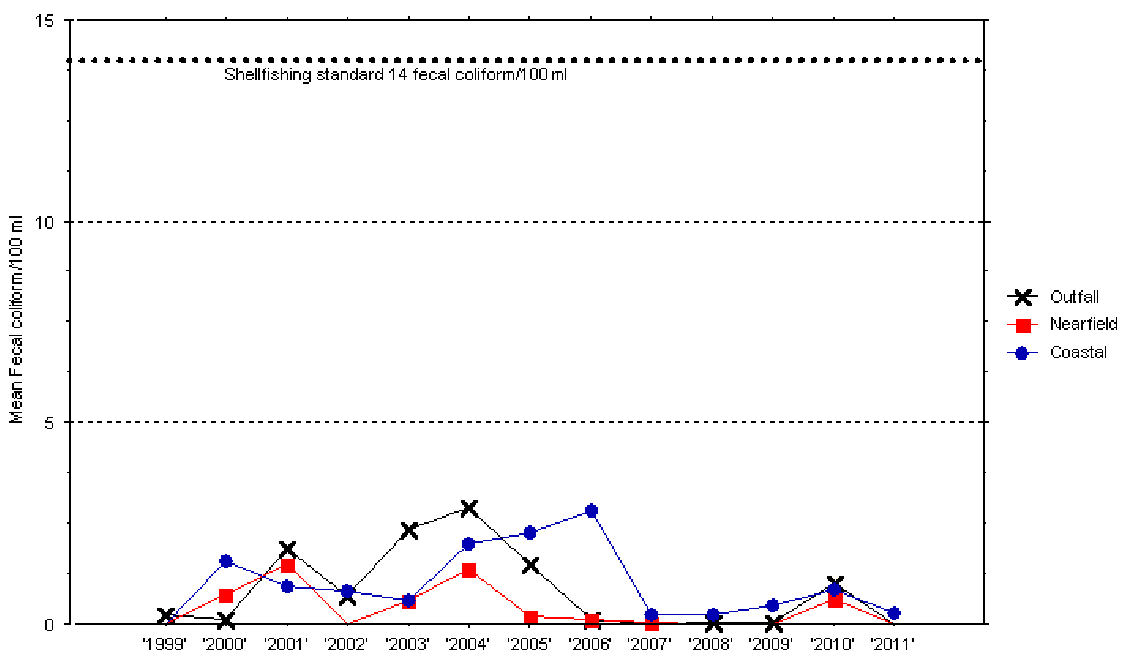

Figure 2 Changes in fecal coliform counts over time 1999-2011.

4.3.2 *Enterococcus*

Figure 3 shows annual averages for *Enterococcus* for the three monitoring areas. The levels are extremely low, far below the 35 organisms/100 ml limit, with average values generally below 3 organisms/100 ml. Geometric means are even lower (Table 4). There has been little inter-annual variation; the highest annual average was 8 organisms/100 ml.

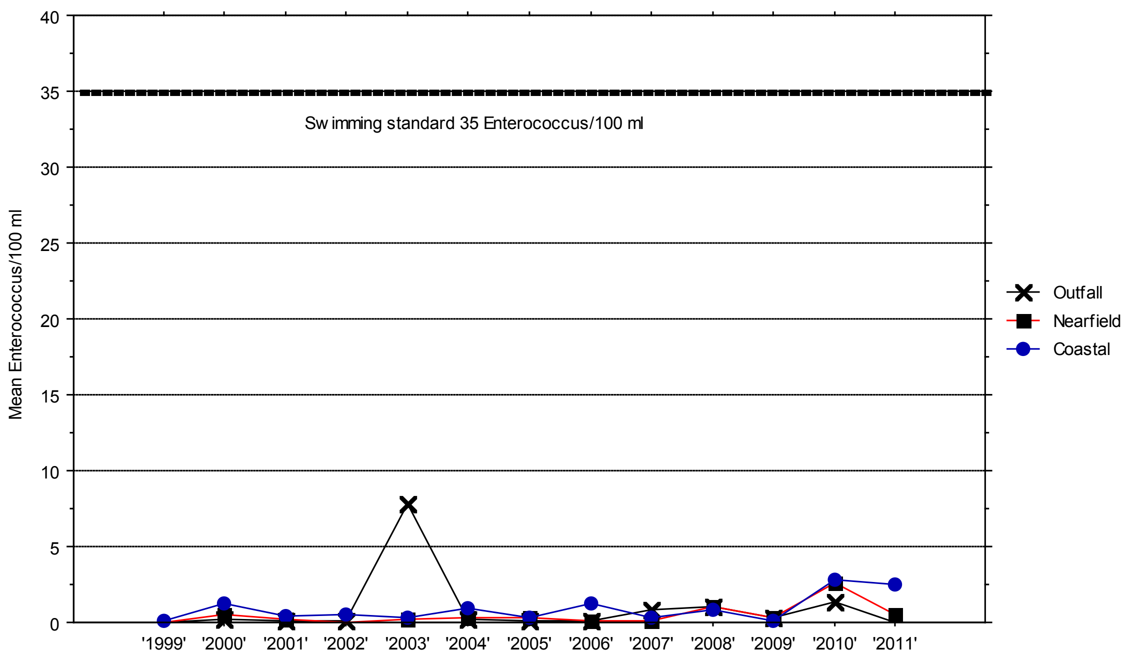

Figure 3 Changes in *Enterococcus* counts over time 1999-2011.

4.4 Adverse Condition Surveys

The purpose of the adverse condition survey is to capture the "worst case" situations, either during plant upset or a significant period of secondary blending as a result of rainstorms. Table 5 shows the results of samples collected during each adverse condition survey; data are categorized by station group.

Table 7 Summary results of adverse condition surveys.

FC = fecal coliform, ENT = *Enterococcus*, ND = No data.

Survey date	Indicator	Bacteria count (organisms/100 ml)					
		Outfall		Nearfield		Coastal	
		Mean	Max	Mean	Max	Mean	Max
Mar 26 01	FC	0.0	0.0	0.0	0.0	0.3	2.0
	ENT	0.0	0.0	0.0	0.0	0.0	0.0
Jul 3 01	FC	1.0	4.0	0.0	0.0	0.9	4.0
	ENT	0.0	0.0	0.3	1.0	0.0	0.0
Oct 12 01	FC	0.0	0.0	1.0	4.0	0.0	0.0
	ENT	0.0	0.0	0.3	1.0	0.0	0.0
Oct 13 01	FC	0.0	0.0	0.5	2.0	0.6	4.0
	ENT	0.0	0.0	0.3	1.2	0.4	2.0
Oct 18 02	FC	0.0	0.0	0.0	0.0	0.5	2.0
	ENT	0.0	0.0	0.0	0.0	0.8	2.0
Dec 19 03	FC	0.0	0.0	0.0	0.0	2.0	4.0
	ENT	7.5	10.0	0.3	1.0	1.0	1.0
Aug 17 04	FC	18.5	50.0	0.5	2.0	0.0	0.0
	ENT	0.8	3.0	0.0	0.0	0.1	1.0
Sep 30 04	FC	0.0	0.0	16.0	50.0	2.7	6.0
	ENT	0.0	0.0	1.5	5.0	1.7	9.0
Apr 13 05	FC	0.0	0.0	0.0	0.0	0.6	4.0
	ENT	0.3	1.0	0.4	2.0	0.0	0.0
Sep 2 05	FC	18.0	36.0	0.0	0.0	ND	ND
	ENT	0.5	1.0	0.0	0.0	ND	ND
Oct 18 05	FC	0.5	2.0	0.3	2.0	6.9	28.0
	ENT	0.3	1.0	0.0	0.0	0.4	2.0
May 16 06	FC	0.0	0.0	0.8	6.0	22.1	50.0
	ENT	0.0	0.0	0.1	1.0	8.0	24.0
Mar 11 08	FC	0.0	0.0	0.0	0.0	0.1	1.0
	ENT	0.0	0.0	3.8	20.0	0.0	0.0
Feb 27 10	FC	ND	ND	ND	ND	-	2.0
	ENT	ND	ND	ND	ND	-	0.0
Mar 17 10	FC	23.5	47.0	13.3	53.0	9.8	32.0
	ENT	0.0	0.0	7.5	30.0	15.3	41.0
Mar 25 10	FC	0.0	0.0	0.5	2.0	0.0	0.0
	ENT	0.0	0.0	0.0	0.0	2.5	10.0
Apr 1 10	FC	0.0	0.0	0.3	1.0	3.8	12.0
	ENT	0.0	0.0	0.0	0.0	18.0	41.0
Aug 27 10	FC	0.0	0.0	0.0	0.0	0.0	0.0
	ENT	0.0	0.0	0.0	0.0	0.0	0.0

Figure 4 compares the fecal coliform results of monthly conditional surveys with adverse condition surveys at each group of stations. Two relatively higher values at the coastal stations during adverse condition surveys in 2005 are responsible for the peak mean count. It is likely that the coastal stations reflect nearshore sources of bacteria in heavy rainstorms.

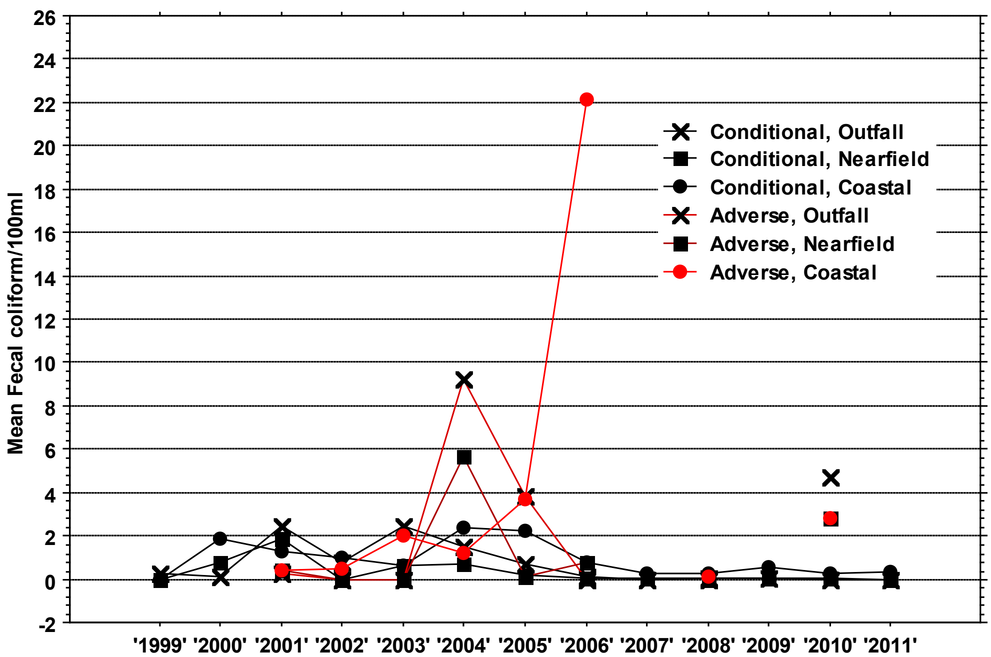

Figure 4 Mean fecal coliform counts by year and area for monthly conditional surveys and adverse condition surveys. For some years, there were no adverse condition surveys.

Figure 5 is a similar plot showing *Enterococcus* results. Average counts for all years are well within water quality standards (35 organisms/100 ml) at all locations and for both adverse and conditional surveys.

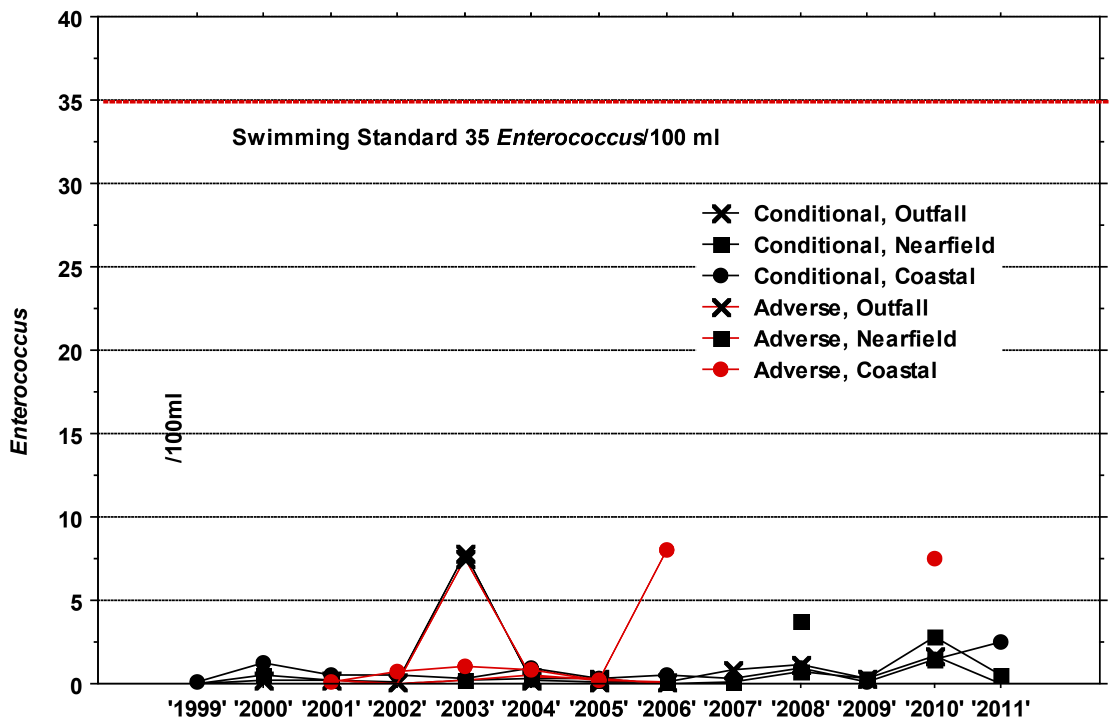

Figure 5 Mean *Enterococcus* counts by year and area for monthly conditional surveys and adverse condition surveys. For some years, there were no adverse condition surveys.

4.5 Effect of sampling depth

During seasons when the water column is stratified, samples are collected subpycnocline as well as at the surface. Figure 6 shows mean fecal coliform and *Enterococcus* counts grouped by sampling area and depth. Although there are no statistically significant differences among the groups, the samples collected subpycnocline at the outfall location, while extremely low, are somewhat higher than the other locations and depths. This would be expected because this is the most conservative condition sampled. Of 182 samples collected at the outfall area stations at the subpycnocline depth, 170 (93%) were non-detects for *Enterococcus*; of 184 samples 159 (86%) were non-detects for fecal coliform.

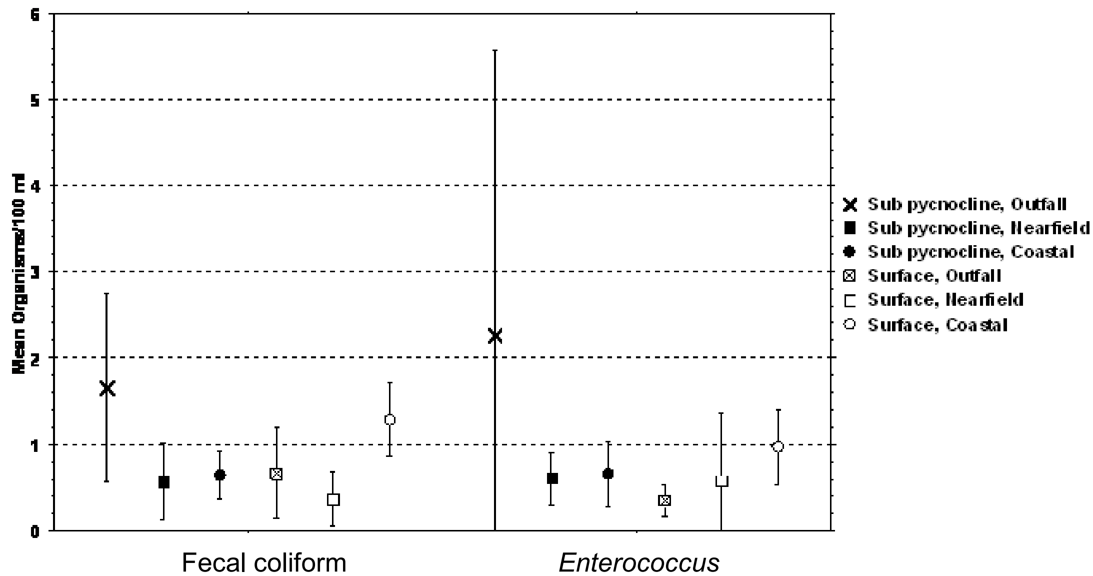

Figure 6 Average bacteria counts for samples collected subpycnocline compared to samples collected at the surface, by station group. Error bars are 95% confidence intervals.

5.0 Summary and Conclusions

This report presents data from more than 2,000 samples collected and analyzed for both fecal coliform and *Enterococcus* since MWRA's outfall went on-line in September 2000. Overall, the data show that the receiving water near the outfall and other areas consistently meets Massachusetts' most stringent water quality standards for Class SA shellfishing and swimming. The geometric mean count for bacteria at the outfall site is 0.2 organisms/100 ml for both fecal coliform and *Enterococcus*. Of samples collected at the two stations closest to the outfall, the vast majority of samples, 90%, were non-detects for fecal coliform and 91% were non-detects for *Enterococcus*. Of 1,828 samples collected at all sites after the outfall went on-line, only two samples exceeded the single-sample maximum value (for designated bathing beaches) for *Enterococcus*.

In the most conservative situation, where dilution is minimized during the stratified period, 93% of samples collected sub-pycnocline at the outfall stations were non-detects for *Enterococcus* and 86% were non-detects for fecal coliform. Mean subpycnocline bacteria counts were well below 3 organisms/100 ml for both indicators at the outfall stations. Over the monitoring period only one subpycnocline sample at an outfall station exceeded the *Enterococcus* single-sample maximum.

A detailed analysis of data collected during adverse condition monitoring tells a similar story. The highest count for fecal coliform collected at the outfall during adverse conditions was 50/100 ml; for *Enterococcus* the highest count was 41/100 ml, well within standards at bathing beaches. Graphical analyses comparing data collected during adverse conditions and during monthly conditional zone surveys show little difference at the outfall location.

Overall, the ambient bacteria monitoring data confirm that water quality standards are met, and water quality is protected by the present level of treatment and disinfection at MWRA's Deer Island Treatment Plant.

6.0 References

Libby PS, Fitzpatrick MR, Buhl RL, Lescarbeau GR, Leo WS, Borkman DG, Turner JT. 2011. **Quality assurance project plan (QAPP) for water column monitoring 2011-2013: Tasks 4-9 and 12**. Boston: Massachusetts Water Resources Authority. Report 2011-02. 72 p.

MWRA. 2009. Department of Laboratory Services Standard Operating Procedure. Membrane Filter Method for Fecal coliforms and *Escherichia coli* in Water using mTEC medium DCN1130.2.

MWRA. 2009. Department of Laboratory Services Standard Operating Procedure. *Enterococci* in Source Waters, Receiving Waters, and Wastewater by the Defined Substrate Method-Enterolert® DCN 1217.3

Appendix

Memorandum of Understanding between MWRA and the Massachusetts Division of Marine Fisheries

The memorandum of understanding that follows was signed in 1999. The Notification Procedures and Monitoring plan was updated in October 2003.

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MEMORANDUM OF UNDERSTANDING

To classify and manage the coastal waters of Massachusetts, the Massachusetts Division of Marine Fisheries (DMF) must determine that shellfish growing areas maintain the National Shellfish Sanitation Program (NSSP) criteria for a given classification. For any shellfish growing area to be managed under conditional classification, the NSSP requires that an area meet approved or restricted criteria under certain predictable conditions and that performance standards be established by the shellfish control agency (DMF).

DMF has determined that performance standards for shellfish growing areas in greater Boston Harbor depend on the operation of Massachusetts Water Resources Authority's (MWRA) Deer Island Wastewater Treatment Plant and the associated sewage collection system. In addition, performance standards for greater Massachusetts Bay depend on the operation of the Deer Island Plant and its discharge through the new outfall. The NSSP requires that a plan exist between the shellfish control agency and the operators of any wastewater treatment facility that may impact shellfish areas. The attached sampling and reporting procedures include performance standards, notification procedures and conditional area monitoring commitments and represent such a plan. In addition, the plan is to be reviewed annually by DMF and MWRA and may be updated as needed by written amendments to the plan. This document acknowledges that, in accordance with MWRA's National Pollutant Discharge Elimination System (NPDES) permit issued by the Massachusetts Department of Environmental Protection (DEP) and the United States Environmental Protection Agency (EPA) and subject to DEP and EPA concurrence, DMF may determine that effluent coliform limits will revert to those specified in Part I.1.a.16 of the permit to ensure protection of public health.

DMF and the MWRA agree to cooperate in protecting the quality of shellfish growing waters potentially impacted by MWRA discharges. This MOU is designed to assure continued adequate communication between MWRA and DMF, and should allow both agencies to work efficiently toward the shared goal of protecting the public health. This cooperative agreement supports maintaining the waters of Massachusetts Bay and Boston Harbor for the harvest of shellfish to the maximum extent possible.

________________ _____________
Doug MacDonald Date
Executive Director
Massachusetts Water Resources Authority

_____________________ _____________
Philip G. Coates Date
Director
Massachusetts Division of Marine Fisheries

Notification Procedures

Whereas the Massachusetts Water Resources Authority (MWRA) operates and maintains the Deer Island Sewage Treatment Plant and the associated collection system and whereas there exists the potential of an adverse change in these pollution sources, the MWRA agrees to notify the Massachusetts Division of Marine Fisheries in the event of the following:

1. Discharge under the following conditions:
   Deer Island Treatment Plant
   Any discharge at the outfall (T01) in violation of the NPDES permit limits for fecal coliform;

2. Discharge from any of the following outfalls or areas:
   Deer Island Treatment Plant
   Emergency outfalls 001, 002, 004, or 005;
   Nut Island Headworks
   Emergency outfalls 101, 102, 103, or the Nut Island Spillway;
   Combined Sewer Overflows Permitted to MWRA
   Any dry weather activations;
   Sanitary Sewer Overflows
   Any overflow or bypasses through MWRA's sewage collection system that impact or have a reasonable potential to impact receiving waters in the vicinity of shellfish growing areas;

   Sludge Pelletizing Plant
   Any major spill that impacts or has a reasonable potential to impact receiving waters.

3. Foreseeable events that have the potential to affect the performance of the treatment facilities and/or sewage collection system to the extent that shellfish growing areas may be adversely impacted.

Notifications for incidents listed above will include the following available information where applicable:

a. Start and stop times
b. Estimated volume of discharge
c. Status of disinfection
d. Cause of discharge
e. Analytical data (fecal coliform counts)

DMF will be notified by phone at (617) 727-3036 between 7:00 AM and 4:00 PM Monday through Friday as soon as possible for any of the above events. If an event occurs or data becomes available after 4:00 PM, notification should be made the following business day. MWRA will make a reasonable attempt to notify DMF after 4:00 PM on weekdays and on weekends by leaving a message on the answering machine at (508) 465-5947. Analytical data, including chlorine residual and coliform counts, will be reported as soon as they become available.

DMF will be included in the distribution list for Deer Island Sewage Treatment Plant Discharge Reports, Operations Summary Reports, and Activation Notification Letters.

Monitoring

MWRA agrees to provide field sampling and laboratory services to assist DMF in the classification of shellfish growing areas in the vicinity of the outfall. MWRA will follow a mutually agreed upon monitoring plan (Attachment A) in partnership with DMF to provide analytical data. The monitoring plan will follow DMF protocols for fecal coliform sampling and analysis. MWRA and DMF agree that the monitoring plan may be changed under mutual agreement as relevant data becomes available, and that these changes will be documented in writing and included in a revised Notification and Monitoring Agreement. MWRA also agrees to provide Boston Harbor monitoring results upon request to document improvements to shellfish growing areas previously impacted by MWRA discharges.

Receiving Water Quality

MWRA acknowledges that, subject to the approval of the Massachusetts Department of Environmental Protection and the United States Environmental Protection Agency, DMF may direct MWRA to modify its treatment processes to ensure that the effluent from the new Deer Island Wastewater Treatment Plant will meet all state water quality standards for fecal coliform and total chlorine residual upon discharge to the receiving water at the new outfall location.

Attachment A

Fecal Coliform Monitoring Plan

The monitoring plan shall have the following two components:

1) Monitoring for Conditional Zone Classification

MWRA will collect and analyze samples for fecal coliform from eleven locations for conditional zone classification. Samples will be collected from the surface and from the water below the pycnocline during periods of stratification. All samples will be processed at MWRA's Central Laboratory according to FDA approved methods for shellfish growing waters. Samples will be collected monthly. The monitoring stations for the conditional zone classification surveys are listed in Table 1.

2) Monitoring during adverse conditions

MWRA will collect and analyze samples for fecal coliform from the eleven conditional zone classification locations as quickly as possible following adverse conditions. Adverse conditions are events that have a reasonable potential to cause MWRA to discharge wastewater with high levels of bacteria including extremely high flows due to heavy rain, treatment plant failures, and unforeseen events. Criteria that determine what constitutes adverse conditions appear in Attachment B. Given that these criteria are met, it is anticipated that MWRA will conduct approximately five adverse conditions surveys per year. The sampling and analytical procedures for the adverse condition surveys are the same as the procedures for the conditional zone classification surveys. A map of the locations appears in Figure 1.

Table 1. Conditional Zone Classification/Adverse Conditions Monitoring Stations

Station ID[1]	Latitude	Longitude	Station Description
F13	42-16.10	70-44.10	ENE OF COHASSET HARBOR
F14	42-18.00	70-48.50	ENE OF NANTASKET BEACH (~3NM)
F18	42-26.53	70-53.30	NAHANT BAY S. OF LITTLES PT (1.5 NM)
F24	42-22.50	70-53.75	INNER MB, NE OF DEER IS.
F25	42-19.30	70-52.58	INNER MB, NE OF NANTASKET BEACH
N02	42-25.65	70-49.31	E. OF DI, S. OF SALEM SOUND
N09	42-20.39	70-47.48	E. OF DI, S. OF SALEM SOUND
N16	42-23.64	70-45.20	OUTFALL DIFFUSER #1
N20	42-22.90	70-49.03	OUTFALL DIFFUSER #55
N04	42-26.64	70-44.22	NORTHEASTERN CORNER OF NEARFIELD
N07	42-21.36	70-42.36	SOUTHEASTERN CORNER OF NEARFIELD

[1] Station locations were selected from farfield and nearfield monitoring locations currently monitored by MWRA under its Outfall Monitoring Plan. The station IDs are followed by an "S" or a "P" to represent surface sample or sub-pycnocline sample respectively.

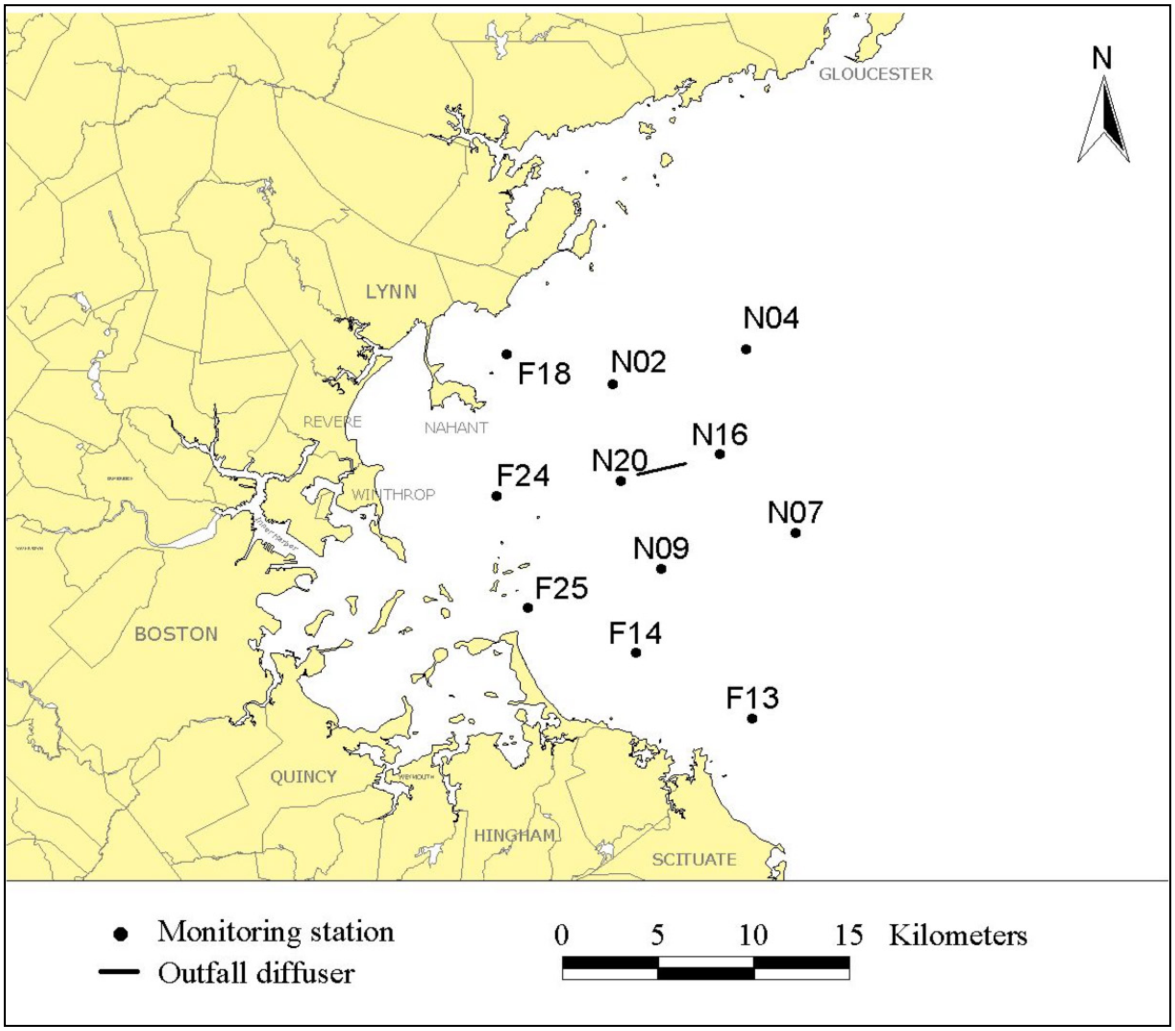

Figure 1. Map of Conditional Zone Classification/Adverse Condition monitoring stations

Attachment B

Criteria for Adverse Conditions Monitoring

Adverse conditions monitoring will occur under conditions that may result in elevated pathogen levels in Massachusetts Bay, as described in Attachment A. This attachment establishes the criteria that will trigger an adverse monitoring survey.

An adverse conditions survey will be triggered by either 1) a reduction in secondary treatment, when the effluent consists of 60% secondary treated flows or less for more than six hours; or 2) complete loss of chlorination for more than six hours. In the event of another type of operational upset that may result in elevated pathogen levels in Massachusetts Bay, MWRA will consult with DMF to determine if an adverse conditions survey is warranted.

- Once it is determined that operational upset/high flow conditions qualify for adverse conditions monitoring, the survey should take place between 10 and 30 hours following the trigger, weather and logistics permitting. If an operational upset is prolonged, DMF, in consultation with MWRA, may decide to extend this time window.

- Every effort shall be made to sample all conditional monitoring stations in a survey; if a survey is abbreviated or cancelled because of weather conditions or equipment problems, the survey should be completed as soon as possible. Locations closest to the outfall have the highest priority of any of the monitoring stations.

- If adverse conditions persist, MWRA (in consultation with DMF) should make an effort to conduct more than one survey over the course of the event.

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