Ambient Monitoring Plan and Contingency Plan for the Massachusetts Bay Outfall:

Monitoring Questions Status and 2000-2018 Threshold Test Results

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Executive Summary

Since September 2000, the Deer Island Treatment Plant has been discharging treated wastewater through an outfall located 9.5 miles offshore in Massachusetts Bay. The Massachusetts Water Resources Authority (MWRA) runs the plant and, as required by its discharge permit, implements the Ambient Monitoring Plan, which is an extensive program to help protect conditions surrounding the outfall including the water, sediments, and marine life. Included in the permit is a Contingency Plan, under which MWRA is required to report results of additional testing against thresholds intended to detect possible degradation of the marine environment.

MWRA developed its monitoring plan in the early 1990s, working with federal and state regulators, regional scientists, and citizens' groups. The plan is structured around a set of specific, testable monitoring questions addressing various aspects of the bay ecosystem. MWRA released the first "Outfall Monitoring Plan" in 1991, and has revised it multiple times, both before and after 2000 when regulators incorporated it into the discharge permit as the Ambient Monitoring Plan. The Outfall Monitoring Science Advisory Panel, established by the permit, assists regulators with evaluating results and developing revisions to the monitoring questions and activities.

The most recent plan revision (2009-2010) included comprehensive evaluations of the 33 monitoring questions and concluded that all questions had been answered. The monitoring that addressed 10 of the questions was deemed no longer necessary, and was ended by MWRA with the approval of regulators and the advisory panel. Other monitoring activities continue, to maintain permit compliance and fulfill Contingency Plan requirements.

This report summarizes the 2011-2018 Ambient Monitoring Plan results, provides answers to the remaining 23 active monitoring questions, and presents a summary of Contingency Plan threshold test results from 2000-2018 with details of the most recent 2017-2018 tests. Background on the history of outfall monitoring is given, with key supporting documents cited.

The results of 2011-2018 monitoring support and strengthen the conclusions drawn in 2010, that all monitoring questions have been answered and the outfall discharge does not have adverse ecosystem effects. Contingency Plan threshold tests to date demonstrate that exceedances have been uncommon and limited in severity. Required investigations of every exceedance have determined no environmental degradation was associated with the outfall discharge.

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Background

This section provides overall historical background and context for the current Ambient Monitoring Plan (AMP; MWRA, 2010) and the Contingency Plan (CP; MWRA, 2001). The emphasis is on the monitoring questions addressed by the AMP, and the CP threshold tests.

1990-1991: Ambient Monitoring Plan development. The plan was initially developed by MWRA, working with the Outfall Monitoring Task Force. The task force was an advisory group established by the Massachusetts Executive Office of Environmental Affairs and the US Environmental Protection Agency (EPA). It was made up of scientists and regulators from state and federal agencies, regional academic scientists, and representatives of non-governmental organizations representing stakeholders and the public. Developers of the monitoring plan followed guidelines on monitoring programs from the National Research Council (NRC, 1990). The monitoring was motivated by public, scientific, and regulatory concerns about bay conditions in the 1980s and early 1990s during planning of the outfall installation, expressed as four general questions:

> Is it safe to eat fish and shellfish?
> Are natural/living resources protected?
> Is it safe to swim?
> Are aesthetics being maintained?

Both state and federal regulators required monitoring of conditions in Massachusetts Bay before the outfall began discharging as a condition of their approval of the outfall siting and construction. For example, an EPA Supplemental Environmental Impact Statement (USEPA, 1988) required monitoring, for assessing potential impact of the discharge beyond what was identified in the impact statement as acceptable, and for collecting data useful for outfall management considerations. MWRA's baseline monitoring was later incorporated into the court order under which MWRA's Boston Harbor Project was overseen.

1991-2011: Monitoring questions. To address its objectives, the monitoring consists of studies designed to answer specific questions about various aspects of the bay ecosystem. From the four general concerns listed above, the task force constructed an initial set of 40 monitoring questions (MWRA, 1991). Later versions of the monitoring plan (e.g. MWRA, 1997) revised and consolidated them into to 33 questions, grouped under four topics: **effluent** (treated wastewater sent to the outfall from the Deer Island Treatment Plant), **water column** (marine water quality in the bay at all depths between the sea surface and the seafloor), **benthic** (life on and within the seafloor), and **fish and shellfish**.

Outfall discharge is regulated through a permit issued in 2000 by the EPA and the Massachusetts Department of Environmental Protection (MADEP) under the National Pollutant Discharge Elimination System. Regulators incorporated the Ambient Monitoring Plan into the permit as an attachment. To help provide regulators with quality advice, the permit established the outfall Monitoring Science Advisory Panel (OMSAP). The panel is made up of regional academic researchers familiar with the technical issues the monitoring addresses, and has taken the role of the now-inactive Outfall Monitoring Task Force. The permit also established two advisory committees to OMSAP, the Public Interest Advisory Committee and the Inter-Agency Advisory Committee.

During the process of developing AMP Revision 1 in 2002-2003 (MWRA 2004) and AMP Revision 2 in 2009-2010 (MWRA 2010), evaluations of monitoring findings led to the determination that 10 of the 33 questions had been fully addressed and relevant monitoring could end. These evaluations were incorporated into the current Ambient Monitoring Plan (AMP Revision 2; MWRA, 2010), which has been endorsed by the OMSAP and approved by EPA and MADEP.

1992-2000: Baseline monitoring conducted before the outfall came online. Under Phase I ("Baseline"; MWRA, 1991), baseline conditions prior to outfall operation were monitored for almost 9 years, from February 1992 through August 2000. Monitoring was overseen by the Outfall Monitoring Task Force, and has provided a valuable characterization of conditions against which new monitoring results are compared.

1995-present: The Contingency Plan. The CP (MWRA 2001) is a companion document to the Monitoring Plan. MWRA developed the CP as a result of an Endangered Species Act consultation between EPA and the National Marine Fisheries Service over the construction and permitting of the bay outfall. Recommendations in the resulting Biological Opinion (NMFS, 1993) included development of a contingency plan. MWRA entered into a memorandum of agreement with EPA and Marine Fisheries under which MWRA agreed to develop such a plan. The Plan was developed by MWRA, reviewed by the Outfall Monitoring Task Force and regulators, and later attached to the permit.

The Contingency Plan specifies numerical thresholds which can suggest that effluent quality or environmental conditions near the outfall may be changing, or might be likely to change in the future. In the event that one of these thresholds is exceeded, the CP sets into motion a process to confirm the exceedance and to determine its causes and potential importance. If the exceedance is attributable to the outfall and determined to represent environmental degradation, MWRA must respond with appropriate action.

2000-Present: Discharge (or "post-diversion") monitoring. Phase II (MWRA, 1997) monitoring, under the permit-attached AMP, started in September 2000 when the discharge to the bay became operational and all effluent was diverted outside the harbor.

The objectives of the post-diversion AMP are:

> Objective 1: Test for compliance with permit requirements.
> Objective 2: Test whether the impact of the discharge on the environment is within the bounds projected by the Supplemental Environmental Impact Statement.
> Objective 3: Test whether change within the system exceeds the Contingency Plan thresholds.

(There is some overlap of Objective 3 with the other objectives.)

2004: The Ambient Monitoring Plan was revised to focus on long-term impacts. MWRA proposed the first revisions to discharge monitoring (AMP Revision 1; MWRA, 2004) based on evaluations during 2002-2003 led by the Science Advisory Panel. The evaluations followed the National Resource Council guidelines and determined that the acute or short-term environmental changes (for example, rapid changes in contaminant concentrations in the environment) earlier thought possible were no longer a concern.

2011-Present: The Ambient Monitoring Plan was revised to refocus monitoring on conditions near the outfall. The current monitoring plan (AMP Revision 2; MWRA, 2010) took effect beginning in 2011. It was developed during 2009-2010 under an evaluation and revision process similar to that followed in

2002-2003. Some of the changes ended special studies (for example, on the metabolism of nutrients and oxygen by sediments, and on the rates of algal growth) that had fully answered the monitoring questions they were designed to address.

Answers to monitoring questions

This section lists the 23 currently active monitoring questions and for each provides an answer based on conclusions both from prior evaluations and results of monitoring completed since 2011.

The most recent prior evaluation was during 2009-2010 (MWRA 2010). It concluded that all questions had been addressed well and outfall discharge was not adversely affecting the Massachusetts Bay ecosystem.

For convenience, in this document the monitoring questions are numbered #1 to #33, following the order they appear in current Ambient Monitoring Plan (MWRA, 2010), where they were not numbered. Questions #1 to #5 are on effluent, questions #6 to #20 are on the water column, questions #21 to #28 are on benthic conditions, and questions #29 to #33 are on fish and shellfish.

The 10 previously answered questions (#6-11, #18, #21, and #28-29) are listed in Appendix A. For explanations of the monitoring results that led to the conclusion that those questions have been fully addressed, see AMP Revision 1 (MWRA, 2004) and AMP Revision 2 (MWRA, 2010).

Relevant excerpts from AMP Revision 2 (MWRA, 2010) are incorporated, in *italics*, throughout the following. References cited within these excerpts are provided in the References Cited section below.

Some questions mention “contaminants”. This is a reference to contaminants of concern as identified by the Outfall Monitoring Task Force during monitoring plan development. They are mostly derived from contaminants studied in the early 1990s by the federal National Status and Trends program, and include trace metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and a list of chlorinated pesticides, for example DDT, its breakdown products, and dieldrin.

Some questions refer to “nearfield” and/or “farfield”. For the water column monitoring, the “nearfield” is a 10 km by 12 km (6 mile by 7.5 mile) area centered on the outfall. Areas more distant from the outfall than the nearfield are referred to as the “farfield”. For sediment monitoring, early modeling of the deposition of effluent solids indicated impacts might be more prominent on the inshore side of the outfall, so all sediments stations in western Massachusetts Bay are evaluated as nearfield stations.

Effluent monitoring questions

The effluent monitoring questions (#1 to #5) are addressed together.

<u>Question #1:</u> Do effluent pathogens exceed permit limits?

<u>Question #2:</u> Does acute or chronic toxicity of effluent exceed permit limits?

<u>Question #3:</u> Do effluent contaminant concentrations exceed permit limits?

<u>Question #4:</u> Do conventional pollutants in the effluent exceed permit limits?

<u>Question #5:</u> What are the concentrations of contaminants in the influent and effluent and their associated variability?

__Answers:__ **Treated wastewater (effluent) from the Deer Island Wastewater Treatment Plant has met all permit limits well over 99% of the time since September 2000 when discharge to the bay began, and continuously since 2006. Contaminant concentrations are consistently low, especially in effluent but also in influent (wastewater entering the plant, before treatment), and their variability is well understood.**

The treatment plant has operated extremely well since it was completed. Through December 2018 the plant qualified for the National Association of Clean Water Agencies Platinum 12 Peak Performance Award, which recognizes facilities with 100% compliance with effluent permit limits over twelve consecutive years.

Additionally, contaminant removal at the plant is greater than was projected when it was designed. Total discharges of both metals and organic compounds remain well below predictions made during the planning and permitting process for the Massachusetts Bay outfall. For example, the discharges in 2017 of mercury, PCBs, and a DDT breakdown product were all about 1% as high as were projected in the SEIS (Werme et al., 2018). Findings from 2011-2018 monitoring are all consistent with the evaluations in MWRA (2010).

Monitoring results demonstrate that ongoing toxics reduction efforts and the high level of wastewater treatment provided at the plant are the best lines of defense for ensuring that its treated effluent discharge does not unduly impact the Massachusetts Bays ecosystem.

Water column monitoring questions

Questions on the water column (marine water quality at all depths from the sea surface down to the seafloor) addressed in current monitoring are grouped under three topics: transport and fate, water chemistry (nutrients and dissolved oxygen), and biology (chlorophyll and plankton).

Transport and fate

__Question #12__: **What are the nearfield and farfield water circulation patterns?**

__Answer:__ **Nearfield and farfield circulation patterns are similar and are strongly impacted by weather and tides, and also influenced by weak background flow originating from outside Massachusetts Bay. Weather-driven and tidal currents effectively dilute and disperse effluent in the bay.** Long-term movement of diluted effluent in the farfield is mainly due to the background flow which enters the bay in the north from the Gulf of Maine offshore, passes southward through the bay, then returns offshore in the south.

The physical oceanography of Mass Bay and Cape Cod Bay is reasonably well understood, including the general characteristics of the water circulation. Nearfield and farfield circulation patterns are similar and mainly consist of persistent, relatively weak background flow determined by conditions offshore; stronger, shorter-lived currents due to weather; and tidal motions. Weather-driven currents change direction randomly, and tidal flows are rotary. Dilution and dispersal of effluent in the nearfield is effective (e.g., Hunt et al. 2002) and mostly due to weather-driven currents and tidal currents. Long-term movement of diluted effluent is mostly controlled by the background flow originating in the Gulf of Maine. MWRA further summarized the main features of regional ocean circulation on p21-22 of AMP Revision 2 (MWRA, 2010):

"Understanding of the physical oceanographic conditions in the bays has been detailed in Libby et al. 2009, and earlier water column reports (e.g. Libby et al. 2003, 2004, 2006a, 2006b, 2007), and in numerous peer-reviewed papers in the scientific primary literature (e.g. Butman 1975, Geyer et al. 1992, Signell et al. 1996, Anderson et al. 2005).

On a regional scale, circulation in the bays is often affected by the larger pattern of water flow in the Gulf of Maine. The western Maine coastal current usually flows southwestward along the coast of Maine and New Hampshire and depending on prevailing oceanographic and meteorological conditions may enter Massachusetts Bay south of Cape Ann (Geyer et al. 1992). Optimal conditions for inflow usually occur during the spring when winds out of the northeast bring significant freshwater inflow from the gulf into the bays and transport generally follows a counterclockwise path along the coast to Cape Cod Bay. Inflow from the gulf is the major source of nutrients to the bay. The inflow also helps to flush the bay, and gives the bay its water quality characteristics including dissolved oxygen levels and plankton communities (including nuisance blooms such as Alexandrium). During the summer, winds are generally from the south; this impedes surface water inflow from the gulf, but causes upwelling along the coast and entry of deep waters from the gulf into the bay."

There is substantial inter-annual variability in the circulation patterns and current speeds, which strongly influences many of the conditions that AMP monitoring activities address. However, the nature and general bounds of this variability is fairly well understood. This knowledge is based on limited direct observations of currents, together with many years of observations of temperature and salinity patterns that are closely tied to circulation processes. It is also based on numerical simulations that compare favorably to the available current observations. An example is the hydrodynamic model that serves as the basis of the experimental Gulf of Maine *Alexandrium catanella* nowcast/forecast simulation (see https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/hab-monitoring-system/gulf-of-maine-alexandrium-catenella-predictive-models/experimental-nowcast-forecast-simulation/ and references cited therein (e.g. He et al., 2008). Another example is the Bays Eutrophication Model (e.g., Zhao et al., 2017).

<u>**Question #13**</u>: **What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?**

<u>**Answer:**</u> **The farfield fate of dissolved, conservative, or long-lived effluent constituents begins with dilution to low concentrations within the bay. Bay waters then exchange with offshore waters and ultimately are replaced, on a timescale of months to years, by the movement of water into and through the bay as part of the long-term background circulation pattern described above.**

As summarized in AMP Revision 2 (MWRA, 2010):

"The combination of the general circulation within Massachusetts Bay and local conditions and mixing determine the fate and transport of effluent discharged from the outfall. Vertical rise of the effluent plume from the sea-floor diffuser is stopped at mid-depth by the density gradients that prevail from April through October. Tides and wind-driven flow displace the plume horizontally 5-10 km in a day over a contorted path. Although there is no prevailing net direction at the outfall site (Butman et al. 1992), this motion helps mix the plume with surrounding water

such that effluent contaminants are diluted to background levels within 20 km of the outfall (Hunt, Mansfield et al. 2002, Libby 2003[1]).

The substantial and seasonal influence of the Gulf of Maine has been observed on circulation, nutrient loading, DO, and nuisance algal species in the bays."

Water chemistry (nutrients and dissolved oxygen)

<u>Question #14</u>: Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are they correlated with changes in the nearfield?

<u>Answer:</u> Nutrient concentrations (especially ammonium) increased in the immediate vicinity of MWRA's outfall (the nearfield) after discharge began. These changes are strongest within about 5 km (3 miles) of the outfall and have not been detected more than 10-20 km (6 – 12 miles) from the outfall, in the farfield.

Recent results (e.g., Taylor 2018, Werme et al., 2018, and Libby et al. 2018) support the evaluation summarized in AMP Revision 2 (MWRA, 2010):

> *"The observed changes in the nutrient regime following diversion are unambiguous: ammonium (NH4) has dramatically decreased in Boston Harbor and nearby coastal waters while increasing moderately in the nearfield. The signature levels of NH4 in the plume are generally confined to an area within 10-20 km of the outfall. The change in NH4 concentrations observed is consistent with model simulations which predicted that the transfer of effluent from Boston Harbor to Massachusetts Bay would greatly reduce nutrients in the harbor and increase them locally in the nearfield (Signell et al. 1996). This change was predicted to have little impact on concentrations in the rest of Massachusetts and Cape Cod Bays.*
>
> *The spatial patterns in NH4 concentrations in the harbor, nearfield and bays since the diversion in September 2000 have consistently confirmed this (Taylor 2006; Libby et al. 2003, 2004, 2006a, 2006b, 2007, 2009)."*

<u>Question #15</u>: Do the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall and at selected farfield stations meet the State Water Quality Standard?

<u>Answer:</u> Yes. Dissolved oxygen levels undergo natural variations but they have consistently met state water quality standards.

While occasional values below numeric water quality standards are observed, recent results, for example, Werme et al. (2018) and Libby et al. (2018), support the evaluation summarized in AMP Revision 2 (MWRA 2010):

> *"The state standard allows for natural variability, and oxygen levels in bottom waters of the nearfield and Stellwagen Basin have not yet fallen below natural background values (Libby et al. 2009, Werme et al. 2008)."*

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[1] The correct citation is Libby et al., 2003.

Question #16: Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Answer: Oxygen concentrations and percent saturation have not changed from baseline conditions.

Recent results, for example, Werme et al. (2018) and Libby et al. (2018), support the evaluation summarized in AMP Revision 2 (MWRA 2010):

> *"There have been limited or no changes noted between baseline and post-diversion DO levels or patterns as documented in Libby et al. (2004, 2006a, 2006b, 2007, 2009). Furthermore, modeling and statistical analyses indicate that bottom water DO levels in Massachusetts Bay are highly correlated with conditions along the bay/Gulf of Maine boundary and that regional processes and advection are the primary factors governing bottom water DO concentrations in the bay (HydroQual 2001, Geyer et al. 2002, Jiang et al. 2007)."*

Biology (chlorophyll and plankton)

Question #17: Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Answer: Monitoring results have uncovered no evidence to link MWRA's discharge with changes in phytoplankton biomass in the nearfield or the farfield.

Recent results, for example, Werme et al. (2018) and Libby et al. (2018), support the evaluations summarized in AMP Revision 2 (MWRA 2010):

> *"The data are summarized in the most recent water column annual report, Libby et al. (2009). The higher nearfield NH_4 concentrations since the outfall went on-line have not translated directly into changes in biomass, whether measured as chlorophyll, POC, or phytoplankton abundance, although there has been a significant increase in winter/spring biomass in the nearfield and most of Massachusetts Bay due to larger scale regional trends in phytoplankton bloom dynamics. In Boston Harbor, the dramatic decrease in NH_4 has been concomitant with significant decreases in other nutrients (Taylor 2006). However, throughout most areas of the bays significant changes in levels and temporal patterns have also occurred for other parameters. Many of these changes were noted on both a station-by-station and grouped-station basis. There were some regional patterns evident in the nutrient data such as the increase in NO_3 concentrations in the winter/spring and fall.*
>
> *Before-After, Control-Impact statistical analyses examined if the changes that have been observed within the nearfield and throughout the bays are significantly different from one another. The only differences were seen for NH_4 concentrations, which were higher in the inner nearfield compared to the outer nearfield, Massachusetts Bay offshore, and Cape Cod Bay during all three seasons ($P<0.002$). None of the other tested changes were significant. This indicates that even though there has been an increase in NH_4 at these stations close to the bay outfall, there have not been any significant changes in chlorophyll or particulate organic carbon (POC) in*

> *this "impacted" area compared to "control" regions of the bays that are 5 to >50 km distant. There certainly have been significant changes in these parameters post-diversion, but they have changed in both impact and control areas and thus appear to be associated with regional processes."*

<u>Question #19</u>: Has the abundance of nuisance or noxious phytoplankton species changed in the vicinity of the outfall?

<u>Answer:</u> Evaluations of monitoring results indicate that nuisance or toxic species observed in Massachusetts Bay result from region-wide blooms transported into the bay from offshore and are not related to outfall discharge.

Recent results and evaluations, for example, Borkman et al. (2016), Werme et al. (2018) and Libby et al. (2018), support the evaluations summarized in AMP Revision 2 (MWRA 2010):

> *"Major red tides occurred in 2005 and 2006 off the Maine coast and in Massachusetts Bay.* Alexandrium *abundance had been low (0-100 cells l-1) from 1992-2004 and was low again in Massachusetts Bay in 2007 even though there was a large bloom observed offshore in the Gulf of Maine. There are no indications of a regional outfall effect on the 2005 and 2006* A. fundyense *blooms; a modeling analysis estimated that if a local outfall effect had occurred, it would have been minor (Anderson et al. 2007). A red tide originating off the coast of Maine entered Massachusetts Bay in 2008, causing shellfish bed closures including in Boston Harbor. This red tide event was briefer and over a smaller geographic area than the previous blooms in 2005 and 2006.*
>
> *The occurrence of large April* Phaeocystis *blooms since 2000 in Massachusetts Bay appears to be influenced by copepod abundance and salinity in February and March. The lower the copepod abundance and the higher the salinity, the more likely there will be a large* Phaeocystis *bloom. These results are consistent with long-term trend analyses, which show post-2000 declining copepod abundance simultaneous with increasing* Phaeocystis *abundance. The duration of these* Phaeocystis *blooms is closely related to surface water temperature.* Phaeocystis pouchetii *is a cold water species that has a physiological upper temperature tolerance of 14°C. A significant linear relationship was found between the day 14°C is reached and* Phaeocystis *bloom duration, which explains 70% of the variance in Massachusetts Bay* Phaeocystis *bloom duration during 2000-2007."*

Domoic acid and the potential for Amnesic Shellfish Poisoning associated with diatoms in the genus *Pseudo-nitzschia* have been of increasing regional concern in recent years. While *Pseudo-nitzschia* spp. diatoms have been present in MWRA's monitoring since 1992, it is important to note that the associated Contingency Plan thresholds have never been exceeded, and in fact, *Pseudo-nitzschia* abundances since outfall start-up have generally been lower than was measured during baseline monitoring between 1992 and September 2000.

<u>Question #20.</u> Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

__Answer__: **No changes in phytoplankton and zooplankton have been associated with the outfall discharge or the nutrients in it.**

While phytoplankton and zooplankton dynamics in Massachusetts and Cape Cod Bays are complex, the outfall-related components of these questions have been adequately answered. Recent results and evaluations, for example, Borkman et al. (2016), Werme et al. (2018) and Libby et al. (2018), support the evaluations summarized in AMP Revision 2 (MWRA 2010):

> ***"Phytoplankton communities:*** *Analyses of long-term phytoplankton trends indicate that there have been shifts within the phytoplankton community assemblage since 2000. Diatoms (with the exception of* Dactyliosolen fragilissimus*) and dinoflagellates have generally declined, while microflagellates and* Phaeocystis *have had relative increases. There is no outfall-related direct link or causality associated with these shifts as many of the changes are occurring over larger spatial scales and, as with the changes in* Phaeocystis *(regional blooms) or* Ceratium *(related to stratification), appear to be related to more regional ecosystem dynamics in the Gulf of Maine.*
>
> ***Zooplankton communities:*** *Long-term trend analyses and pre-/post-diversion comparisons indicate a general decline in zooplankton abundance (with the exception of* Calanus finmarchicus*) from 2001 to 2006 before increasing again in 2007. The timing of this decline coincides with the diversion of the outfall, but there are no plausible linkages between the diversion and apparent decline, which is region-wide. The changes in zooplankton abundance could also be related to a variety of factors from top-down controls due to grazing by ctenophores or other predators, to bottom-up control via* Phaeocystis *blooms in the spring (poor food source) or lack of substantial fall phytoplankton blooms (reduced food source), to physical hemispheric climatic processes for example the North Atlantic Oscillation, or freshening of the Northwest Atlantic due to Arctic melting. Alternatively, different oceanographic regimes (i.e., variable influence of nearshore vs. offshore water masses) having different fauna (*Calanus*-dominated vs.* Oithona*-dominated) may be operative in and co-varying with* Phaeocystis *vs. non-*Phaeocystis *bloom years.*
>
> *A special study using sensitive nitrogen isotope tracers to follow the uptake of nitrogen from sewage in zooplankton, sponsored by the Provincetown Center for Coastal Studies (PCCS) (Moore, CR[2] et al. 2005, based on Montoya et al. 2003) showed that*
>
> > *'after one year there was no appreciable change to the sources of nitrogen to the food web. That is, when archived (pre-outfall) zooplankton were compared with post outfall zooplankton, ^{15}N values were not significantly different at the depths sampled. The PCCS-sponsored study concluded that zooplankton in Massachusetts Bay continues to reflect the isotopic composition of marine sources of nitrogen. In general, summer sampling results within Cape Cod Bay are correlated with the MWRA results, showing an incremental return to expected ^{15}N ratios within 20-40 km, just entering Cape Cod Bay. In cooler winter months however, migration of sewage-N as far as 80 km was reported by*

[2] This report was omitted from the references list in MWRA (2010). The correct citation is: Moore G, Mayo C, Collier J, Bessinger M, Montoya J. 2005. Effects of Boston Outfall on the Marine Community of Cape Cod Bay. Provincetown Center for Coastal Studies. March 7, 2005. http://coastalstudies.org/cms/wp-content/uploads/2013/12/CCBFinalCCC.pdf

the PCCS-Georgia Tech study, presumably when uptake by phytoplankton is significantly reduced.' "

The "PCCS-Georgia Tech study" referenced is Moore et al. (2005).

Benthic monitoring questions

The benthic (life on and within the sea floor) questions are grouped under three topics: sediment contamination and tracers, sediment oxygenation and infaunal communities, and hard bottom.

Sediment contamination and tracers

Question #22: **Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?**

Answer: The only signature of sewage contamination detected in sediments is increased counts of spores of an indicator bacterium (*Clostridium perfringens*) in surficial sediments in the immediate vicinity (within 2 km) of the outfall.

Changed levels of this indicator bacteria are not detected elsewhere in Massachusetts Bay or Cape Cod Bay (e.g., Nestler et al., 2018).

Question #23: **Have the concentrations of contaminants in sediments changed?**

Answer: Yes. Concentrations of monitored contaminants in Massachusetts Bay sediments have generally decreased.

Recent results in Nestler et al. (2018) and Werme et al. (2018) document that there has been no increase in contaminant concentrations in sediments near the discharge, in fact, targeted contaminants in Massachusetts Bay sediments have decreased.

For 22 of the 26 sediment contaminants for which Contingency Plan thresholds have been established, average 2017 concentrations were even lower than the lowest measurements before the outfall came online, between 1992 and September 2000. Mean concentrations in nearfield sediments of the remaining 4 contaminants with CP thresholds were lower in 2017 than most (but not all) years between 1992 and 2000.

Sediment oxygenation and infaunal communities

Question #24: **Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?**

Answer: No. The thickness of the sediment oxic layer has increased.

Recent results from Nestler et al. (2018) and Werme et al. (2018) document that sediments in the vicinity of MWRA's outfall in western Massachusetts Bay have in fact become more oxic, that is, the thickness of the sediment oxic layer has increased compared to results obtained during the pre-diversion baseline period 1992 through 2000. This is exactly the opposite of what would be expected if effluent solids or the discharge of organic matter were adversely impacting the sediments.

The following two questions are addressed together:

Question #25: Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?

Question #26: Has the soft-bottom community changed?

Answer: While monitoring results indicate some changes in the soft-bottom community have occurred, analysis shows that outfall discharge is not degrading their habitat.

Recent results of Nestler et al. (2018) and Werme et al. (2018) support evaluations contained in AMP Revision 2 (MWRA 2010):

> *"Soft-bottom sediments in the nearfield support typical New England coastal infaunal assemblages. Stations with fine sediments have communities dominated by polychaete worms, while sandier stations have distinct assemblages dominated both by polychaetes and by amphipods. Communities in the nearfield through baseline were characteristic of New England shallow subtidal sediments subjected to natural disturbance (Hilbig and Blake 2000), for example sporadic sediment resuspension and transport.*
>
> *Infaunal benthic communities found at farfield stations share many species with those found in the nearfield, but also support a wider variety of species characteristic of New England coastal habitats. Multivariate analyses of the infaunal species abundance data consistently show the importance of grain size and regional (or depth) differences between samples as important structuring factors for community composition, a pattern that has not changed during discharge monitoring."*

Examples of the multivariate analyses referenced are given in Figures 4-5 and 4-6 of MWRA (2010).

From 2010 through 2014, two of the four nearfield infaunal diversity indices for which CP thresholds exist were higher than the upper threshold ranges. These threshold exceedances were evaluated extensively. Results of these evaluations indicated the high diversities represented natural fluctuations in regional infaunal communities that were not observed during baseline monitoring. All evidence indicated that the high diversity exceedances were regional in nature and were not substantially influenced by outfall discharge. High diversity is generally considered an indication of healthy sediments. Following OMSAP's review and concurrence, in 2017 regulators approved MWRA's proposal to delete the high range infaunal diversity thresholds.

Hard bottom

Question #27: Has the hard-bottom community changed?

Answer: Monitoring results have not documented major impacts attributable to the outfall discharge. In fact, two outfall risers (the dome like sea-floor structures through which effluent is discharged) support very similar communities of sea anemones, sea stars, and other organisms as they did before the discharge started in September 2000.

Recent results from Nestler et al. (2018) and Werme et al. (2018) support evaluations contained in AMP Revision 2 (MWRA 2010):

> *"The hard-bottom benthic communities near the outfall remained relatively stable over the baseline period, and have not changed substantially with activation of the outfall in fall 2000.*

Major departures from baseline conditions have not occurred during the post-diversion years, however some modest changes have been observed, including decreases in the number of upright algae at some stations and increases in drape and decreases in percent cover of coralline algae at some stations, mainly drumlin top stations north of the outfall (Maciolek et al. 2008, 2009).

It is unlikely that the decrease in upright algae was attributable to diversion of the outfall, since abundances of upright algae were quite variable throughout the baseline period, reflecting both temporal and spatial heterogeneity. A general decline in the number of algae had started in the late 1990's and now appears to be reversing at a number of stations. The decline has been most pronounced at the northern reference stations and may, in part, reflect physical disturbance of the seafloor from an increase in anchoring activity of LNG tankers at these locations after 2001. Disturbance of the seafloor in the form of overturned boulders and areas of shell lag has been noted at stations T7-1 and T7-2 in the last several years."

Fish and shellfish monitoring questions

Following the answers, the discussion for these three questions is addressed together:

Question #30: **Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?**

Answer: No, with the exception that concentrations of contaminants in mussels show modest increases immediately adjacent to the outfall (within 100 m).

Question #31: **Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?**

Answer: No. The increases in mussels just noted are not to levels that represent a threat to mussels or to people.

Question #32: **Are the contaminant levels in fish and shellfish different between the outfall site, Boston Harbor, and a reference site?**

Answer: The patterns observed during the 1990s remain: generally highest contaminant concentrations in fish and shellfish caught in Boston Harbor, lower concentrations near the outfall, and lowest concentrations in Cape Cod bay. Contaminant concentrations in flounder and lobster caught near the outfall have generally decreased since 2000. The bioaccumulation of contaminants in mussels deployed at the edge of the outfall's zone of initial dilution has decreased since 2006.

Tissue contaminant monitoring is conducted each three years. No Contingency Plan thresholds were exceeded in any tissue during the 2018 monitoring of winter flounder, lobster, and mussel tissues. Results from the 2018 monitoring are still undergoing data analysis and evaluation as of this writing (Sept 2019), but results of the sampling and analyses in 2015 (Nestler et al., 2016) support evaluations contained in AMP Revision 2 (MWRA 2010):

***"Flounder contaminants**. Analyses of the monitoring data for flounder found that the spatial distribution of the levels of contaminants in flounder fillet and liver is consistent with regional distributions of sediment contamination; levels are higher in Boston Harbor than offshore in Massachusetts Bay and Cape Cod Bay (Hunt et al. 2006; Nestler et al. 2007). Mercury levels in* *edible tissue were found to be higher than expected in 2003, although still lower than contingency plan thresholds (Nestler et al. 2007). Total PCBs were also found to be higher in the post-discharge period, possibly as a result of the wetter/snowier weather during 2000-2002, which may have resulted in increased flux of contamination in precipitation and runoff (Hunt et al. 2006). Reports also found that levels of metals in liver are often highest at the outfall site, but tend to be more variable than levels of organic contaminants, show no clear temporal trend, and are comparable during the pre- and post-discharge period (Nestler et al. 2007).*

Before-After, Control-Impact statistical analyses were carried out on flounder tissue contaminant data (Kane-Driscoll et al. 2008). No increases in concentrations of contaminants in flounders at the Outfall Site as a result of the relocation of the outfall were found. Concentrations of all contaminants in flounder were below US Food and Drug Administration (FDA) action limits and MWRA thresholds. Concentrations of all contaminants, except PCBs, were below EPA screening-level Risk-based concentrations (RBCs). Concentrations of PCBs at all locations exceeded the EPA screening-level RBC, and 2006 concentrations of PCBs in flounder liver and fillet from the Outfall Site were significantly higher than concentrations at Cape Cod Bay.

***Lobster results**. The highest levels of organic contaminants tended to be found in lobsters collected from Deer Island Flats in Boston Harbor and the lowest levels were typically found at East Cape Cod Bay (Nestler et al. 2007). In general, contaminant concentrations in lobster meat in 2006 were comparable to, or at the lower end of, the historical range across all stations. Concentrations in hepatopancreas of several organic compounds increased in 2006 in comparison to 2003. For example, the concentrations of 4,4'-DDE at all locations were dramatically higher in 2006 than in previous years, matching historical highs at Deer Island Flats and East Cape Cod Bay. Increases were also observed in chlordane and selected PAHs at some locations. Levels of PCB congeners 138 and 153 were generally comparable to historical levels. Concentrations of metals in 2006 were also generally within historical ranges. A few metals, however, were at the upper end of the historical range, including nickel at Deer Island Flats and zinc at the outfall site (Nestler et al. 2007).*

Before-After, Control-Impact statistical analyses were carried out on lobster tissue data (Kane-Driscoll et al. 2008). No increases in concentrations of contaminants in lobsters at the outfall site as a result of the relocation of the outfall were found. Concentrations of all contaminants were below MWRA thresholds and available FDA action limits, and concentrations of most contaminants were also below EPA screening-level RBCs. Although concentrations of PCBs exceeded the EPA screening-level RBC at all locations, 2006 concentrations of PCBs in lobsters from the Outfall Site are not significantly different from concentrations at Cape Cod Bay.

***Mussel results**. In the early part of the period after the outfall was relocated (2001–2003) concentrations of certain contaminants (mercury, lead, total DDT, total PCBs, total PAHs, total chlordane, dieldrin, hexachlorobenzene, lindane, and high molecular weight (HMW) PAH) were significantly higher in mussels deployed at the outfall site than during the pre-discharge period (1998–2000) (Hunt, Abramson et al 2002, Wisneski et al. 2004[3]). . . . Most pesticides were within the historical range measured at the outfall site.*

[3] The correct citation is Lefkovitz et al., 2004.

Total chlordane was an exception, being significantly higher in mussels deployed at the outfall site during the early post-discharge period compared to pre-discharge levels, and higher at the outfall site than at any other station in 2001 and 2002. In 2006, however, levels of chlordane trended substantially downward at the outfall site and were at or near historical lows at all stations (Nestler et al. 2007). Similar to chlordane, concentrations of HMW PAH and total PAHs (mostly because of the contribution of HMW PAH) increased at the outfall site coincident with outfall startup. Although HMW PAHs at the outfall site were elevated in the post-discharge period (2001-2006) in comparison to pre-discharge, concentrations were lower in 2006 than in the earlier period (2001–2003) (Nestler et al. 2007).

Concentrations of total PAHs and total chlordane in mussels deployed at the outfall site exceeded Contingency Plan caution levels in 2001 and 2002, and PAH thresholds were exceeded in 2003 (Hunt et al. 2006). An investigative study examined factors affecting contaminant levels and assessed the potential for environmental impact (Hunt et al. 2002). This study found that measured levels of PAHs and chlordane in mussels were below levels associated with impacts to growth and other chronic adverse impacts to aquatic organisms. In 2006, concentrations of total PAHs and chlordane were lower, and none of the contaminants exceeded the U.S. Food and Drug Administration (FDA) action limits or MWRA caution or warning thresholds.

Before-After, Control-Impact statistical analyses were carried out on mussel data (Kane-Driscoll et al. 2008). Post-relocation (After) concentrations of lead, PCBs, high molecular weight PAHs, total PAHs, chlordane and 4,4' DDE were statistically significantly greater than Before at the outfall site taking into account changes at the control site (Cape Cod Bay). Although levels of these contaminants are higher at the outfall site, the concentrations are below MWRA threshold levels and FDA action limits. Also current concentrations of PAHs in mussels at all locations are below U.S. Environmental Protection Agency (EPA) benchmarks for the protection of aquatic organisms, and concentrations of lead, mercury, chlordane, and 4,4'-DDE were below EPA screening-level human health risk-based concentrations (RBCs)[4]. Average concentrations of PCBs exceeded the EPA screening-level RBC at all locations, although concentrations of PCBs at the outfall site were significantly lower than concentrations at Cape Cod Bay, indicating a broader regional distribution of PCBs. These results are consistent with expectations."

<u>Question #33</u>: Has the incidence of disease and/or abnormalities in fish or shellfish changed?

<u>Answer</u>: The incidence of disease and/or abnormalities in winter flounder (the target fish for this monitoring) have decreased, both in fish caught in Boston Harbor and in those caught near the outfall.

The recovery of the winter flounder population in Boston Harbor from the extremely high levels of contaminant associated pathology that were observed in the 1980s is one of the great environmental success stories associated with the Boston Harbor clean-up project (Moore, Pembroke, et al., 2018). The incidence of targeted disease in winter flounder has decreased, both in fish caught in Boston Harbor and in those caught near the outfall.

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[4] *EPA RBCs are based on conservative estimates of the rates of consumption of fish or shellfish, and do not constitute regulation or guidance. RBCs are used primarily to screen out chemicals as contaminants of concern in an initial phase of a risk assessment.*

Liver tumors, which were once present in 12% of flounder caught on Deer Island flats, have not been observed since 2004, and levels of Centrotubular Hydropic Vacuolation (CHV) in flounder livers, a condition associated with exposure to contaminants have decreased substantially in Harbor flounder (Moore, Nestler, and Rutecki, 2018). Importantly, while the health of flounder in the Harbor has improved, there has been no decline in health in winter flounder caught near the outfall in Massachusetts Bay. In fact, levels of CHV in flounder caught near the outfall are lower than they were in the early 1990s (Moore, Pembroke, et al., 2018). These recent results are consistent with the evaluations contained in AMP revision 2 (MWRA 2010).

Results of 2000-2018 Contingency Plan threshold tests

The Contingency Plan thresholds (MWRA, 2001) are based on permit limits, Massachusetts state water quality standards, and expert judgment. There are two types of threshold. “Caution level” thresholds indicate a need for a closer look at the data to determine the reason for an observed change. “Warning level” thresholds are a higher level of concern, for which the permit requires a series of steps to evaluate whether adverse effects occurred and if so, whether they were related to the discharge. If exceedances were related to the discharge, MWRA might need to implement corrective action.

The threshold tests (MWRA, 2001) can be grouped in the same four categories as for the monitoring questions above: effluent, water column, benthic conditions, and fish and shellfish. Tables 1 through 4 summarize the results of threshold testing in each of these four categories, respectively, for the period from outfall startup in September 2000 through the end of 2018.

Threshold test results for the most recent monitoring (during 2017 and 2018) are provided in Appendix B. In addition to showing the most recent threshold test results, the tables in Appendix B complement Tables 1 to 4 in that they include the values for the thresholds in each individual test.

Effluent threshold testing (Table 1) at the Deer Island Treatment Plant includes pH, Fecal coliform, residual chlorine, suspended solids, carbonaceous biological oxygen demand (cBOD), acute toxicity, chronic toxicity, PCBs, plant performance, plant flow, total nitrogen load, and oil and grease.

Water column threshold testing (Table 2) includes dissolved oxygen concentration, percent saturation, and depletion rate, in the outfall nearfield, and at Stellwagen Bank National Marine Sanctuary; chlorophyll a; and three nuisance/noxious phytoplankton species (*Pseudo-nitzchia*, *Phaeocystis*, and *Alexandrium*).

Benthic conditions threshold testing (Tables 3a and 3b) includes sediment contaminants (includes PAHs, other organics, and metals), the redox potential discontinuity (RPD) from sediment profile imaging, and infauna community diversity parameters.

Fish and shellfish threshold testing (Table 4) includes flounder disease, and tissue contaminants for flounder, lobster, and mussels.

There have been minor modifications to the Contingency Plan since it took effect in 2000. As required by the permit, each modification was implemented only after review, evaluation, and approval by regulators and the Outfall Monitoring Science Advisory Panel. In 2001 the water column dissolved oxygen and dissolved oxygen percent saturation thresholds were altered to incorporate natural fluctuations below the numeric water quality standards. Benthic invertebrate diversity thresholds were modified in 2017 to remove threshold levels triggered by high diversity. Because regional blooms had been consistently responsible for water column *Phaeocystis* threshold exceedances, they were eliminated from the Contingency Plan in 2017.

Table 1. Contingency Plan threshold exceedances, 2000-2018, for effluent.

	pH	Fecal coliform	Chlorine, residual	Suspend-ed solids	cBOD	Acute toxicity	Chronic toxicity	PCBs	Plant perform-ance	Flow	Total N load	Oil and grease
2000										n/a	n/a	
2001												
2002												
2003												
2004												
2005												
2006												
2007												
2008.												
2009												
2010												
2011												
2012												
2013												
2014												
2015												
2016												
2017												
2018												

CAUTION LEVEL WARNING LEVEL

“n/a” (not applicable) in 2000: Test requires a full year of monitoring; was not possible as the plant began operating in late 2000.

Table 2. Contingency Plan threshold exceedances, 2000-2018, for water column.

	DO NEARFIELD			DO STELLWAGEN		CHL-A NEARFIELD				*Pseudo-nitzchia*			*Phaeocystis*			*Alexandrium*	
	Conc.	% sat.	Deplet-ion rate	Conc.	% sat.	Annual	Winter /spring	Summer	Autumn	Winter /spring	Summer	Autumn	Winter /spring	Summer	Autumn	Nearfield	PSP incidence
2000		*	n/a		*	n/a	n/a	n/a		n/a	n/a		n/a	n/a			
2001																	
2002																	
2003																	
2004																	
2005																	
2006																	
2007																	
2008.																	
2009																	
2010																	
2011																	
2012																	
2013																	
2014																	
2015																	
2016																	
2017													**	**	**		
2018													**	**	**		

CAUTION LEVEL WARNING LEVEL

* Fall 2000 dissolved oxygen (DO) exceedances led to incorporation into threshold testing of the State Standard's text regarding "unless natural conditions are lower". Under the current implementation of the threshold testing there would not have been DO exceedances in fall 2000.

** Review by EPA and OMSAP in 2017 showed the prior *Phaeocystis* threshold exceedances were caused by regional *Phaeocystis* blooms unrelated to the outfall. EPA and OMSAP approved removal of the *Phaeocystis* thresholds in 2017.

"n/a" (not applicable) in 2000: Test requires a full year of monitoring; was not possible as the plant began operating in late 2000.

Table 3a. Contingency Plan threshold test results, 2000-2018, for sediment contaminants. No exceedances.

	POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)															OTHER ORGANIC CONTAMINANTS			METALS							
	Acenapthene	Acenaphylene	Anthracene	Benzo(a)anthra-cene	Benzo(a)pyrene	Chrysene	Dibenzo(a,h)anthracene	Fluroanthene	Fluorene	Napthalene	Phenanthrene	Pyrene	Total high MW PAH	Total low MW PAH	Total PAH	p,p'-DDE	Total DDTs	Total PCBs	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001																										
2002																										
2003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005																										
2006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2008																										
2009	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011																										
2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014																										
2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2017																										
2018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CAUTION LEVEL   WARNING LEVEL

\- Denotes years in which the AMP did not require measurements be undertaken so CP thresholds were not tested.

Table 3b. Contingency Plan threshold exceedances, 2000-2018, for redox potential discontinuity (RPD) depth and infaunal metrics.

	RPD DEPTH	BENTHIC PARAMETERS				
		Species per sample	Fisher's log-series alpha	Shannon -Wiener alpha	Pielou's Evenness	% opportu-nists
2000	-	-	-	-	-	-
2001						
2002						
2003						
2004						
2005						
2006						
2007						
2008.						
2009						
2010				CAUTION LEVEL	CAUTION LEVEL	
2011				CAUTION LEVEL	CAUTION LEVEL	
2012				CAUTION LEVEL	CAUTION LEVEL	
2013				CAUTION LEVEL	CAUTION LEVEL	
2014				CAUTION LEVEL	CAUTION LEVEL	
2015						
2016						
2017						
2018						

(green) CAUTION LEVEL (orange) WARNING LEVEL

Note: All exceedances were relative to the upper threshold levels. Review by OMSAP demonstrated that exceedances of the upper levels for Shannon-Weiner alpha and Pielou's Evenness were not indicative of degraded conditions, and recommended that from 2017 on, only values less than the lower thresholds for these variables be considered exceedances.

Table 4. Contingency Plan threshold test results, 2000-2018, for fish and shellfish.

	Flounder						Lobster					Mussel						
	Liver disease (CHV)	Tissue		Tissue (lipid-normalized)			Tissue		Tissue (lipid-normalized)			Tissue			Tissue (lipid-normalized)			
		PCB	Mercury	Chlordane	Dieldrin	DDT	PCB	Mercury	Chlordane	Dieldrin	DDT	PCB	Lead	Mercury	Chlordane	Dieldrin	DDT	PAH
2000		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001															(caution level)			(caution level)
2002															(caution level)			(caution level)
2003																		(caution level)
2004		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2006																		
2007		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2008		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2009																		
2010		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012																		
2013		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015																		
2016		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2017		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2018																		

CAUTION LEVEL   WARNING LEVEL

- Denotes years in which the AMP did not require measurements be undertaken so CP thresholds were not tested.

CHV – Centrotubular hydropic vacuolation
DDT – Dichloro-diphenyl-trichloroethane
PCB – Polychlorinated biphenyl
PAH – Polycyclic aromatic hydrocarbon

As demonstrated by the numerous blank cells in Tables 1-4, threshold exceedances have been sparse overall, relative to the extensive scope of the CP. In the first several years after 2000, as DITP operations became better established, exceedances became less common. Exceedances of thresholds associated with treated wastewater have not occurred since 2006. Overall, exceedances of thresholds associated with environmental monitoring have been infrequent, and have occurred only for a limited subset of the threshold tests. For all exceedances, in-depth evaluations have led to the conclusions that they do not indicate degradation of the Massachusetts Bay environment associated with the outfall discharge (e.g., Hunt et al. 2002, Libby et al. 2007, Nestler et al. 2014).

Conclusions

The results of monitoring since 2011 strongly support the conclusions drawn in 2010, that all of the monitoring questions have been adequately answered. In addition, the results of all Contingency Plan threshold tests (from 2000 through the end of 2018) demonstrate that exceedances have generally been uncommon and limited in severity. Required investigations of each threshold exceedance have led to the conclusion that they do not indicate environmental degradation associated with MWRA's outfall discharge. These investigations are documented in more detail in the references cited.

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Appendix A: Monitoring questions previously answered

For full explanations of monitoring results related to these previously answered questions, see AMP Revision 1 (MWRA, 2004) and AMP Revision 2 (MWRA, 2010). Here, only a listing of the questions is provided.

As noted above, the numbering here is relative the order in which the 33 questions appear in MWRA (2010), where they were not numbered.

Previously answered water column monitoring questions

Dilution

Question #6: Are the model estimates of short-term (less than 1 day) effluent dilution and transport accurate?

Question #7: Do levels of contaminants outside the mixing zone exceed State Water Quality Standards?

Pathogens

Question #8: Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?

Question #9: Are pathogens transported to beaches at levels that might affect swimmer health?

Aesthetics

Question #10: Has the clarity and/or color of the water around the outfall changed?

Question #11: Has the amount of floatable debris around the outfall changed?

Biology (phytoplankton production)

Question #18: Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations or Boston Harbor and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Previously answered benthic monitoring questions

Sediment contamination and tracers

Question #21: What is the level of sewage contamination and its spatial distrubution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?

Benthic nutrient fluxes

Question #28: How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?

Question #29: Have the rates of these processes changed?

Appendix B: Contingency Plan thresholds and 2017-18 threshold test results

Contingency Plan threshold test results for the most recent monitoring (2017-2018) are included in Tables B1 to B4.

The content of these tables corresponds to that of Tables 1-4 (pages 22 – 26 above): Effluent threshold tests are in Table B1, water column threshold tests are in Table B2, benthic conditions threshold tests are in Tables B3a and B3b, and fish and shellfish threshold tests are in Table B4.

In addition to showing the most recent threshold test results, Tables B1 to B4 complement Tables 1 to 4 in that they include the values for the thresholds in each individual test.

The tables contain the results of threshold tests run on effluent and environmental monitoring results from 2018, with one exception: the sediment contaminant thresholds results (Table B3a) are from 2017, the most recent sampled year (they are sampled every third year).

Table B1. Contingency Plan threshold values and 2018 results for effluent.

Parameter	Baseline	Caution Level	Warning Level	2018 Results
pH	NA	None	<6 or >9	Not exceeded
Fecal coliform	NA	None	>14,000 fecal coliforms/100 mL	Not exceeded
Chlorine, residual	NA	None	>631 µg/L daily, >456 µg/L monthly	Not exceeded
Suspended solids	NA	None	>45 mg/L weekly >30 mg/L monthly	Not exceeded
cBOD	NA	None	>40 mg/L weekly, >25 mg/L monthly	Not exceeded
Acute toxicity	NA	None	LC50 <50%	Not exceeded
Chronic toxicity	NA	None	NOEC <1.5% effluent	Not exceeded
PCBs	NA	Aroclor>0.045 ng/L	None	Not exceeded
Plant performance	NA	5 violations/year	Compliance <95% of the time	Not exceeded
Flow	NA	None	>436 MGD average dry days	Not exceeded
Total nitrogen load	NA	>12,500 mtons/year	>14,000 mtons/year	Not exceeded
Oil and grease	NA	None	>15 mg/L weekly	Not exceeded

NA = not applicable

cBOD = carbonaceous biological oxygen demand

LC50 = 50% mortality concentration

NOEC = no observable effect concentration

PCB = polychlorinated biphenyl

Plant performance = compliance with permit conditions

Table B2. Contingency Plan threshold values and 2018 results for water column.

Parameter	Baseline	Caution Level	Warning Level	2018 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	6.83 mg/L Not exceeded
Nearfield percent saturation	65.3%	<80%	<75%	75.5% Not exceeded
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	7.07 mg/L Not exceeded
Stellwagen percent saturation	67.2%	<80	<75%	76.3% Not exceeded
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.020 mg/L/d Not exceeded
Chlorophyll				
Annual	72 mg/m^2	>108 mg/m^2	>144 mg/m^2	71 mg/m^2 Not exceeded
Winter/spring	50 mg/m^2	>199 mg/m^2	None	73 mg/m^2 Not exceeded
Summer	51 mg/m^2	>89 mg/m^2	None	58 mg/m^2 Not exceeded
Autumn	90 mg/m^2	>239 mg/m^2	None	95 mg/m^2 Not exceeded
Nuisance algae nearfield *Pseudo-nitzschia*				
Winter/spring	6,735 cells/L	>17,900 cells/L	None	122 cells/L Not exceeded
Summer	14,635 cells/L	>43,100 cells/L	None	245 cells/L Not exceeded
Autumn	10,050 cells/L	>27,500 cells/L	None	518 cells/L Not exceeded
Nuisance algae nearfield *Alexandrium catenella*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	4 cells/L Not exceeded
PSP toxin extent	NA	New incidence	None	No new incidence Not exceeded

*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat "unless background conditions are lower." Results are therefore compared to the baseline rather than to the caution and warning levels. PSP = paralytic shellfish poisoning. NA = not applicable.

Table B3a. Contingency Plan threshold values and 2017 results for sediment contaminants. *

Parameter	Baseline	Caution Level	Warning Level	2017 Results
Polycyclic aromatic hydrocarbons (PAHs) (ng/g dry weight)				
Acenaphthene	22.7 – 43.5	None	500	24.8 Not exceeded
Acenaphylene	30.3 – 43.1	None	640	24.5 Not exceeded
Anthracene	101 – 159	None	1,100	86.2 Not exceeded
Benzo(a)anthracene	206 – 302	None	1,600	230 Not exceeded
Benzo(a)pyrene	204 – 298	None	1,600	145 Not exceeded
Chrysene	164 – 296	None	2,800	191 Not exceeded
Dibenzo(a,h)anthracene	27.8 – 38.3	None	260	34.1 Not exceeded
Fluoranthene	422 – 621	None	5,100	308 Not exceeded
Fluorene	35.5 – 66.6	None	540	29.1 Not exceeded
Naphthalene	53.6 – 103	None	2,100	36.4 Not exceeded
Phenanthrene	273 – 431	None	1,500	220 Not exceeded
Pyrene	412 – 579	None	2,600	281 Not exceeded
Total HMW PAH	2,790 – 3,850	None	9,600	2,450 Not exceeded
Total LMW PAH	1,390 – 1,630	None	3,160	870 Not exceeded
Total PAHs	4,180 – 5,400	None	44,792	3,320 Not exceeded
Other organic contaminants (ng/g dry weight)				
p,p'-DDE	0.386 – 1.00	None	27	0.2 Not exceeded
Total DDTs	2.51 – 5.69	None	46.1	0.3 Not exceeded
Total PCBs	10.2 – 20.2	None	180	4.8 Not exceeded
Metals (µg/g dry weight)				
Cadmium	0.0727 – 0.185	None	9.6	0.1 Not exceeded
Chromium	59.2 – 79.9	None	370	27 Not exceeded
Copper	19.1 – 25.2	None	270	11 Not exceeded
Lead	41.1 – 46.3	None	218	23 Not exceeded
Mercury	0.159 – 0.353	None	0.71	0.2 Not exceeded
Nickel	15.7 – 17.2	None	51.6	9.4 Not exceeded
Silver	0.335 – 0.485	None	3.7	0.1 Not exceeded
Zinc	49.5 – 57.5	None	410	33 Not exceeded

HMW = high molecular weight; LMW = low molecular weight   * Exceedances are greater than (>) values given.

Table B3b. Contingency Plan threshold values and 2018 results for redox potential discontinuity (RPD) depth and infaunal metrics.

Parameter	Baseline	Caution Level	Warning Level	2018 Results
Sediment parameters				
RPD depth	NA	<1.18 cm	None	5.09 cm Not exceeded
Benthic community parameters				
Species per sample	NA	<42.99	None	60.8 Not exceeded
Fisher's log-series alpha	NA	<9.42	None	12.1 Not exceeded
Shannon diversity	NA	<3.37	None	3.65 Not exceeded
Pielou's evenness	NA	<0.57	None	0.62 Not exceeded
% opportunists	NA	>10%	>25%	1.79% Not exceeded

HMW = high molecular weight; LMW = low molecular weight

NA = not applicable; RPD = redox potential discontinuity

Table B4. Contingency Plan threshold values and 2018 results for fish and shellfish.*

Parameter	Baseline	Caution Level	Warning Level	2018 Results
Flounder disease				
Liver disease (CHV)	24.4%	>44.9%	None	6% Not exceeded
Flounder meat				
PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.036 ppm Not exceeded
Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.0573 ppm Not exceeded
Flounder meat, lipid normalized				
Chlordane	242 ppb	484 ppb	None	27 ppb Not exceeded
Dieldrin	63.7 ppb	127 ppb	None	0 ppb Not exceeded
DDT	775.9 ppb	1552 ppb	None	107 ppb Not exceeded
Lobster meat				
PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.009 ppm Not exceeded
Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.170 ppm Not exceeded
Lobster meat, lipid normalized				
Chlordane	75 ppb	150 ppb	None	2.6 ppb Not exceeded
Dieldrin	161 ppb	322 ppb	None	0 ppb Not exceeded
DDT	341.3 ppb	683 ppb	None	28.5 ppb Not exceeded
Mussel tissue				
PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.013 ppm Not exceeded
Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.14 ppm Not exceeded
Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.01 ppm Not exceeded
Mussel tissue, lipid normalized				
Chlordane	102.3 ppb	205 ppb	None	33 ppb Not exceeded
Dieldrin	25 ppb	50 ppb	None	0 ppb Not exceeded
DDT	241.7 ppb	483 ppb	None	71 ppb Not exceeded
PAH	1080 ppb	2160 ppb	None	726 ppb Not exceeded

CHV = centrotubular hydropic vacuolation

* Exceedances are greater than (>) values given.

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