Indicator bacteria in Massachusetts Bay 1999-2014: Water quality monitoring in receiving waters of the Massachusetts Water Resources Authority outfall

Massachusetts Water Resources Authority
Environmental Quality Department
Report 2016-01

Citation:

Codiga DL, Rex AC, Coughlin K. 2016. **Indicator bacteria in Massachusetts Bay 1999-2014: Water quality monitoring in receiving waters of the Massachusetts Water Resources Authority outfall.** Boston: Massachusetts Water Resources Authority. Report 2016-01. 20 p.

Acknowledgements. Dave Wu, Ken Keay, and Betsy Reilley provided technical reviews and input on the analysis and reporting. Doug Hersh assisted with data management.The staff of the MWRA Department of Laboratory Services, under the direction of Mike Delaney and managed by Laura Ducott, collected the observations.

Indicator bacteria in Massachusetts Bay 1999-2014: Water quality monitoring in receiving waters of the Massachusetts Water Resources Authority outfall

Prepared by:

Daniel L. Codiga, Andrea C. Rex, and Kelly Coughlin

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

June 2016

Environmental Quality Department Technical Report 2016-01

SUMMARY

This report is an update to an earlier analysis (Rex, 2011) of monitoring data for sewage indicator bacteria (fecal coliform and *Enterococcus*) in central-western Massachusetts Bay surrounding the location of the effluent outfall from the MWRA Deer Island Treatment Plant. The analysis treats observations from vessel-based surveys conducted since 1999 under the terms of a memorandum of understanding (MOU; included as an appendix to Rex, 2011) between MWRA and the Massachusetts Division of Marine Fisheries. This includes both the monthly year-round *conditional zone classification* ("conditional") surveys and the less frequent *adverse conditions* ("adverse") surveys, the latter carried out only in response to changes in treatment plant operations during what are considered worst case conditions for potential increased bacteria discharge (as detailed in Attachment B of the MOU). Each survey visits 11 sites, which are analyzed here in three groups: outfall (two stations, near the easternmost and westernmost endpoints of the outfall), nearfield (four stations, north and south of outfall stations) and coastal (five stations, west of outfall and nearfield stations). Samples are collected at the surface during all surveys and also near the seafloor on surveys carried out when density stratification is appreciable, typically between May and October. The most recent additional 3.5 years of observations, through the end of 2014, are included here.

Conclusions of the earlier study are unchanged and can be summarized as follows. The vast majority of samples are non-detects, having bacteria levels below detectability by the methods used. Annual averages are much lower than water quality standards for shellfishing (fecal coliform) and swimming (*Enterococcus*). Based on more than 14 years of monitoring since the outfall went online, water quality standards are being met very consistently and the evidence suggests that the likelihood of violations is extremely low. Differences in results among the three station groups are minor. As would be expected due to the likelihood of reduced dilution, during stratification the frequency of detections and the levels of counts near the seafloor at the outfall stations are generally higher; however, the increases are modest and even those data include only a single exceedance of one water quality standard, which was due to one individual sample, through all the years of sampling. Conditional and adverse survey results are difficult to distinguish from each other. Detection frequencies, and levels of counts when detected, are at least as high at coastal stations as at nearfield stations. Results continue to support the conclusion that the outfall does not substantially affect sewage indicator bacteria levels in Massachusetts Bay, even in the immediate vicinity of the discharge.

Table of Contents

List of Tables

List of Figures

1. 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 Treatment Plant (DITP) outfall complies with water quality standards (Massachusetts Class SA) for shellfishing and for primary contact recreation. The outfall went online in September 2000. This report summarizes more than 15 years of data collected, for two 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 characteristics of the observations are described and discussed.

2. Background: Permit limitations and water quality standards

The DITP effluent outfall was built with the goal of achieving as much dilution as practicable. The outfall is a deep rock tunnel leading 9.5 miles away from Deer Island and ending in a diffuser 1.25 miles long that comprises 53 working risers topped by multi-port caps sitting on the seafloor. The water depth at the diffuser is approximately 30-34 meters (100-110 feet) and the minimum available dilution is 70-fold (Hunt *et al.*, 2010). 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 Class 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.).

There was also 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/100 ml, and additionally no more than 10% of individual samples shall 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, and the Notification Plan and Monitoring Plan as updated in 2003, are included in Rex (2011).

In short, the monitoring consists of surveys visiting 11 stations. There are both routine monthly surveys for Conditional Zone Classification (hereafter "conditional surveys") and less frequent, as-needed responsive Adverse Condition surveys (hereafter "adverse surveys"). Adverse surveys are required should conditions occur at the treatment plant, such as an extended chlorination failure or long period of blending primary-treated with secondary-treated effluent, that could potentially increase discharge of bacteria. If other types of operational upsets occur, MWRA consults DMF to determine whether an adverse survey is needed.

In addition to fecal coliform, from the start MWRA monitored *Enterococcus*, during surveys as well as in the effluent, because of an emerging regulatory initiative to change the bacterial indicator in marine recreational waters to *Enterococcus*. In 2007, Massachusetts did change to an *Enterococcus*-based standard, with geometric mean limit of 35 organisms/100 ml and single sample maximum of 104 organisms/100 ml. (The federal fecal coliform-based standard for shellfish-growing waters, and DITP permit limitations for effluent bacteria, remain unchanged.)

3. 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 sub-pycnocline. 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 considered here) were eliminated. For consistency, only those stations that have been sampled throughout the period 1999-2014 have been included in this analysis (Figure 1; Table 1). For some data analyses, the stations are treated in three groups: outfall, nearfield, and coastal. Although both conditional and adverse surveys target sampling at all 11 stations, conditional surveys can be scheduled during relatively agreeable weather conditions, while adverse surveys do not have this flexibility and therefore sea state and other logistical circumstances occasionally preclude all stations from being reached during them.

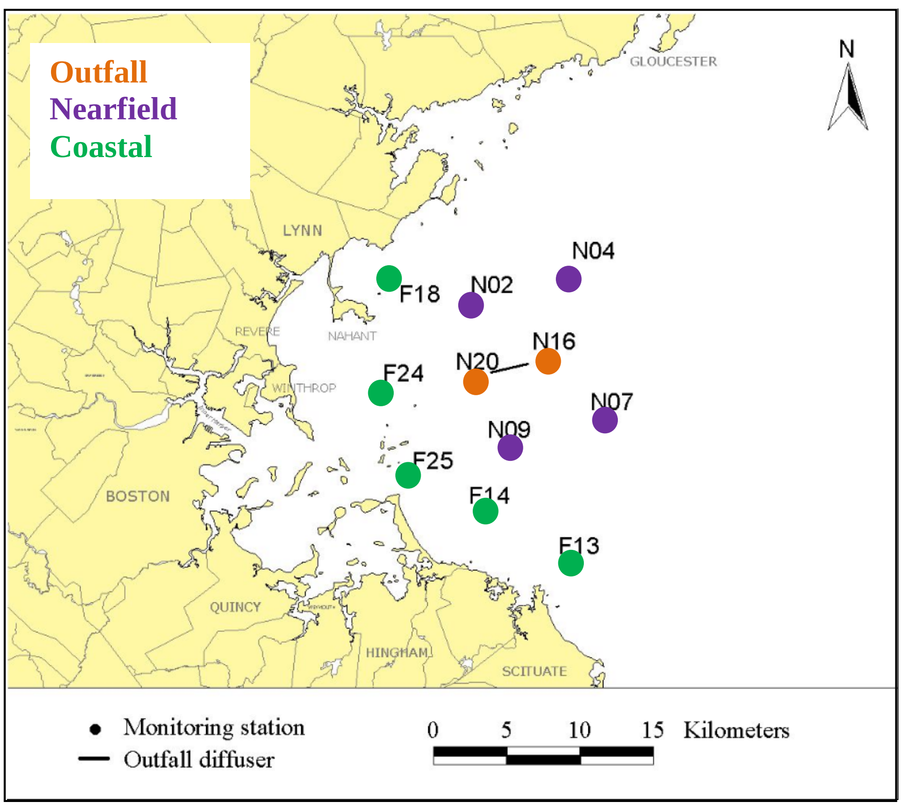

Figure 1. Map of stations sampled consistently throughout the monitoring program.

Table 1. Station information.

Area	Station	Location description	Average water depth (meters)	Latitude N (deg-min)	Longitude W (deg-min)
Outfall	N16	Near East End of Outfall Site	42	42-23.64	70-45.20
	N20	Near West End of Outfall Site	31	42-22.90	70-49.03
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
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

3.2 *Sampling schedule*

3.2.1 Conditional surveys

The DMF and FDA require that conditional 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 online in September 2000. Monthly conditional surveys have been ongoing since October 2000.

3.2.2 Adverse surveys

Adverse surveys assess water quality under worst case conditions. Secondary treatment and disinfection are the phases of treatment that significantly reduce pathogens and indicator bacteria. An adverse survey is triggered primarily by either (1) conditions leading to 60% or less of the total flow receiving secondary treatment for more than six hours, due to high flow beyond the capacity of the secondary treatment process causing effluent to consist of blended primary and secondary treated effluent; or (2) complete loss of chlorination for more than six hours. There have been 19 adverse surveys; dates are shown in Table 2. None of these events involved failure of disinfection.

Table 2. Dates of adverse surveys.

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	Mar 26	Oct 18	Dec 19	Aug 17	Apr 13	May 16		Mar 11		Feb 27				Dec 11
	Jul 03			Sep 30	Sep 02					Mar 17				
	Oct 12				Oct 18					Mar 25				
	Oct 13									Apr 01				
										Aug 27				

3.3 *Sample collection*

Water samples are collected at the surface (depth of 1 meter) during all surveys. If there is appreciable stratification (generally from May to October), a sample is also collected below the pycnocline, at 2 meters above the seafloor. Presence or absence of a pycnocline during a given survey is determined using the water column profiles collected by the most recent outfall ambient water quality monitoring program survey (for information on that program see, e.g., Libby *et al*. 2014). Surface samples are collected using a 2 liter Kemmerer sampler and sub-pycnocline samples are collected using a 2.5 liter Niskin sampler deployed by winch and line. The samples are transferred to 250 ml sterile sample bottles, placed in an ice-filled cooler maintained at <10^{o} C temperature, and transported to MWRA's Department of Laboratory Services at Deer Island. Bacteria analyses are initiated within six hours of sampling. Further details of survey procedures are included in MWRA's Standard Operating Procedure documentation (MWRA, 2015a).

3.4 *Measurements and analysis*

Table 3 shows the laboratory methods, including changes that have occurred to them. Currently, fecal coliform bacteria are enumerated by a membrane filtration method approved by the US Food and Drug Administration (FDA) for shellfish-growing waters (mTEC) and *Enterococcus* are enumerated by the defined substrate method Enterolert®. Details of these procedures are in MWRA's Department of Laboratory Services Standard Operating Procedures (MWRA, 2013, 2015b) and will not be repeated here. Physical and chemical measurements are recorded, but are not reported here.

Table 3. Laboratory methods and list of parameters sampled.

Parameter	Method, Reference ***(Time period used)***
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)***
Temperature, Salinity, pH Sample depth, Water depth	In field: Yellow Springs International (YSI) 600XL sonde with 650 MDS (Multi-parameter Display System) logger

The lower detection limit for fecal coliform has been either 1 or 2 organisms/100 ml, depending on the method. When samples exceed the upper detection limit for fecal coliform, 50 organisms/100 ml, they cannot be further quantified. 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. Internal studies done by MWRA have found that the methods yield comparable results.

For statistical purposes, samples in which no bacteria were found (non-detects; results below the detection limit) were defined to have counts of 0 organisms/100 ml.

Water quality standards are written in terms of geometric means, which are appropriate measures of central tendency for log-normally distributed data. For convenience and because this dataset has such a high proportion of non-detects, arithmetic means are used for some results. Arithmetic means are increased more by high individual values, and are therefore a more conservative metric; the geometric mean is always lower than the arithmetic mean (except when all of the averaged samples have the same value, in which case the two means are equal).

Given the temporal and spatial characteristics of the sampling, to yield the most representative results the means were computed using data (i) from each of the three groups of stations individually, as well as all stations together; and (ii) from individual annual periods, as well as all available years together.

4. Results and discussion

4.1 *All stations*

A total of 3,078 samples were analyzed for fecal coliform and 3,026 samples for *Enterococcus* during the sampling period, May 1999 to December 2014. Table 4[1] shows summary statistics for all samples from conditional and adverse surveys, divided between pre- and post-diversion periods (before and after the diversion of the DITP effluent from Boston Harbor to the Massachusetts Bay outfall, when it went online in September 2000). The vast majority of samples were non-detects, including at least 90% of samples at outfall sites for both indicators.

Table 4. Descriptive statistics for fecal coliform and *Enterococcus*, comparing data from pre- and post-diversion periods, and among monitoring areas. Results for Outfall area are in bold.

Indicator	Period (pre or post diver-sion)	Area	Count	Number of Non-Detects	Non-Detects (%)	Number Fecal coliform >28 /100 ml or *Enterococcus* >104 /100 ml	Percent Fecal coliform >28 /100 ml or *Enterococcus* >104 /100 ml	Organisms/100 ml water			
								Arith-metic Mean	Geometric Mean	Min	Max
Fecal Coliform	All	All	3,078	2,742	89	20	0.6	0.7	0.2	0	>50
	Pre	**Outfall**	**12**	**11**	**92**	**0**	**0.0**	**0.2**	**0.1**	**0**	**2**
		Nearfield	12	11	92	0	0.0	0.2	0.1	0	2
		Coastal	29	27	93	0	0.0	0.3	0.1	0	6
	Post	**Outfall**	**586**	**543**	**93**	**7**	**1.2**	**0.9**	**0.2**	**0**	**>50**
		Nearfield	1,005	956	95	4	0.4	0.3	0.1	0	>50
		Coastal	1,434	1,194	83	9	0.6	0.9	0.3	0	>50
Entero-coccus	All	All	3,026	2,739	91	3	0.1	0.9	0.2	0	303
	Pre	**Outfall**	**8**	**8**	**100**	**0**	**0.0**	**0.0**	**0.0**	**0**	**0**
		Nearfield	10	9	90	0	0.0	0.1	0.1	0	1
		Coastal	22	17	77	0	0.0	0.5	0.3	0	4
	Post	**Outfall**	**586**	**529**	**90**	**1**	**0.2**	**1.3**	**0.2**	**0**	**303**
		Nearfield	1,000	930	93	1	0.1	0.7	0.1	0	185
		Coastal	1,400	1,246	89	1	0.1	1.0	0.2	0	109

The relevant water quality standards are as follows (see Section 2 above): for shellfishing waters, fecal coliform shall not exceed a geometric mean of 14 organisms/100 ml and no more than 10%

[1] Note that Table 4 in Rex (2011) contained some minor errors. A corrected version is included in the Attachment at the end of this report. The corrections do not change any of the conclusions of Rex (2011).

of individual samples may exceed 28 organisms/100 ml; for primary contact recreation, *Enterococcus* shall not exceed a geometric mean of 35 organisms/100 ml and a single sample maximum of 104 organisms/100 ml will not be exceeded.

When bacteria were detected, with very few exceptions counts were much lower than the standards. The percentage of counts exceeding the higher, individual-sample based standards (28 fecal coliform/100 ml and 104 *Enterococcus*/100 ml) is well less than 0.5% for most station groups, with a maximum of 1.2% (outfall, post-diversion, fecal coliform). Of 2,986 samples collected after the outfall went online, three exceeded the 104 *Enterococcus*/100 ml single-sample limit, one of which was at an outfall site: outfall station N20, sub-pycnocline, 9/24/2003 (303 organisms/100 ml); nearfield station N09, surface, 10/12/2010 (185 organisms/100 ml); and coastal station F25, sub-pycnocline, 7/11/2011 (109 organisms/100 ml).

4.2 *Outfall stations*

Table 5 lists all samples positive for fecal coliform at outfall stations since sampling began. Of 586 samples collected post-diversion, only 43 (about 7.3%) had any fecal coliform detected. Relative to the shellfishing single-sample standard of 28 organisms/100 ml, all but 8 samples (about 1.3%) were lower, meeting the standard of less than 10%. Three samples exceeded the upper detection limit of 50 organisms/100 ml; with the possible exception of those, all samples were well less than the former 200 organism/100 ml standard, which had been applicable for primary recreation in earlier years.

Enterococcus results are in Table 6. Of 586 samples collected post-diversion, only 57 (about 9.7%), had any *Enterococcus* detected. Only two individual samples were higher than the geometric mean limit of 35 organisms/100 ml; one of those (303 organisms/100 ml, outfall station N20, sub-pycnocline, 9/24/2003) is the only exceedance of a water quality standard (single-sample limit 104 *Enterococcus*/100 ml, primary contact recreation) during more than 15 years of monitoring.

4.3 *Spatial and temporal patterns*

4.3.1 Fecal coliform

Figure 2 shows year to year variations in fecal coliform counts for each station group. Averages 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. Counts at the outfall and coastal sites tend to be slightly higher than at the nearfield sites. All annual averages are far below the standard for shellfish-growing water (geometric mean below 14 organisms/100 ml).

4.3.2 *Enterococcus*

Figure 3 shows annual averages for *Enterococcus* for the three station groups. Arithmetic means are generally less than 3 organisms/100 ml. Geometric means (Table 4) are lower, by definition as noted above, and far below the 35 organisms/100 ml limit. Inter-annual variation is minor; the highest annual average was 8 organisms/100 ml (outfall group, 2003).

In both Figure 2 and Figure 3 there is evidence (as in Table 4) that on average, over all years of sampling, counts are at least as high at coastal stations as they are at nearfield stations.

Table 5. All sample results detecting fecal coliform at outfall stations.

The first sample listed is from the pre-diversion period, all others are post-diversion.

Date sampled	Station	Depth sampled	Survey type	Fecal coliform /100ml
7/19/1999	N20	Sub pycnocline	Conditional	2
12/19/2000	N20	Surface	Conditional	2
6/21/2001	N16	Sub pycnocline	Conditional	2
6/21/2001	N20	Sub pycnocline	Conditional	>50
6/21/2001	N20	Surface	Conditional	>50
7/3/2001	N20	Sub pycnocline	Adverse	4
10/25/2001	N20	Sub pycnocline	Conditional	14
7/23/2002	N16	Sub pycnocline	Conditional	2
12/10/2002	N16	Surface	Conditional	18
12/10/2002	N20	Surface	Conditional	11
7/17/2003	N16	Sub pycnocline	Conditional	2
7/17/2003	N20	Sub pycnocline	Conditional	6
8/19/2003	N20	Sub pycnocline	Conditional	4
9/24/2003	N16	Sub pycnocline	Conditional	6
9/24/2003	N20	Sub pycnocline	Conditional	>50
9/24/2003	N20	Surface	Conditional	28
10/7/2003	N20	Sub pycnocline	Conditional	4
2/9/2004	N16	Surface	Conditional	4
2/9/2004	N20	Surface	Conditional	4
8/17/2004	N16	Sub pycnocline	Adverse	18
8/17/2004	N16	Surface	Adverse	2
8/17/2004	N20	Sub pycnocline	Adverse	50
8/17/2004	N20	Surface	Adverse	4
9/7/2004	N20	Sub pycnocline	Conditional	2
10/4/2004	N20	Sub pycnocline	Conditional	36
12/16/2004	N20	Surface	Conditional	8
1/26/2005	N20	Surface	Conditional	6
2/14/2005	N16	Surface	Conditional	2
8/9/2005	N20	Sub pycnocline	Conditional	4
9/2/2005	N20	Sub pycnocline	Adverse	36
9/19/2005	N16	Sub pycnocline	Conditional	2
9/19/2005	N16	Surface	Conditional	2
9/19/2005	N20	Sub pycnocline	Conditional	4
10/18/2005	N16	Sub pycnocline	Adverse	2
1/11/2006	N16	Surface	Conditional	2
8/9/2006	N16	Sub pycnocline	Conditional	1
8/9/2006	N20	Sub pycnocline	Conditional	1
9/8/2006	N20	Surface	Conditional	1
10/8/2008	N16	Sub pycnocline	Conditional	1
7/7/2009	N16	Sub pycnocline	Conditional	1
3/17/2010	N20	Surface	Adverse	47
7/15/2013	N20	Sub pycnocline	Conditional	2
1/10/2014	N16	Surface	Conditional	2
12/11/2014	N20	Surface	Adverse	20

Table 6. All sample results detecting *Enterococcus* at outfall stations.

All samples post-diversion.

Date sampled	Station	Depth sampled	Survey type	*Enterococcus* /100ml
12/19/2000	N20	Surface	Conditional	2
1/29/2001	N20	Surface	Conditional	4
6/21/2001	N20	Sub pycnocline	Conditional	1
6/21/2001	N20	Surface	Conditional	2
8/27/2001	N20	Surface	Conditional	1
10/4/2001	N16	Sub pycnocline	Conditional	1
9/26/2002	N16	Sub pycnocline	Conditional	1
12/10/2002	N16	Surface	Conditional	1
12/10/2002	N20	Surface	Conditional	1
9/24/2003	N16	Sub pycnocline	Conditional	6
9/24/2003	N16	Surface	Conditional	1
9/24/2003	N20	Sub pycnocline	Conditional	303
9/24/2003	N20	Surface	Conditional	10
12/16/2003	N20	Surface	Conditional	1
12/19/2003	N16	Surface	Adverse	10
12/19/2003	N20	Surface	Adverse	5
1/21/2004	N20	Surface	Conditional	1
7/6/2004	N16	Surface	Conditional	1
7/6/2004	N20	Sub pycnocline	Conditional	1
8/17/2004	N16	Sub pycnocline	Adverse	3
9/7/2004	N16	Sub pycnocline	Conditional	1
12/16/2004	N16	Surface	Conditional	2
12/16/2004	N20	Surface	Conditional	2
1/26/2005	N20	Surface	Conditional	2
4/13/2005	N16	Surface	Adverse	1
5/5/2005	N20	Surface	Conditional	1
9/2/2005	N20	Sub pycnocline	Adverse	1
10/18/2005	N20	Sub pycnocline	Adverse	1
8/9/2006	N16	Sub pycnocline	Conditional	2
10/4/2006	N20	Surface	Conditional	1
12/11/2006	N20	Surface	Conditional	1
8/10/2007	N16	Surface	Conditional	10
9/20/2007	N16	Sub pycnocline	Conditional	10
9/20/2007	N20	Surface	Conditional	10
8/4/2008	N16	Sub pycnocline	Conditional	10

(Continued next page)

(Table 6. Continued)

Date sampled	Station	Depth sampled	Survey type	*Enterococcus* /100ml
8/4/2008	N20	Sub pycnocline	Conditional	20
9/4/2008	N20	Sub pycnocline	Conditional	10
8/3/2009	N20	Sub pycnocline	Conditional	10
1/14/2010	N16	Surface	Conditional	10
5/4/2010	N16	Sub pycnocline	Conditional	10
6/14/2010	N20	Sub pycnocline	Conditional	10
7/2/2010	N20	Surface	Conditional	10
8/6/2010	N16	Surface	Conditional	10
11/3/2010	N20	Sub pycnocline	Conditional	10
9/1/2011	N20	Surface	Conditional	10
4/17/2012	N20	Surface	Conditional	10
5/7/2012	N16	Sub pycnocline	Conditional	10
9/7/2012	N16	Surface	Conditional	98
9/7/2012	N20	Sub pycnocline	Conditional	20
9/7/2012	N20	Surface	Conditional	10
12/4/2012	N20	Surface	Conditional	10
3/18/2013	N16	Surface	Conditional	10
6/5/2013	N16	Surface	Conditional	20
4/3/2014	N16	Surface	Conditional	10
5/6/2014	N20	Sub pycnocline	Conditional	10
6/10/2014	N16	Sub pycnocline	Conditional	30
12/11/2014	N20	Surface	Adverse	30

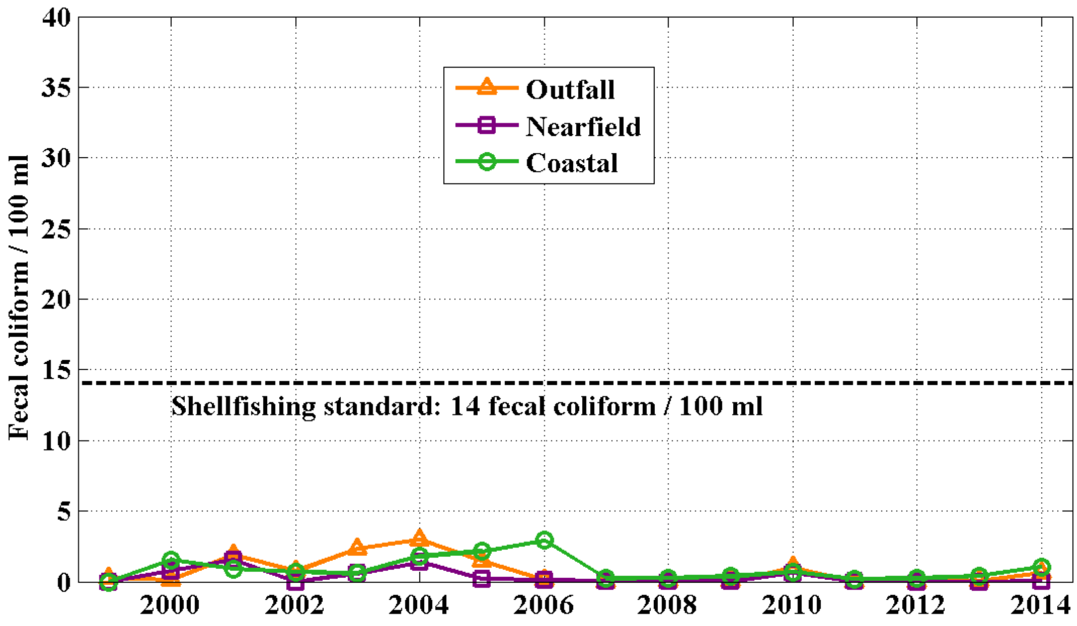

Figure 2. Changes in fecal coliform counts, 1999-2014.

Annual averages by station group, computed by arithmetic mean, using both conditional and adverse survey data together.

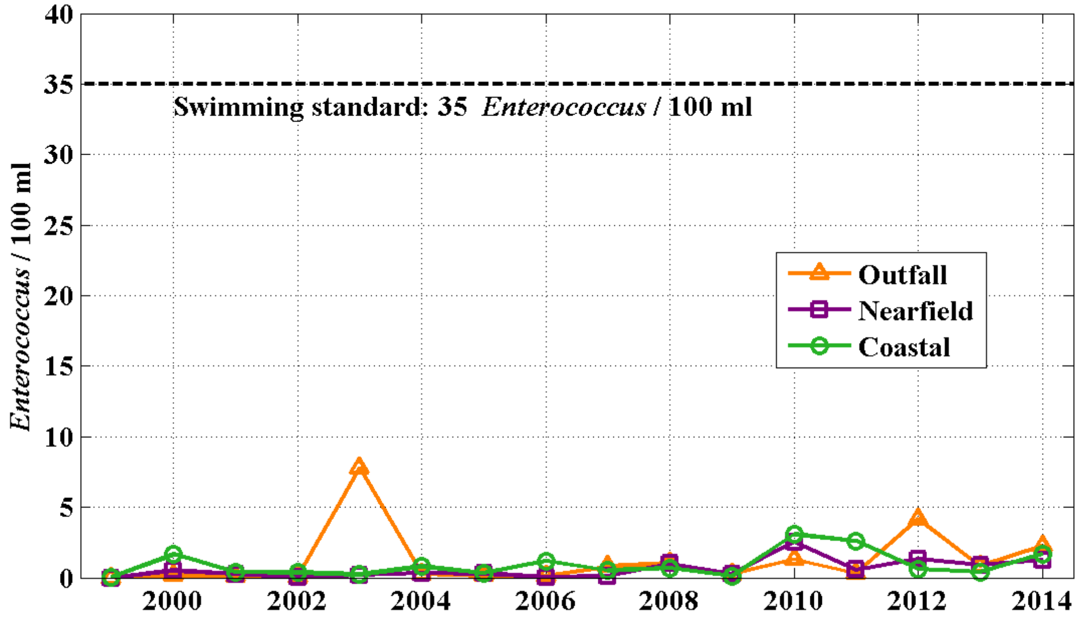

Figure 3. Changes in *Enterococcus* counts, 1999-2014.

Annual averages by station group, computed by arithmetic mean, using both conditional and adverse survey data together.

4.4 *Adverse surveys*

The purpose of the adverse surveys is to capture worst-case situations, such as a significant period of blending (see Section 3.2.2), which could become necessary during large rainstorms. Table 7 shows the results of samples collected during each adverse survey, categorized by station group. Figure 4 compares fecal coliform from conditional and adverse surveys at each group of stations. Two relatively higher values at the coastal stations during adverse surveys in 2006 are responsible for the peak mean count. It is likely that the coastal stations reflect nearshore sources of bacteria in heavy rainstorms. 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 conditional and adverse surveys.

4.5 *Effect of sampling depth*

During seasons when the water column is stratified, sub-pycnocline samples are collected 2 m above the seafloor, in addition to the surface samples. Figure 6 shows mean fecal coliform and *Enterococcus* counts, using all years and all surveys, grouped by sampling area and depth. Although there are no statistically significant differences among the groups, the samples collected sub-pycnocline at the outfall location, while extremely low, are somewhat higher than the other locations and depths. This is as expected because bottom water samples at those sites during stratification are likely to represent relatively low effluent dilution. Of 230 samples collected at the outfall area stations at the sub-pycnocline depth, 204 (89%) were non-detects for fecal coliform; of 228 samples for *Enterococcus*, 205 (90%) were non-detects.

5. Conclusions

This report presents data from over 3,000 samples collected and analyzed for both fecal coliform and *Enterococcus* from 1999, shortly before MWRA's Massachusetts Bay outfall went online in September 2000, through the end of 2014. Overall, the data show that the receiving water in the sampled areas consistently meets Massachusetts Class SA water quality standards. The vast majority of samples collected at the two stations closest to the outfall were non-detects: 93% for fecal coliform and 90% for *Enterococcus*. The geometric mean count for bacteria at the outfall sites over all sampled years is 0.2 organisms/100 ml for fecal coliform and the same for *Enterococcus.* Of 2,986 samples collected at all sites after the outfall went online, only three exceeded the single-sample maximum value (for designated bathing beaches) for *Enterococcus*.

Even for conditions expected to lead to higher counts—when dilution is minimized during the stratified period, for samples collected sub-pycnocline (near-bottom) at the outfall stations—80% of samples for fecal coliform and 90% of samples for *Enterococcus* were non-detects. Mean sub-pycnocline bacteria counts at the outfall stations were well below 3 organisms/100 ml for both indicators. Among sub-pycnocline samples from outfall stations, over all years of monitoring only one individual sample exceeded one water quality standard (the *Enterococcus* single-sample limit).

Analysis of data collected during adverse condition monitoring tells a similar story. There are only minor differences between data collected at the outfall location during less-frequent adverse surveys and during monthly conditional surveys. The highest count for fecal coliform collected at the outfall during adverse surveys was 50/100 ml; for *Enterococcus* the highest count was 30/100 ml, well within standards for bathing beaches.

Overall, the observations confirm that water quality standards are being met very consistently, and water quality is protected by the present level of treatment and disinfection at MWRA's Deer Island Treatment Plant. Furthermore, counts at coastal stations are generally at least as high as at nearfield stations, suggesting they may be influenced by nearshore sources of bacteria during heavy rainstorms at least as much as by the outfall. Together with the fact that there are only minor differences between data collected during less-frequent adverse surveys and during monthly conditional surveys, this lends support to the conclusion that the outfall does not substantially affect sewage indicator bacteria levels in Massachusetts Bay, even in the immediate vicinity of the discharge.

Table 7. Summary results of adverse surveys, all years.

Survey date	Indicator	Bacteria count (organisms/100 ml)					
		Outfall		Nearfield		Coastal	
		Mean	Max	Mean	Max	Mean	Max
26-Mar-01	FC	0	0	0	0	0.3	2
	ENT	0	0	0	0	0.3	1
3-Jul-01	FC	1	4	0	0	0.6	4
	ENT	0	0	0.3	1	0	0
12-Oct-01	FC	0	0	1	4	0	0
	ENT	0	0	0.3	1	0	0
13-Oct-01	FC	0	0	0.5	2	0.6	4
	ENT	0	0	0.5	1	0.8	3
18-Oct-02	FC	0	0	0	0	0.8	2
	ENT	0	0	0	0	0.8	2
19-Dec-03	FC	0	0	0	0	2	4
	ENT	7.5	10	0.3	1	1	1
17-Aug-04	FC	18.5	50	0.5	2	0	0
	ENT	0.8	3	0	0	0.2	1
30-Sep-04	FC	0	0	16	50	4.8	18
	ENT	0	0	1.5	5	2.6	10
13-Apr-05	FC	0	0	0	0	0.4	4
	ENT	0.3	1	0.4	2	0	0
2-Sep-05	FC	18	36	0	0	ND	ND
	ENT	0.5	1	0	0	ND	ND
18-Oct-05	FC	0.5	2	0.3	2	8.6	36
	ENT	0.3	1	0	0	0.4	2
16-May-06	FC	0	0	0.8	6	21.6	>50
	ENT	0	0	0.1	1	8.8	29
11-Mar-08	FC	0	0	0	0	0.1	1
	ENT	0	0	3.8	20	1	10
27-Feb-10	FC	ND	ND	ND	ND	2	2
	ENT	ND	ND	ND	ND	0	0
17-Mar-10	FC	23.5	47	13.3	53	8.6	32
	ENT	0	0	7.5	30	14.2	41
25-Mar-10	FC	0	0	0.5	2	0.4	2
	ENT	0	0	0	0	4	10
1-Apr-10	FC	0	0	0.3	1	3	12
	ENT	0	0	0	0	14.4	41
27-Aug-10	FC	0	0	0	0	0.1	1
	ENT	0	0	0	0	4	20
11-Dec-14	FC	10	20	0.3	1	15.6	48
	ENT	15	30	2.5	10	14.2	51

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

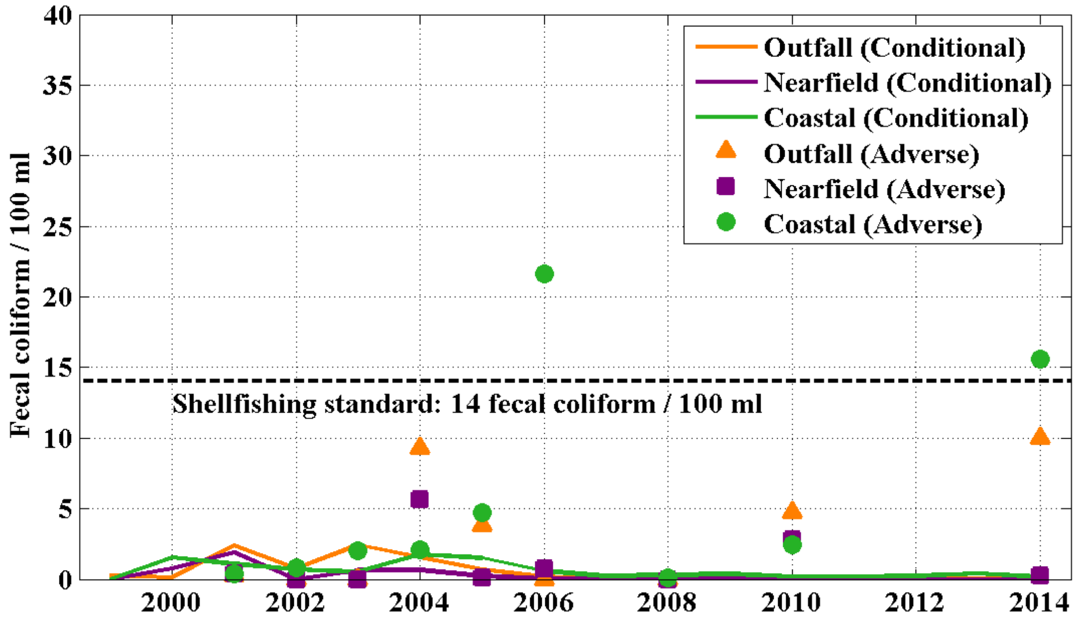

Figure 4. Mean fecal coliform counts, annual averages by station group, using conditional survey data (lines) or adverse survey data (symbols).

Some years (see Table 2) had no adverse surveys.

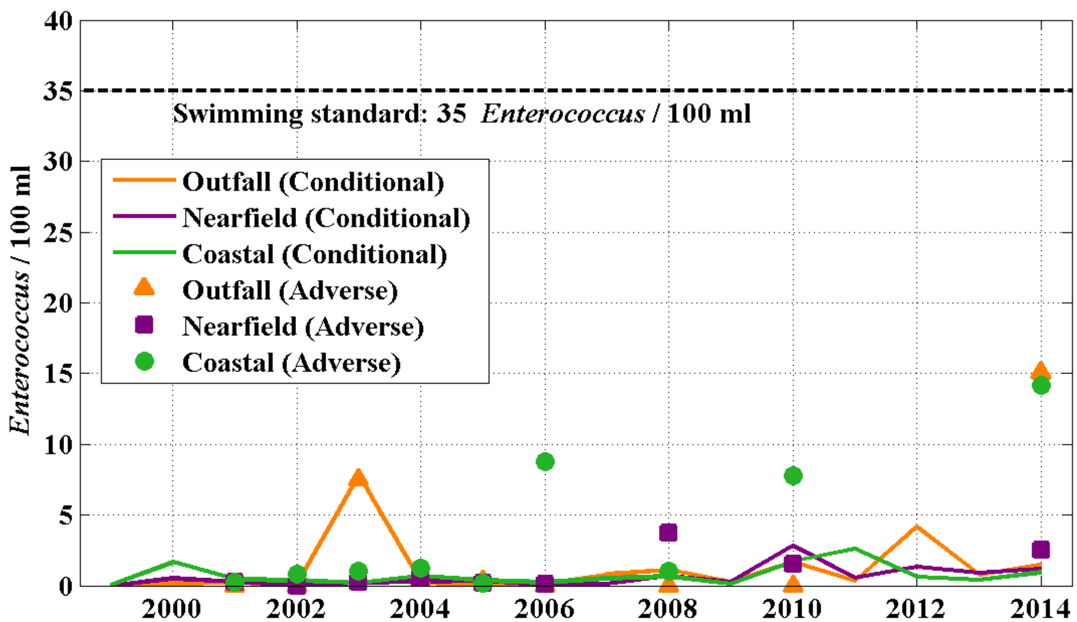

Figure 5. Mean *Enterococcus* counts, annual averages by station group, using conditional survey data (lines) or adverse survey data (symbols).

Some years (see Table 2) had no adverse surveys.

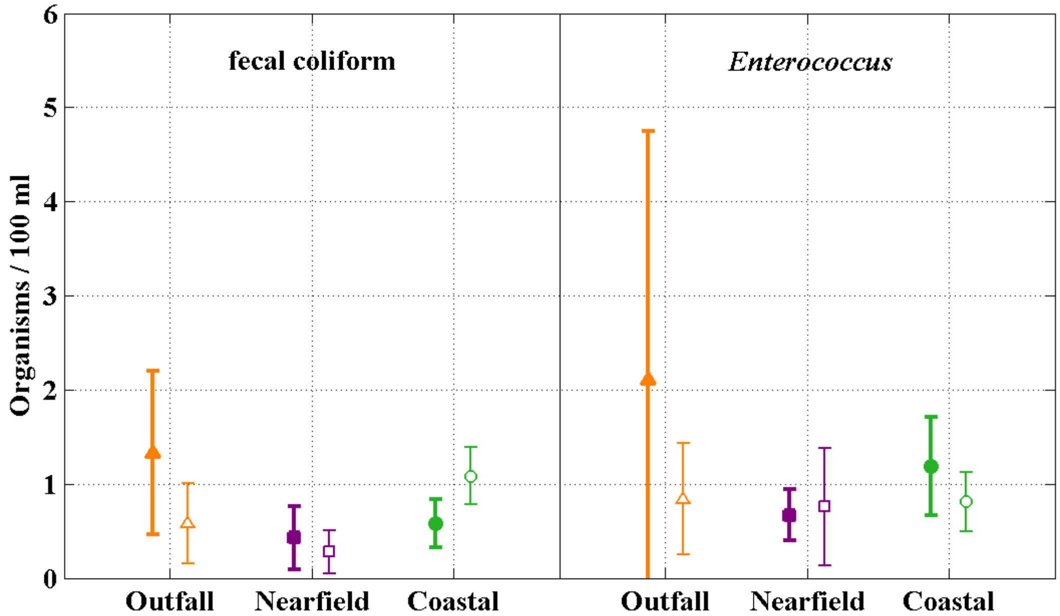

Figure 6. Average bacteria counts for samples collected sub-pycnocline (solid symbols and heavy lines, left in pairs) compared to samples collected at the surface (open symbols and light lines, right in pairs), by station group.

Error bars are 95% confidence intervals.

6. References cited

Hunt, CD, Mansfield, AD, Mickelson, MJ, Albro, CS, Geyer, WR, Roberts, PJW, 2010. Plume tracking and dilution of effluent from the Boston sewage outfall. Mar. Env. Res., 70(2), 150-161. DOI:10.1016/j.marenvres.2010.04.005

Libby PS, Fitzpatrick MR, Buhl RL, Lescarbeau GR, Leo WS, Borkman DG, Turner JT. 2014. Quality assurance project plan (QAPP) for water column monitoring 2014-2016: Tasks 4-7 and 10. Boston: Massachusetts Water Resources Authority. Report 2014-01. 67p. http://www.mwra.state.ma.us/harbor/enquad/pdf/2014-01.pdf

MWRA. 2013. *Enterococci* in Source Waters, Receiving Waters, and Wastewater by the Defined Substrate Method-Enterolert®. Department of Laboratory Services Standard Operating Procedure. DCN 1217.4.

MWRA. 2015a. Conditional Zone Classification Survey. Department of Laboratory Services Standard Operating Procedure. DCN4001.1.

MWRA. 2015b. Membrane Filter Method for Fecal coliforms and *Escherichia coli* in Water using mTEC medium. Department of Laboratory Services Standard Operating Procedure. DCN1130.3.

Rex, A. 2011. Ambient water quality monitoring of the Massachusetts Water Resources Authority effluent outfall: indicator bacteria in Massachusetts Bay 1999-2011. Boston: Massachusetts Water Resources Authority. Report 2011-20. 16 pages + Appendix. http://www.mwra.state.ma.us/harbor/enquad/pdf/2011-20.pdf

Attachment: Corrected Table 4 of Rex (2011)

Table 4. Descriptive statistics for fecal coliform and *Enterococcus*, comparing data from pre- and post-effluent diversion and among monitoring areas. Results for Outfall area are in bold.

Indicator	Period (pre or post diver-sion)	Area	Count	Number of Non-Detects	Non-Detects (%)	Number Fecal coliform >28 /100 ml or *Enterococcus* >104 /100 ml	Percent Fecal coliform >28 /100 ml or *Enterococcus* >104 /100 ml	Organisms/100 ml water			
								Arith-metic Mean	Geometric Mean	Min	Max
Fecal Coliform	All	All	2,371	2,071	87	19	0.8	0.8	0.2	0	>50
	Pre	**Outfall**	**12**	**11**	**92**	**0**	**0.0**	**0.2**	**0.1**	**0**	**2**
		Nearfield	12	11	92	0	0.0	0.2	0.1	0	2
		Coastal	29	27	93	0	0.0	0.3	0.1	0	6
	Post	**Outfall**	**458**	**418**	**91**	**7**	**1.5**	**1.1**	**0.2**	**0**	**>50**
		Nearfield	748	703	94	4	0.5	0.5	0.1	0	>50
		Coastal	1,112	901	81	8	0.7	1.0	0.3	0	>50
Entero-coccus	All	All	2,320	2,084	90	3	0.1	0.9	0.2	0	303
	Pre	**Outfall**	**8**	**8**	**100**	**0**	**0.0**	**0.0**	**0.0**	**0**	**0**
		Nearfield	10	9	90	0	0.0	0.1	0.1	0	1
		Coastal	22	17	77	0	0.0	0.5	0.3	0	4
	Post	**Outfall**	**458**	**414**	**90**	**1**	**0.2**	**1.1**	**0.2**	**0**	**303**
		Nearfield	744	694	93	1	0.1	0.6	0.1	0	185
		Coastal	1,078	942	87	1	0.1	1.0	0.2	0	109

Notes:

1. Corrections do not change any conclusions of Rex (2011).
2. Details of corrections are as follows:
   a. A small number of previously omitted data are incorporated, including the first datum of the three listed in the correct description of the data appearing at the end of the body text in section 4.1 of Rex (2011).
   b. Values in the column "Percent Fecal coliform >28 /100 ml or Enterococcus >104 /100ml" are a factor of 100 higher; though labeled as percentages, the values in Rex (2011) were fractions.
   c. The "Enterococcus, Pre-diversion, Nearfield" values for Arithmetic Mean and Geometric Mean are no longer transposed with each other.
3. Except for the fact that it includes data through mid-2011 instead of through the end of 2014, the corrected table here has identical structure to that in Section 4.1 above.

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
www.mwra.com