AECOM
9 Jonathan Bourne Drive
Pocasset, MA 02559
www.aecom.com
508.833.6950 tel
508.833.6951 fax

Memorandum

To	George Meservey, Director of Planning & Community Development Michael Domenica, PE, Program Manager
CC	Betsy Shreve, AICP, AECOM Project Director Sia Karplus, Science Wares, Inc. Paula Winchell, AECOM
Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task Number 4.a.1 – Adaptive Management Plan** **Draft Technical Memorandum of Water Quality Monitoring and Modeling: Consolidation and Comparison of Baseline Monitoring Data Sets**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
Date	03/25/16

1. Introduction

a. The Orleans Marine and Freshwater Quality Task Force (OWQTF) and the Pleasant Bay Alliance (Alliance) coordinate the main water quality monitoring efforts in Orleans. The Alliance coordinates a comprehensive water quality monitoring program for Pleasant Bay. Volunteers currently collect samples from 24 stations, although the total number of stations has varied over the years ranging from 20 to 34. The University of Massachusetts School for Marine Science and Technology (SMAST) analyzes these samples and provides annual reports. Every five years, the Alliance evaluates this data. The most recent report includes updated statistical and trend analysis for data from 2000 through 2014 (Cadmus Group 2015). The Alliance provided the AECOM team the aggregated data sets from 2000 through 2015 in an Access database format for the 24 stations in Pleasant Bay.

b. The OWQTF organizes water quality sampling for the Nauset Harbor watershed and the Orleans portion of Pleasant Bay. Volunteers collect samples from three monitoring stations and the SMAST analyzes these samples and provides annual reports. Historic data sets for the Nauset Harbor watershed were provided by the Town of Orleans planning department as separate Excel spreadsheets for 2003 through 2014. A consolidated spreadsheet for 2003 through 2009 was also provided. The consolidated data sets for Pleasant Bay (2000 through 2015) and Nauset Harbor (2003 through 2014) have been provided electronically by AECOM to the Orleans Planning Department.

2. Background

The natural estuaries in the town of Orleans, Massachusetts (Town) have been extensively studied over the last several decades (Massachusetts Estuaries Project (MEP) Reports, 2006, 2012). Research and monitoring data show that the estuarine ecosystems in Orleans are impacted by increased nutrient loading and eutrophication (MEP, 2006, 2012). The Town is currently planning to implement nutrient remediation measures to improve ecologic conditions in these systems. The Town is planning ongoing monitoring to quantify changes and trends in water quality and biological parameters that result from these nutrient remediation efforts.

The purpose of this Technical Memorandum (TM) is to evaluate the adequacy of sampling locations and sampling methodology (protocols and parameters) in order to accomplish the following monitoring objectives:

- Establish current baseline conditions for evaluating water quality improvements as the town's overall nutrient management program is implemented;
- Establish baseline conditions for evaluating specific demonstration projects;
- Allow Massachusetts Estuaries Project (MEP) model revisions where physical conditions and nutrient loads have changed;
- Verify MEP model runs made as part of Comprehensive Wastewater Management Plan updates; and
- Determine data gaps and recommend additional monitoring to meet the above monitoring goals.

To make this assessment, existing water quality data collected from 2000 to 2015 by citizen volunteers and analyzed by the Massachusetts Estuaries Project (MEP) laboratory for Orleans have been consolidated and reviewed, and missing data gaps have been identified. In addition, this water quality information is compared to baseline monitoring data from the MEP reports for Pleasant Bay and Nauset Harbor and trends have been documented.

Findings and recommendations for additional monitoring to meet the above monitoring goals are outlined below. Subsequent TMs will present the details of the recommended monitoring plans for meeting specific goals and objectives. TM 4.a.2: *Long Term Waterbody Monitoring* will present the plan for compliance monitoring for the Total Maximum Daily Load (TMDL) for nitrogen as well as Massachusetts Department of Environmental Protection (MA DEP) habitat restoration goals. TM 4.a.3: *Non-Traditional Performance Analysis* will present the plan for monitoring non-traditional demonstration projects, and TM 4.a.4: *MEP Study Update Monitoring* will address the data needs for accurate and complete MEP model updates.

3. Definitions

Recorded water quality parameters contained in the data sets for Pleasant Bay and Nauset Harbor include: weather, wind force, wind direction, water condition, secchi depth, DI salinity, field corrected salinity, sample time, sample depth, in situ dissolved oxygen (DO), in situ DO (as percent saturation), in situ water temperature, laboratory salinities, laboratory conductivity, soluble reactive phosphate (SRP), ammonium (NH_4), nitrate (NO_3), dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), total dissolved nitrogen (TDN), particulate organic nitrogen (PON), total organic nitrogen (TON), total nitrogen (TN), particulate organic carbon (POC), chlorophyll *a* and pheophitin. Several of these terms, including weather, wind force, wind direction, water condition, sample depth, and field temperature are recorded to characterize the conditions under which the water quality sample is taken.

The water quality parameters are defined as follows:

Ammonium (NH_4) - A molecule with a positive charge containing nitrogen and hydrogen.

Nitrate (NO_3) - A molecule with a negative charge containing nitrogen and oxygen with the molecular formula NO3-.

Dissolved Inorganic Nitrogen (DIN)/Total Inorganic Nitrogen - The sum of the concentrations of nitrate, nitrite and ammonia.

Dissolved Organic Nitrogen (DON) - The soluble form of nitrogen bound to a molecule which contains carbon (such as amino acids, peptides, humic substances and protein), and which had its origin in living material. DON is measured as all organic nitrogen contained in particles less than 0.7 microns or 0.22 microns, depending on the laboratory protocol employed. The primary source of DON is atmospheric deposition.

Particulate Organic Nitrogen (PON) - The nitrogen contained in suspended particles of organic matter in the water column. Particulate matter is larger than a standard filter size which generally ranges between 0.7 and 0.22 microns, depending on the laboratory protocol used. Subtracting the dissolved organic nitrogen fraction from total organic nitrogen yields PON.

Bioactive Nitrogen (BioN) - The sum of Dissolved Inorganic Nitrogen + Particulate Organic Nitrogen.

Total Dissolved Nitrogen (TDN) - The sum of DON and DIN.

Total Organic Nitrogen - The sum of DON and PON.

Total Nitrogen (TN) - The combined sum of all organic and inorganic forms of nitrogen in a water sample. These forms of nitrogen can include nitrate, nitrite, ammonia, particulate organic nitrogen and dissolved organic nitrogen.

Dissolved Oxygen (DO) - The amount of elemental oxygen, O_2, in solution under existing atmospheric pressure and temperature. Low levels of dissolved oxygen (DO) can slow the growth rate and reduce the survival of many aquatic organisms (Gosling 2003; Whetstone et al. 2005). Field dissolved oxygen and field dissolved oxygen percent saturation refer to different methods of measuring DO.

Particulate Organic Carbon (POC) - The carbon contained in suspended particles of organic matter in the water column. Particulate matter is larger than a standard filter size which generally ranges between 0.7 and 0.22 microns.

Soluble Reactive Phosphorus (SRP) - Inorganic phosphorus also referred to as orthophosphate which occurs as ions of HPO4-, with a small percentage present as PO4-. This macronutrient is required for the growth of marine organisms and in marine ecosystems is often present in low and, perhaps, limiting concentrations.

Total Phytopigments - The sum of chlorophyll *a* and phaeophytin *a*. **Chlorophyll *a*** is a green pigment responsible for the absorption of light to provide energy for photosynthesis. **Phaeophytin *a*** is also a photosynthetic pigment, often produced by the degradation of chlorophyll *a*. Total pigment concentration can be used as a proxy for food concentration.

Salinity - The concentration of sodium, potassium, magnesium, calcium, bicarbonate, carbonate, sulfate, and halides (chloride, fluoride, bromide) in water. DI salinity, field corrected salinity and laboratory salinity and conductivity refer to different methods of measuring salinity.

Secchi Depth - The depth at which a circular plate with black and white sections (Secchi disk) is no longer visible from the surface of ocean water, used to determine water clarity.

Turbidity - The relative clarity of a liquid, determined by measuring the amount of light that is scattered by suspended particles in the water column. The presence of suspended or colloidal matter or planktonic organisms reduces light penetration and increases turbidity.

4. Procedures and Protocols of Existing Monitoring Programs

a. Quality Assurance Project Plan (QAPP)

For data collection procedures and laboratory analysis protocols, both the Alliance and the OWQTF use the QAPP developed for the MEP by SMAST. According to the "Guidelines for Acceptable Water Quality Monitoring Sampling Approaches" contained in this QAPP, water is tested routinely in Orleans for the following basic parameters:

- Dissolved oxygen,
- Temperature,
- Salinity,
- Water clarity,
- Water samples for laboratory nutrient analysis, and
- Weather/tide observations.

Appendix A includes the QAPP's Field Sampling Protocols and Data Sheets that accompany water samples.

According to the QAPP, sampling stations are placed along the long axis of an embayment, and within major coves or tidally restricted basins. Each station has a unique identification code. Station locations have been selected to be representative of overall embayment water quality conditions, not localized "hot spots". Stations were placed to give good geographic coverage throughout the inner and outer (where possible) portions of an embayment. Sample stations include central basins sampled by boat (best), boatyard docks, town landings or piers. An offshore reference station was also established for each embayment, outside of the influence of the ebb tidal plume from adjacent systems. All sampling stations are identified on a USGS Quadrangle sheet or Nautical Chart, with associated GPS latitude/longitude coordinates. The QAPP's Appendices I through XX have figures with maps showing all monitoring stations that are part of the MEP. Figures 1 and 2 show the locations of the monitoring stations in Pleasant Bay and Nauset Harbor respectively. GPS coordinates for these stations are included with the consolidated data sets.

Insert Figures 1,2 maps of sampling stations:

Each year, dates and times for sampling are selected based on tidal regime, generally from 6:00 am to 9:00 am during the 3 hours around mid-ebb tide. Samples are typically collected the first and third weeks in July and August, with one sample in September. During this prescribed monitoring period, all personnel take samples at all stations throughout a given embayment. This simultaneous sampling schedule is critical to allow site-to-site comparisons of data. The critical seasonal interval for water quality sampling is June through mid-September, when the lowest DO levels are expected and macronutrients in the water column are typically lowest, though inorganic N concentrations can also vary inter-annually, and along salinity gradients in estuaries.

Water samples at shallow stations (<1.5m) are collected only near the surface, and at the surface and bottom at deeper water stations (>1.5m). This vertical sampling allows for an evaluation of water column stratification and its associated nutrient and DO numbers. Surface water samples are collected at 15 centimeters below the surface, and bottom water samples 30 to 50 cm above the bottom. These depths have been determined by SMAST as representative of estuarine water quality that is important to ecosystems health. Collection of a sample 15 cm below the surface prevents entrainment of the overlying air into DO samples, and keeps floating material from fouling nutrient samples. Sampling 30 to 50 cm above bottom prevents stirring of the bottom sediments and subsequent contamination of the nutrient sample.

Bacterial sampling from sources such as waterfowl can be conducted in parallel with the nutrient sampling, with samples typically collected from the surface. In addition, storm water bacteria sampling may be conducted which focuses upon land-based point inputs, primarily from direct storm water inflows. These measurements can help determine nutrient sources with greater specificity than nitrogen sampling. Sampling is usually conducted during the daylight hours of a storm event, and should be timed to capture the first flush of rainfall discharge from storm water discharge pipes. Additional samples may also be collected upstream and downstream of the discharge pipe within river systems.

A specific volunteer or professional sampler is identified for each sampling event for each station. The Monitoring Coordinator also conducts a joint visit to each site prior to sampling. The QAPP specifies that all samples must be collected by trained staff or specially trained volunteers. SMAST reviews data for adherence to analytical protocols and to established holding times, surrogate recoveries, initial and continuing calibrations, matrix spikes during analysis, laboratory duplicates, and blank contamination. SMAST may use T-tests for paired samples and analysis of variance for interpretation. Data is transcribed for statistical analysis and each data point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in project files, which are maintained at SMAST.

Equipment used for sampling includes: thermometer, hydrometer, conductivity meter, oxygen meter (calibrated to dissolved gas standards), and Secchi Disk. For salinity, specific conductivity is preferred over hydrometer readings. The electrochemical sensors used to take an instantaneous reading of DO concentration and saturation in the field measure the current passing through a special electrode, which is proportional to the concentration of oxygen at the electrode surface. Because salinity impacts the amount of oxygen that can be dissolved in seawater at a given temperature, salinity affects the accuracy of field readings for DO. Salinity-corrected field DO is reported in the data sets provided by SMAST for 2008 through 2012 (Howes et al, 2012). The continuous sonde data for DO that is reported in the MEP report was collected using optical sensors.

b. Responsible Parties

Established by Town Meeting in 2000, the OWQTF is charged with the “development and maintenance of a database on the condition of Orleans marine resources since 1988 as a foundation for pertinent decisions at all levels of Town government”. Since 2001, the OWQTF has been coordinating with the Alliance and SMAST to distribute sampling equipment and provide annual training to citizen volunteers in Orleans for ongoing sampling that now includes three stations in Nauset Harbor, approximately sixteen of the twenty-four stations in Pleasant Bay and three stations in Cape Cod Bay, including Rock Harbor, Namskaket and Little Namskaket. A freshwater monitoring program addresses approximately seventeen lakes and ponds.

The OWQTF also handles the logging-in of water samples coming in from the field in Orleans, and for chain-of-custody documentation. Chatham and Orleans alternately deliver water samples to the SMAST laboratory in New Bedford for analysis. The data is recorded in Excel spreadsheets and provided to the Town as a one year data set. The town planner ensures that these spreadsheets are maintained on the Town’s computer system. OWQTF also participates in technical discussions related to all monitoring efforts and programs that involve Orleans. This committee also coordinates some of the Town’s short-term water quality monitoring projects, and provides recommendations to the Board of Selectmen (BOS) on issues related to water quality when requested.

The Alliance was formed in 1998 to oversee resource management planning for Pleasant Bay. For the past fifteen years, the Alliance has organized and trained volunteers to collect water quality data from sampling stations bay-wide, which are sampled two times per month during July and August and once in early September. Fourteen of these stations are in Orleans’s waters, although volunteers from Orleans coordinate with Chatham to sample two additional stations. The Alliance contracted Cadmus Group to analyze the monitoring data for statistical changes over time. These core water quality sampling efforts are enhanced by the following additional environmental monitoring activities in and around Orleans:

- SMAST: Targeted monitoring and evaluations for Cedar Pond (2007), Boland Pond (2007), Namskaket Marsh (vegetative survey, 2015) and Nauset Inlet to update flow and nutrient data (2015) were undertaken.

- Center of Coastal Studies: Ongoing monitoring in Pleasant Bay, Nauset Harbor, Rock Harbor/Cedar Pond, and Cape Cod Bay as follows:

    - Pleasant Bay: A tide gage was installed in Meetinghouse Pond in 2005, providing continuous measurements since 2007. An ecosystem-wide study was recently initiated that includes bathymetric mapping, benthic habitat mapping, surveys for finfish and shellfish and seal population studies.

    - Nauset Estuary: The Center’s Coastal Geology Program has completed the field component for benthic mapping and bathymetry throughout the system. Report and maps are pending.

    - Rock Harbor/Cedar Pond: Water quality is monitored weekly from April - November for nutrients, temperature, salinity, DO, pH, chlorophyll, and turbidity. A continuous data logger for temperature, conductivity, and DO is maintained in Cedar Pond year round. For the rest of the estuary system, water quality parameters are measured every 2 weeks, May-October. Data exists for the mouth of Rock Harbor starting in 2006, and four additional stations were added in 2012. Data and analysis is presented in a final report (Center for Coastal Studies, 2014).

- o Cape Cod Bay: Deep water quality is monitored once a month, year round using hydrographic profiling instrumentation that measure conductivity, temperature, depth, DO, fluorescence, and photosynthetically active radiation (PAR). Phytoplankton and zooplankton samples are collected weekly during the North Atlantic right whale (NARW; *Eubalaena glacialis*) Cape Cod Bay Seasonal Management Area (SMA) period (January - May) and monthly from February – October. Aerial surveys for NARWs with opportunistic sightings of other marine mammals is conducted from December – May. Data and analysis is presented in a final report (Center for Coastal Studies, 2012).

- Woods Hole Group: 2015 study for dredging of Nauset estuary was completed (Woods Hole Group, final report pending).

- Association for the Preservation of Cape Cod (APCC): Namskaket Creek marsh is located on the border of Orleans and Brewster. An outdated one-foot culvert was replaced by two larger, side-by-side, box culverts in January 2007, allowing for increased infiltration of salt water into the marsh. The APCC monitored the marsh for one year before restoration (in 2006) and five years after restoration (2007 through 2011) in order to track the health of Namskaket marsh before and after tidal restoration of Namskaket Creek. Monitoring included vegetation (species and abundance within a 1 meter square (m^2) quadrat), birds (species, abundance and behavior within delineated area) and salinity (pore and surface water).

- APCC: A study of Rock Harbor marsh was conducted in 2006. The marsh is restricted by Dyer Prince Road. The study includes pore and surface water salinity measurements, plant identification and percent cover (estimated within m^2 quadrats). Bird monitoring was conducted, including point source counts and activity; and nekton (fish) were caught, identified, measured and weighed. Water temperature, DO, pH, and specific conductivity was measured at the fishing stations.

- Cape Cod Commercial Hook Fishermen Association: A 2006 field study of Rock Harbor marsh off of Rock Harbor Road included pore and surface water salinity measurements and plant identification and percent cover (estimated within 1 meter square quadrats). Bird monitoring included point source counts and activity; and nekton were caught, identified, measured and weighed.

- Coastal Zone Management: The 2000 – 2003 Cape Cod Salt Marsh Assessment Project included studies of Boat Meadow Creek and Nauset Estuary at Mary Chase marsh in Eastham. Plant identification and percent cover was estimated within m^2 square quadrats, and pore and surface water salinity measurements were taken.

- US Geologic Survey (USGS): Groundwater evaluations have been completed for the tri-town plume and potential impact to Namskaket Marsh (final report pending, presentation made by Dr. Peter Weiskel to the Orleans Board of Selectmen on April 20, 2011).

- Division of Marine Fisheries: The agency is providing ongoing technical support to Orleans regarding diadromous fish populations in Pilgrim Lake and Cedar Pond.

- Cape Cod Commission (CCC): The Commission reviewed and interpreted the freshwater pond volunteer monitoring data in 2006.

- Horsley and Witten, Inc.: In 2003, a qualitative survey of pond shore vegetation was completed at eleven freshwater ponds in the Pleasant Bay Area of Critical Environmental Concern including the following ponds in Orleans: Crystal, Pilgrim, Little Quanset, Sarah's, Gould and Uncle Seth's.

5. Monitoring Demonstration Projects

The preferred locations of demonstration sites selected by Shellfish, Permeable Reactive Barrier and Floating Constructed Wetlands teams are shown in Figure 3.

Insert Figure 3

Based on the MEP model, both the Nauset Harbor and Pleasant Bay System watersheds have recommended nitrogen removal rates that are significantly higher than the expected TN or BioN removal of demonstration projects. The target nitrogen load reduction for the entire Pleasant Bay System is almost 17,000 kg N/year, with each sub-watershed in the Pleasant Bay system having a lower target nitrogen removal rate than the system as a whole. The target nitrogen load reduction for the Nauset Harbor system is approximately 8,600 kg N/year, while the Town Cove sub-embayment target load reduction is approximately 6,700 kg N/year. Since these estuarine systems circulate water and mix nutrients, it is not likely that a relatively small uptake of nitrogen in just one sub-embayment will register a reduced TN concentration at its sentinel station, even if it is a significant percent of the nitrogen load reduction for that sub-watershed.

Therefore, to quantify the nitrogen-removal of a demonstration project, monitoring plans will need to be designed to capture localized water quality improvements near the demonstration sites. In the case of the shellfish and floating wetland demonstration projects this goal is accomplished by understanding the baseline (reference) conditions at each of the sites in addition to post monitoring, once the demonstration projects are installed. For these demonstration projects, positioning monitoring stations upstream, instream and downstream of the demonstration project location and with a high spatial resolution will be necessary. Water quality samples are then analyzed for different nitrogen fractions, including nitrate, ammonia, DON, PON as well as other water quality indicators such as DO and pigments. TM 4.a.3 presents a detailed monitoring plan for the demonstration projects based on this approach.

In terms of establishing baseline conditions, The MEP report for Nauset Harbor watershed includes fifteen monitoring stations, WMO-25 to WMO-40, as shown in Figure 2. The only stations that have a complete set of data from 2003-2014 are WMO- 27 (the Sentinel Station for the Nauset Harbor in Town Cove), WMO-34 (Mill Pond), and WMO-38 (Salt Pond). The remaining monitoring stations only have consistent data for 2003 through 2004, with sporadic data collected in 2005. These three stations do not provide sufficient spatial resolution within the sub-embayments of this estuary to establish a baseline to compare against demonstration monitoring data. Although Pleasant Bay is sampled at twenty-four stations, there are long distances between stations. Moreover, the standard deviation for annual average values in both Pleasant Bay and Nauset Harbor ranges from 10 percent to over 50 percent. This indicates that there is a large range of values in the approximately five data points collected within a season. Averaging these data points to establish an annual value for a given parameter is the accepted practice of the MEP for overall water quality determination. This data set is valuable for long term study and gross comparisons within the watershed, however, in order to quantify a small change in nitrogen that is removed from a shellfish or floating wetland installation, pre installation samples taken in close proximity to the demonstration sites are needed to establish reference values at a given demonstration location.

For permeable reactive barriers (PRB), the expected monitoring protocol will involve direct measurements of groundwater upstream, within and downstream of the PRB installation. This will enable clear quantification of the effectiveness of this technology. To capture the impact of a PRB to the waterbody, monitoring stations where groundwater is expected to enter the estuary are recommended.

Current stations are not adequate for establishing baseline conditions with enough precision to identify fluctuations from demonstration monitoring. A detailed monitoring program will need to be developed with high spatial and temporal resolution and input from experts as part of the water quality and wastewater planning process. TM4.a.3: *Non-Traditional Technology Performance Monitoring* will present the specifics of a recommended monitoring program for each proposed demonstration.

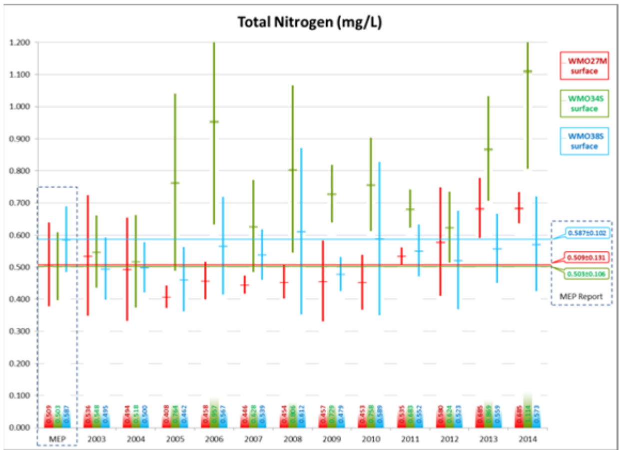
6. Evaluation of Current Data Sets and Comparison with MEP Baselines

a. Nauset Harbor Data Review

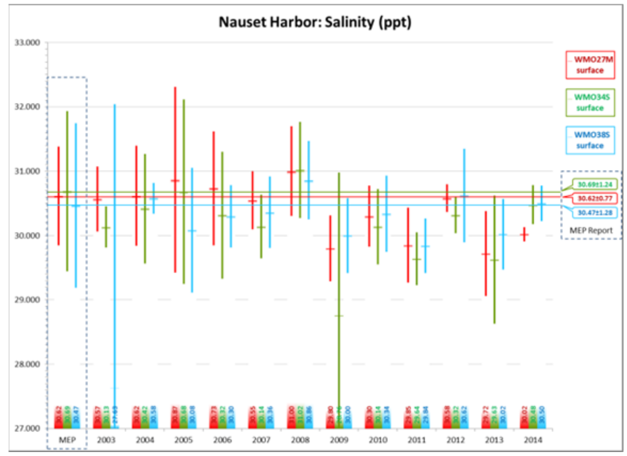
The Nauset Harbor baseline parameters reported in the MEP Report (SMAST, 2012) include:

- TN and salinity at stations WMO 25 – 40, for the years 2001 – 2004.
- DO and Chl-*a* are provided in the MEP report as a trace of continuous monitoring SONDE data over an approximately 30 day period in 2003. The methodology used to present the measurements in the report is not comparable to the methodology used for grab samples collected in subsequent years. The source data required to make a meaningful comparison of the data sets was not available. Grab sample data collected in 2003 – 2004 as part of the MEP field investigations are presented for comparison with current data.

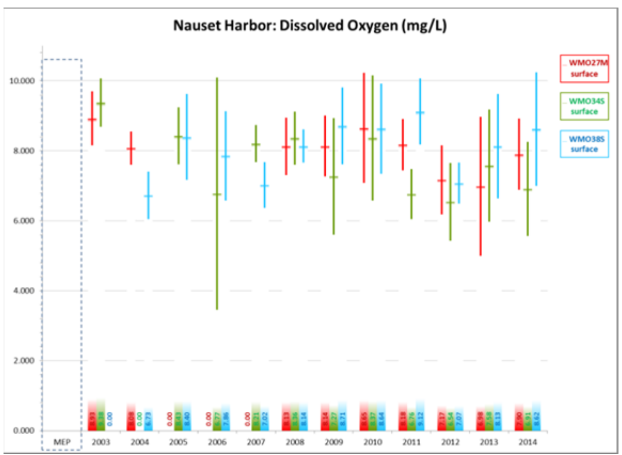
Figure 4 (a-d) compares the values from the MEP Report (2001-2004 averages) to the years 2003 through 2014 for TN and salinity, at stations WMO-27 (Town Cove, red data), WMO-34 (Mill Pond, green data) and WMO-38 (Salt Pond, blue data). DO and Chl-*a* are compared to grab sample data for 2003 and 2004. Figures 5 and 6 show the difference between surface and bottom measurements at Mill Pond and Salt Pond for these same parameters. Town Cove only has samples taken at one depth.



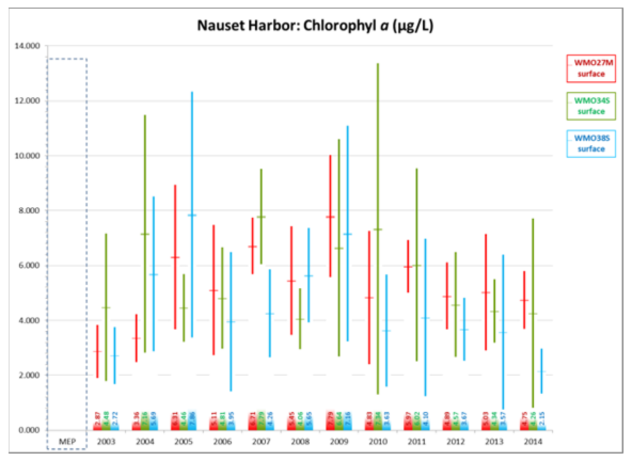
(a)



(b)

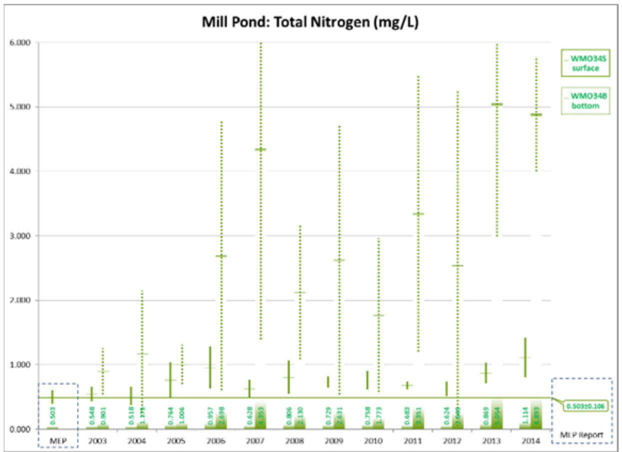


(c)

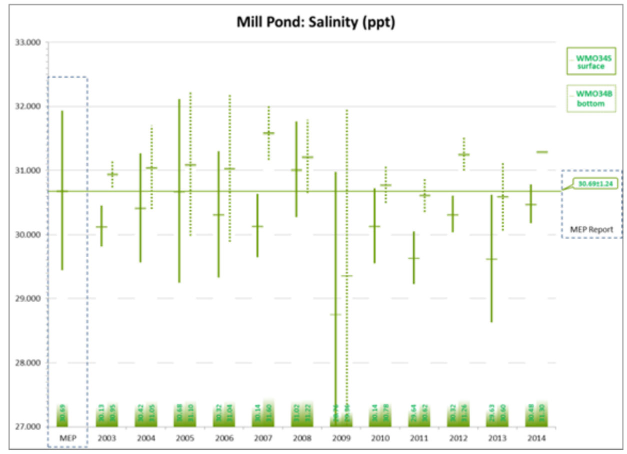


(d)

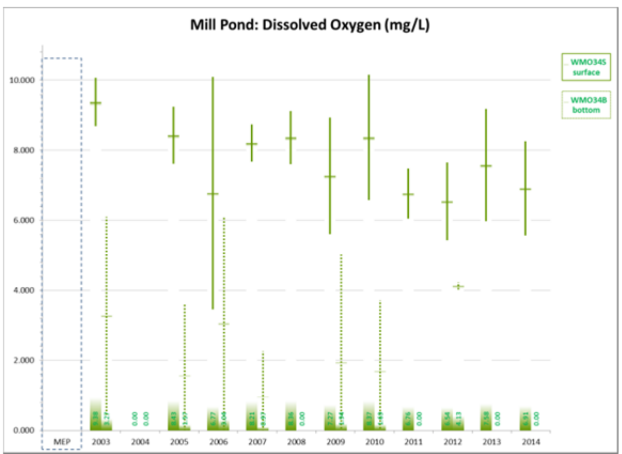
Figure 4: Comparison of data in the MEP report to recently collected data for Nauset Harbor (Town Cove, Mill Pond and Salt Pond sites) for: (a) TN (mg/L), (b) salinity (ppt), (c) DO (mg/L); and (d) chlorophyll a (mg/L)



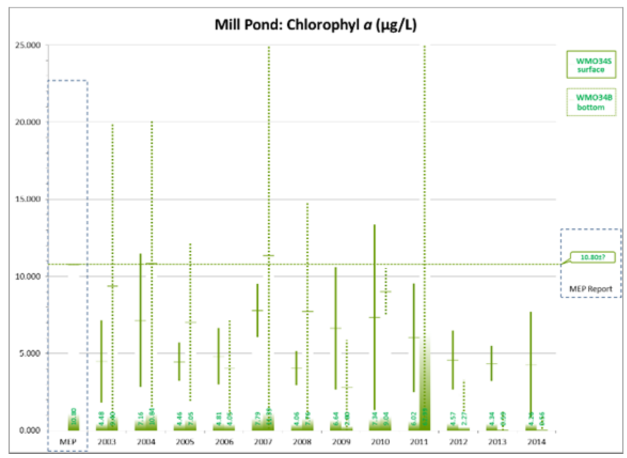
(a)



(b)

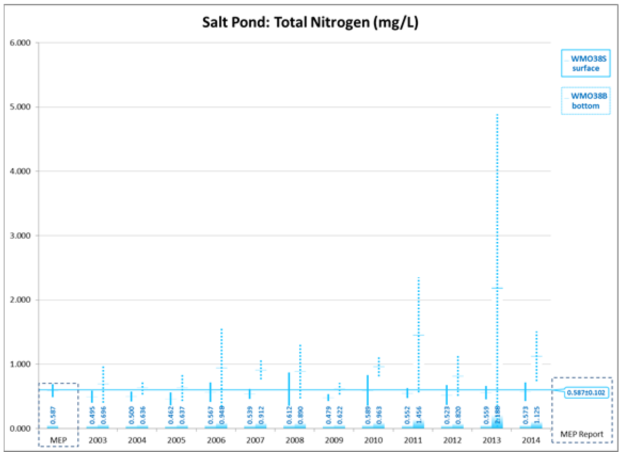


(c)

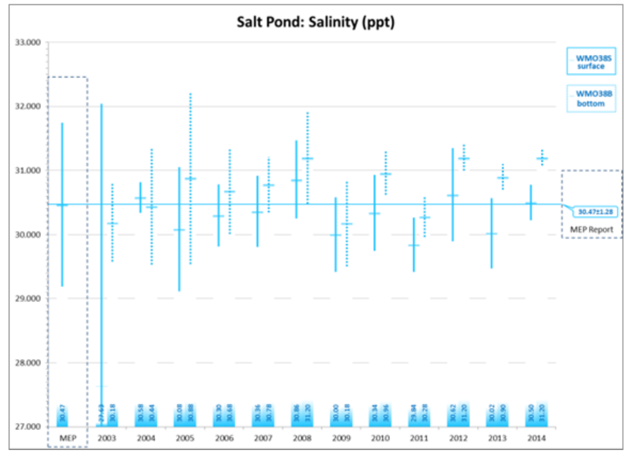


(d)

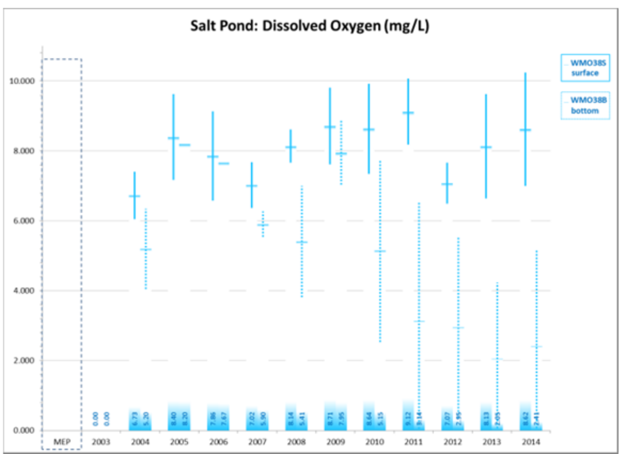
Figure 5: Comparison of data in the MEP report to recently collected data for Nauset Harbor (Mill Pond) showing the difference between surface and bottom measurements for: (a) TN (mg/L), (b) salinity (ppt), (c) DO (mg/L); and (d) chlorophyll a (mg/L).



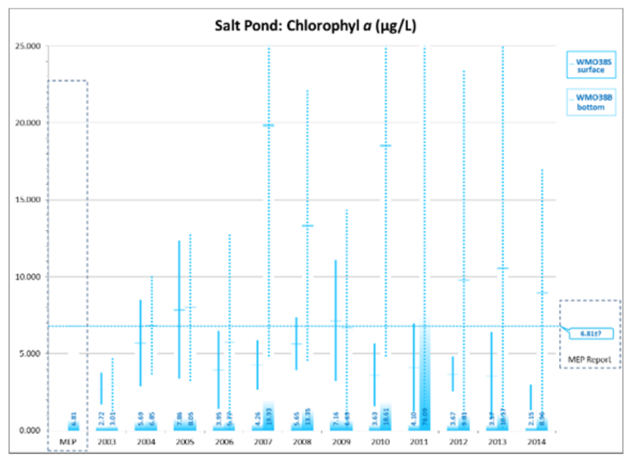
(a)



(b)



(c)



(d)

Figure 6: Comparison of data in the MEP report to recently collected data for Nauset Harbor (Salt Pond) showing the difference between surface and bottom measurements for: (a) TN (mg/L), (b) salinity (ppt), (c) DO (mg/L); and (d) chlorophyll a (mg/L).

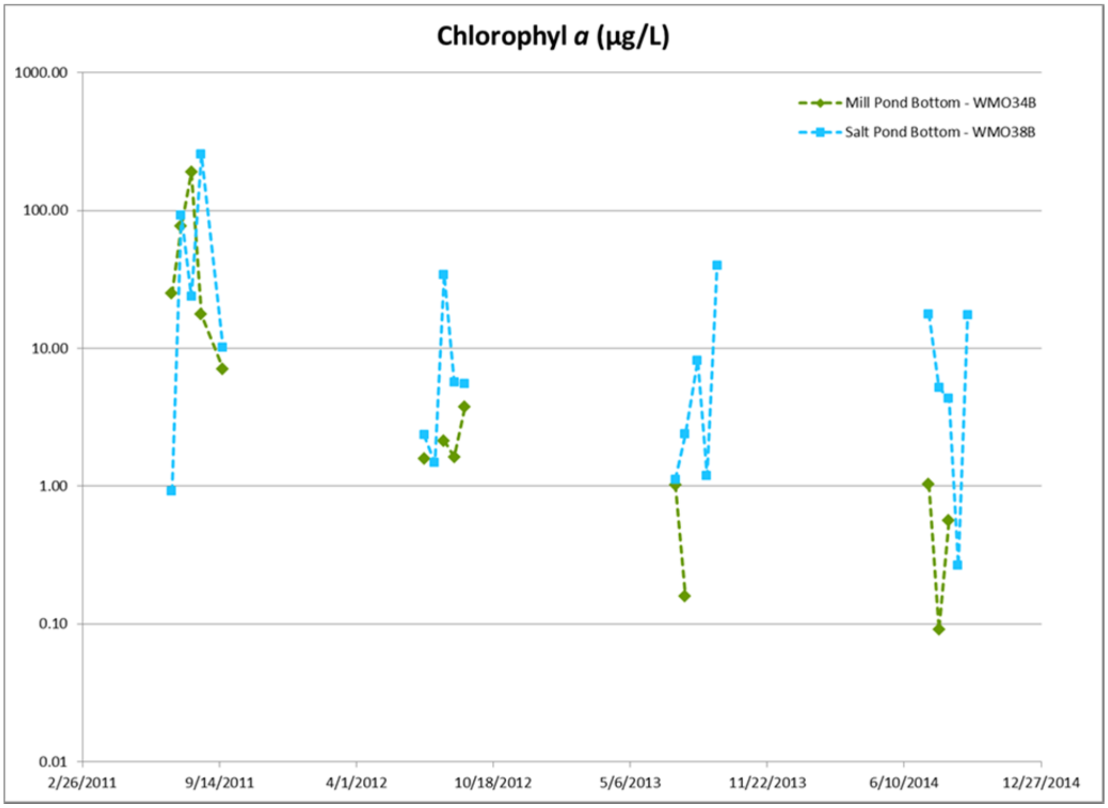


Figure 7: Chl-a for Mill Pond (WMO-34B) and Salt Pond (WMO-38B as a function of time (2011-2014)

b. Nauset Harbor Assessment

Figure 4 compares the MEP report to recently collected data for Nauset Harbor. The MEP report based water quality assessments on data from fifteen stations (only data from three stations shown). Currently, there are three stations being sampled, representing the Town Cove, Mill Pond and Salt Pond systems. To establish robust baseline conditions for Nauset Harbor, additional stations are recommended so that trends and values shown at the single stations in these sub-embayments can be compared to data from additional locations in the same system. Comparison of these stations is as follows:

- TN: Since 2011, Town Cove has been consistently higher than the MEP baseline values; Mill Pond has been consistently higher than the MEP baseline values since 2010; and since 2011, Salt Pond has been consistently lower than the MEP baseline values, but has been rising towards the baseline since 2012.
- Salinity: Town Cove has been consistently lower than the MEP baseline value since 2009; Mill Pond has been consistently lower than the MEP baseline value since 2009, but in 2011 began approaching that baseline; and Salt Pond has been above and below the MEP baseline value since 2003, and in 2014 was essentially at that baseline.
- DO: Town Cove and Mill Pond have been consistently lower than the MEP data from the data sets from 2003; and Salt Pond has been higher than the MEP data from 2004.

- Chl-*a*: Town Cove has been consistently higher than the MEP data from the data sets for 2003 but is declining; Mill Pond has been oscillating above and below the MEP data for 2003 but was lower in 2014; and Salt Pond has been higher than the MEP data for 2004 since 2009, but in 2010 began to decrease and in 2014 was slightly lower relative to 2004. There is significant variation in the data, as shown by the standard deviation bars.

While the Total Maximum Daily Load (TMDL) for TN has not yet been established by the Environmental Protection Agency for Town Cove and Mill Pond, neither Town Cove nor Mill Pond meet the target load for nitrogen that is prescribed in the MEP Report, which is 58.718 kg/day and 9.219 kg/day respectively. In addition, TN concentrations are higher than the MEP recommended threshold of 0.45 mg/L at the Sentinel Station in Town Cove. Nitrogen concentrations are also higher relative to the 2003 reference point. Increasing DO and Chl-*a* echo this TN trend. Lower salinity may indicate an occluded inlet and shoaling relative to the 2003 value.

An analysis of the available data also highlights the importance of surface and bottom measurements to understanding water quality trends as seen in Figures 5 and 6. Differences in data values for surface and bottom sampling locations are apparent for all four parameters at both stations where data was available for comparison. One notable example is the TN values. Focusing on trends at the surface will miss the higher TN values at the bottom in both Mill Pond (WMO-34B) and Salt Pond (WMO-38B). The MEP report seems to have reported surface TN data, but sampling depth is not stated in the documentation.

Another notable feature of the data was discovered when examining Chl-*a* for Mill Pond (WMO-34B) and Salt Pond (WMO-38B). Figures 4d and 5d show very large standard deviation for the 2001 bottom Chl-*a* data. Plotting each measurement as a function of time (Figure 7) suggests an exponential decline over the course of years. Note the logarithmic vertical scale of the graph. This may have been caused by an algal bloom occurring during the sampling time at Salt Pond (WMO-38B) in 2011, with the values in subsequent years showing a continuous declining trend. By 2014, values in Salt Pond had returned to typical pre-2011 levels. However, values in Mill Pond had decreased to near zero by 2014, possibly indicating a permanent change in this ecosystem. However, a change in the water depth from which the sample is taken can also impact results.

The significant difference between surface and bottom data in Nauset Harbor emphasizes the importance of sampling different depths in the water column in order to characterize water quality. The information in Figure 7 indicates that potentially significant spikes over the course of a season, as well as trends over the course of multiple seasons, may be obscured by simply averaging together data from individual year samples.

A brief review of the data sets provided to Orleans shows large anomalies in some of the data. These may be the result of sampling errors, an atypical event or natural temporal and spatial variations within a particular sub-embayment. For the purpose of this analysis, two anomalies for DO concentration, likely data entry or sampling equipment errors, were removed based on correlation to the DO percent saturation recorded for the same sampling event.

The comparison of current data sets to MEP baseline values for DO and Chl-*a* revealed several issues. MEP reported DO and Chl-*a* data as collected using continuous monitoring sondes deployed at the bottom of the water column for approximately 30 days, and tabulated as histograms. Surface data for DO and Chl-*a* was not collected as part of this MEP effort, and standard deviation for Chl-*a* data is not provided. Sonde data is not available in a way that allows extracting values that correlate with the sampling times established for grab sampling. Future monitoring efforts should include a review of data sets for outliers soon after the data is provided, and a provision that historic sonde data sets include a list of measured values and the date and time of each measurement.

c. Pleasant Bay Data Review: Bay-Wide Trends

In order to evaluate trends within all of Pleasant Bay, the Cadmus Report pooled water quality data from samples from all 34 monitoring stations (Cadmus 2015). The number and frequency of samples was considered adequate for establishing trends in overall data parameters. Water between Pleasant Bay and the Atlantic Ocean is currently exchanged through two tidal inlets. South Inlet was formed in 1987, and North Inlet was formed in 2007 when a breach occurred at the southern end of an unbroken, ten-mile stretch of barrier system known as “North Beach”. Geographically the breach is located in North Chatham in the vicinity of Strong Island and Ministers Point. The formation of this new inlet was expected to bring increased tides and flushing to the bay. Both before and after the 2007 breach, several bay-wide trends are evident. The post-breach trends include:

- Increasing DIN, BioN;
- Decreasing Pigments;
- Increasing DO;
- Trends in TN, PO_4 not considered statistically significant; and
- Increased salinity.

Figure 8 presents trends normalized to post-breach 2008 data for different nitrogen fractions and pigments. TN includes DON, PON, and DIN. TN is not used to establish the TMDL for Pleasant Bay because DON, which is mainly from atmospheric deposition, is almost 70 percent of the contribution of TN in this system (Figure 9, grey area at the top indicates DON contribution). BioN is used for the TMDL because it only includes DIN (anthropogenic sources) and PON.

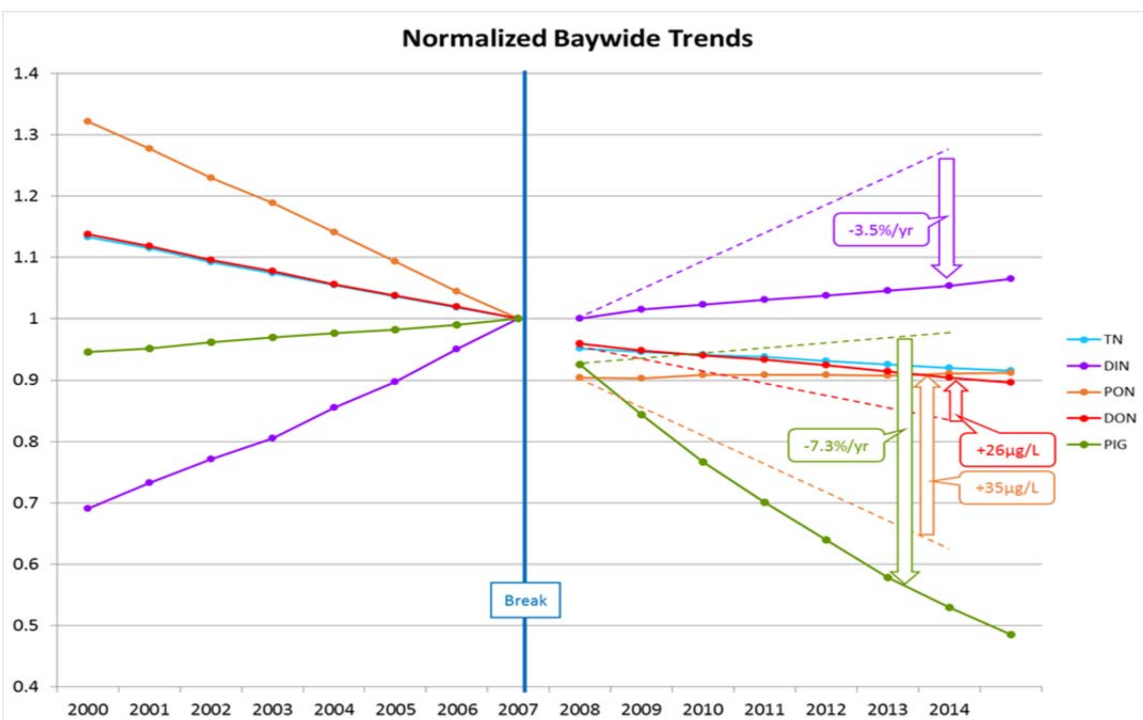


Figure 8: Normalized Trends in Nitrogen Species and Phytopigments

d. Pleasant Bay Data: Bay-Wide Assessment

A Bay-wide analysis of the data shows several unexpected trends:

- DIN is increasing at a slower rate after the break, but PON and DON are not changing in ways that are consistent with this trend;
- BioN (DIN +PON) is increasing but pigments are decreasing;
- While Bay-wide trends show an increase in BioN, individual sampling station values increase at only two locations while eight show a decrease. Nine locations show no statistically significant difference;
- DO is higher at the bottom of the water column; and
- Temperatures are higher at the bottom of the water column.

As shown in Figure 8, DIN was increasing rapidly before the inlet breach. After the breach, DIN continued to increase, but at a significantly slower rate. A steady decline in PON was occurring before the breach. If increased flushing due to the breach was responsible for improving water quality, the expected drop in PON would be more pronounced after the break. Instead, PON started to climb slightly. From 2000 to 2006, PON decreased from 165 μg/L to 131 μg/L, a reduction of 34 μg/L. If this rate had continued from 2008 to 2014, the concentration would have declined from 113 μg/L to 79 μg/L. The actual data shows an increase in PON of 1 μg/L (from 113 μg/L to 114 μg/L) over that time period. This results in 35 μg/L more PON from 2008 to 2014 than would be expected if the pre-breach trends had continued.

DON was also decreasing before the breach. This drop in DON would also have been expected to accelerate after the breach, but the data shows it is decreasing more slowly. Atmospheric trends should be expected to continue unaffected by the breach, but DON from biological activity should be lower if there were increased flushing. Instead the rate of DON decrease lessened. From 2000 to 2006, DON dropped from 484 μg/L to 434 μg/L, a reduction of 50 μg/L. If this rate continued from 2008 to 2014, the expected decrease would have been from 408 μg/L to 358 μg/L. Data shows a 24 μg/L reduction in the concentration of DON, to 384 μg/L. Thus, there is 26 μg/L more DON from 2008 to 2014 than what would be expected if the pre-breach trends had continued. If flushing were improving water quality, then the DON should have decreased below 358 μg/L, the value that would have been measured if the pre-breach trends continued. If this change in BioN were due to increased flushing accelerated decreases in PON and DON should be observed, but this is not the case.

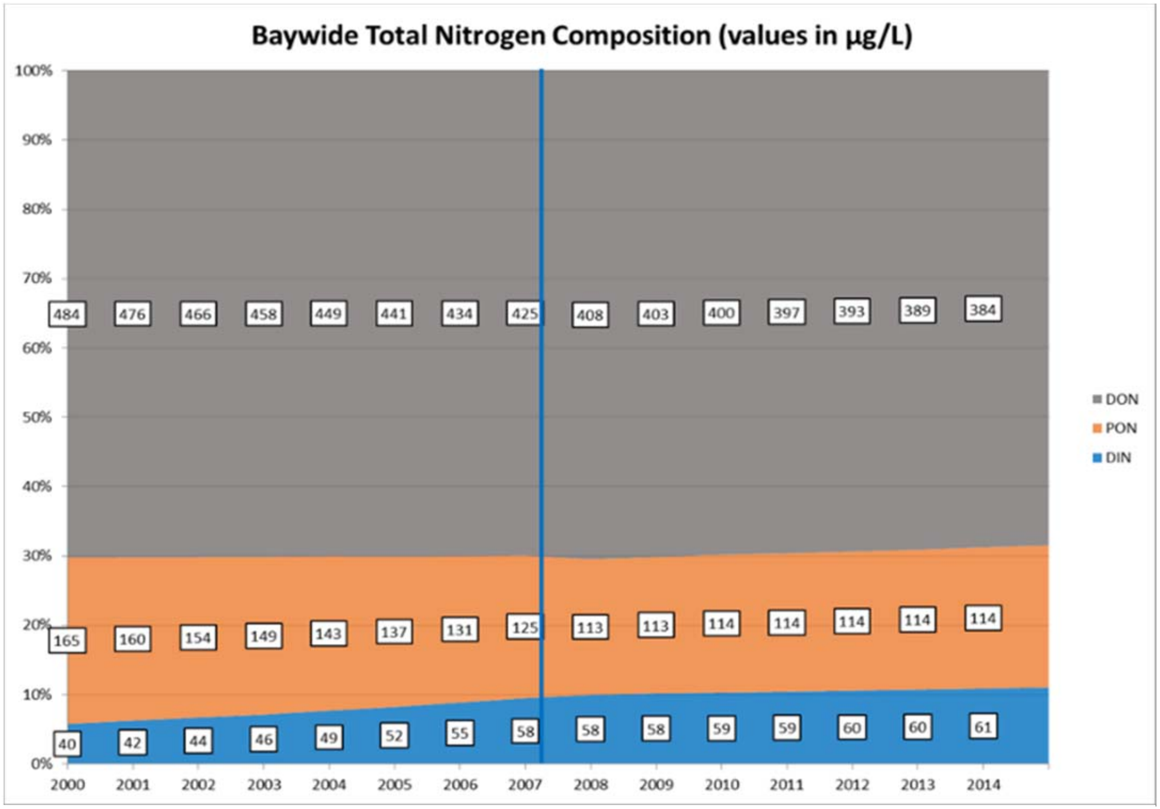


Figure 9: Nitrogen Species as a Percent of Total Nitrogen

A possible explanation for the observed post-breach DIN, DON and PON trends is that macroalgae is outcompeting phytoplankton for DIN uptake, and at the same time contributing additional DON and PON to the water column (MEP 2006). This explanation needs field verification, but matches several observed features of the Bay-wide data:

- The decrease in the rate of increase of DIN concentration at the breach cannot be explained by source reduction.
- Inconsistent DON and PON trends, which seem to rule out increased flushing as an explanation.
- There is 61 g/L more PON and DON combined than would have been expected if pre-breach trends continued, 35 g/L and 24 g/L respectively.
- PON comes from particles of decomposing organic matter and as it continues to break down, some becomes DON. The observed higher concentration of PON relative to DON suggests that the nitrogen fraction is coming from physically large organic matter.
- The rapid decrease in pigments, which had been increasing slightly before the breach, is not matched by a corresponding magnitude of decline in DIN. Figure 8 shows a net 7.3 percent per year decrease relative to the pre-breach trend for pigments (green line) and a net 3.5 percent per year smaller increase relative to the pre-breach trend for DIN (purple line). This suggests that something other than reduced DIN is responsible for the loss of pigments

There are several potential explanations for the seemingly contradictory bay-wide trend that BioN (DIN and PON) is increasing and pigments are decreasing. Pigment reductions may be explained by lower populations of phytoplankton and other microalgae, but BioN may also be stimulating the growth of macroalgae. Macroalgae populations can be promoted by nitrogen levels that are lower than optimal for phytoplankton, yet still elevated (Hein, 1995). Sampling during the summer may not measure DIN and PON accurately because DIN is consumed and PON is produced as part of macroalgae cycling. Summer sampling may be underestimating actual DIN inputs, and may not capture PON. Increased grazing by zooplankton may also be reducing phytoplankton populations. Pigments are the sum of Chl-*a* and phaeophitin. It may be more accurate to track Chl-*a* alone for a more representative measure of microalgae.

Macroalgae may also be impacting sedimentation as it becomes PON. The fraction of BioN related to PON may be resulting in increased deposition of organic matter to the sediments, and not necessarily increased pigment concentrations from algae. This would not show up in water sampling that occurs every 2 weeks, which is likely not to capture algae die-off and accumulation. Although higher DO in bottom samples may be indicating improved conditions, this may also be an artifact of snapshot sampling of this highly dynamic constituent. The DO and temperature difference between surface and bottom indicates an inversion, which may be caused by a number of different factors, such as: (1) the relationship between water temperature and oxygen saturation; (2) less wind and therefore less mixing with the surface which lowers oxygen saturation; (3) less decomposition versus photosynthesis; and (4) time of day samples are taken.

Data analysis is based on the assumptions that DIN is comprised of nitrate and ammonium, DON is from particles smaller than a certain threshold, and PON is from particles larger than a certain threshold. Based on the SMAST Laboratory Analysis QAPP, the threshold is believed to be in the range of 0.22 to 0.45 microns. Macroalgae is likely not included in the reported concentrations, and water analysis does not account for sediment accumulation. Clarification from SMAST is required.

e. Pleasant Bay Data Review: Individual Sites

Long term data sets from Pleasant Bay were investigated to determine whether current water quality data are sufficient to establish baseline conditions for evaluating non-traditional demonstrations in Orleans. According to the Alliance, twenty-four stations are currently monitored in Pleasant Bay. Based on a recent evaluation (Cadmus 2015), as many as thirty-four stations have been monitored over the past fifteen years, and there is sufficient data from twenty (20) of these stations to enable long term trend analysis. This report presents trend lines that were fitted to sampling data for each of these 20 stations, including trends before and after the 2007 breach at Nauset Beach. The specific parameters include: dissolved inorganic nitrogen (DIN), bioactive nitrogen (BioN), total nitrogen (TN), phosphate (PO_4), total phytopigments (pigments), dissolved oxygen (DO) and salinity. This trend analysis for Pleasant Bay monitoring stations includes the following stations in Orleans (Cadmus 2015):

- Meetinghouse Pond (PBA-16);
- The River at Rattles Dock (WMO-10);
- Namequoit South (PBA-12);
- Namequoit North (PBA-13);
- Namequoit Mid (WMO-6);
- Arey’s Pond (PBA-14);

- Kescayogansett Pond (Lonnie's, PBA-15);
- Paw Wah Pond (PBA-11);
- Little Pleasant Bay near Quanset (PBA-8);
- Pochet Mouth (WMO-3);
- Pochet Upper (WMO-5);
- Quanset Pond (PBA-10); and
- Little Quanset Pond (WMO-12).

Stations in Orleans that were not included in this evaluation because of significant gaps in data include the following:

- Pochet (mid): WMO-4 which has not been sampled since 2004;
- The River (mid): WMO-8 which does not have data from 2005-2013;
- Namequoit River (mouth) WMO-7 which has not been sampled since 2004;
- Round Cove: WMO- 9 which does not have data from 2006 to 2013; and
- Pleasant Bay north of Round Cove: PBA-7 which does not have data after 2005.

In the Cadmus Report, the statistical significance of trend lines for individual sampling locations was assessed based on a 5 percent significance level, which corresponds to a 95 percent likelihood that the trend line slope is due to an actual change and not random variation. Based on a 5 percent significance level there are some sites with statistically significant trends, however there are **no consistent trends** in water quality parameters across the twenty (20) Bay-wide monitoring stations that were analyzed.

For each of the Pleasant Bay sites in Orleans, **no statistically significant results** (at 95 percent confidence) were found for the following parameters:

From Table 1, DIN, SRP (PO_4), DO and salinity data is not statistically significant for stations in Orleans. DO is highly dependent on time of day, so lack of trends with statistical significance may indicate variability in sample collection times, even if the samples were acquired within the QAPP range. The lack of trends for DIN and PO_4 may be a function of the sampling period being restricted to summer when biologic activity is widely variable. Another observation for Orleans sites (Cadmus 2015) is that when BioN has a statistically significant result, the BioN is decreasing.

		DIN	BioN	TN	SRP (PO_4)	pigment	DO	salinity
Meetinghouse Pond	(PBA-16)	X	-	X	X	-	X	X
Namequoit South	(PBA-12)	X	-	-	-	-	-	-
Namequoit North	(PBA-13)	-	X	X	X	-	X	X
Namequoit Mid	(WMO-6)	X	-	-	X	-	X	X
Pochet Upper	(WMO-5)	X	X	X	-	-	-	X
Kescayogansett Pond (Lonnie's)	(PBA-15)	X	-	-	-	-	X	X
Paw Wah Pond	(PBA-11)	X	-	-	X	-	X	-
Pochet Mouth	(WMO-3)	X	-	-	X	-	X	X
Little Quanset Pond	(WMO-12)	-	-	-	X	X	-	-
Arey's Pond	(PBA-14)	X	X	X	X	-	-	X
Quanset Pond	(PBA-10)	-	-	-	-	-	X	X

Table 1: Water Quality Parameters with no statistically significant results at the 95 percent confidence interval are indicated by an X. Boxes with a dash indicate statistically significant trends (based on Cadmus 2015).

Appendix F of the Cadmus Report presents graphed data for DIN, BioN, TN, SRP (PO_4), Pigments, DO and salinity for all monitoring locations (Cadmus 2015). These data were also evaluated and are presented in Table 2. Black text, a black "X" or arrow "↑" indicate an improved water quality value; and red text, a red "X" or arrow "↓" indicate a degraded water quality value. When values are not statistically significant, they are shown in brackets.

		BioN Above TMDL (X) or Below/Near TMDL (X)	Pigments Below 5 µg/L or Decreasing	DO Increasing (↑) or Decreasing (↓) or Steady State below 6 mg/L (SS)	DIN Increasing (X) or Decreasing (X) or Steady State (SS)	ACTION
Meetinghouse Pond	(PBA-16)	X	X	[↓]	[SS]	Confirm System Health
Namequoit South	(PBA-12)	X	X	↑	[X]	Confirm System Health
Namequoit North	(PBA-13)	[X]	X	[↑]	X	Confirm System Health
Namequoit Mid	(WMO-6)	X	X	[SS]	[X]	Confirm System Health
Pochet Upper	(WMO-5)	[X]	X	↑	[X]	Confirm System Health
The River at Rattles Dock	(WMO-10)	X	X	↑	[X]	Determine Why Inconsistent
Kescayogansett Pond (Lonnie's)	(PBA-15)	X	X	[SS]	[X]	Determine Why Inconsistent
Paw Wah Pond	(PBA-11)	X	above 5 µg/L	[SS]	[SS]	Determine Why Inconsistent
Pochet Mouth	(WMO-3)	X	X	[SS]	[X]	Determine Why Inconsistent
LPB Near Quanset (Big Bay NE)	(PBA-8)	[X]	X	↑	X	Determine Why Inconsistent
Little Quanset Pond	(WMO-12)	X	[X]	↓	X	Treat as Impaired
Arey's Pond	(PBA-14)	[X]	above 5 µg/L	↓	[SS]	Treat as Impaired
Quanset Pond	(PBA-10)	X	above 5 µg/L	[↑]	X	Treat as Impaired

Table 2: Water Quality Parameters with Action Items. Both statistically significant trends as well as trends that are not statistically significant are shown (based on Cadmus 2015).

From Table 2, BioN is below or near TMDL for seven of 13 stations in Orleans, and pigments are either below an acceptable level of 5 µg/L or are decreasing with statistical significance at all stations that were evaluated except three. This unexpected decrease in BioN and Pigments was further evaluated by reviewing Secchi depth (turbidity) data and calculating the standard deviation for select sites (Figure 10 and 11). Secchi depth was normalized to the average depth from years 2000 through 2002. In Figure 10, the solid lines indicate stations where Secchi depth is increasing (turbidity is decreasing) and that water clarity is improving after 2010. Data from Figure 8 shows decreasing pigments, which matches data (stations represented by solid lines) in Figure 10, suggesting decreased turbidity. However, neither DIN nor DO consistently follow the BioN and pigment trends for water quality improvement. DIN is increasing at both Quanset Pond and the Lower River, but only Quanset Pond shows a statistically significant increase in BioN.

These results are not surprising since in estuaries, N concentrations, especially the inorganic forms, typically vary widely seasonally, interannually, and along salinity gradients. As detailed in the discussion on Bay-wide trends, the timing of sample collection and macroalgae uptake and organic contributions may be impacting DIN, DON and PON concentrations. Systems may be achieving water quality standards based on N sampling, measures of algal biomass (e.g., chlorophyll a), water clarity (e.g., Secchi depth) or DO, yet still show inconsistencies in long term data sets because nitrogen fractions are cycling in new ways in response to environmental changes. For example, the concentration of the primary N variables may not correlate well with one or more response variables such as phytoplankton production. Physical factors such as salinity, pH and temperature gradients and input and outputs of fresh or salt water (e.g. flushing) play an important role in the N process and phytoplankton productivity.

Discerning patterns in N loads and cycling is further complicated by biogeochemical processes such as: N2 assimilation directly from the atmosphere by N fixation; the high solubility of DIN, especially nitrite and nitrate that does not precipitate easily or sediment out when freshwater enters a brackish zone; varying sediment biogeochemical conditions (e.g., due to macroinfauna presence/absence, oxic or anoxic conditions in the overlying bottom water, and water column depth). Biological factors such as the increase or decrease in seagrass and submerged aquatic vegetation, macroinfaunal community structure, phytoplankton species composition, and organic carbon concentrations can also play a role in N dynamics.

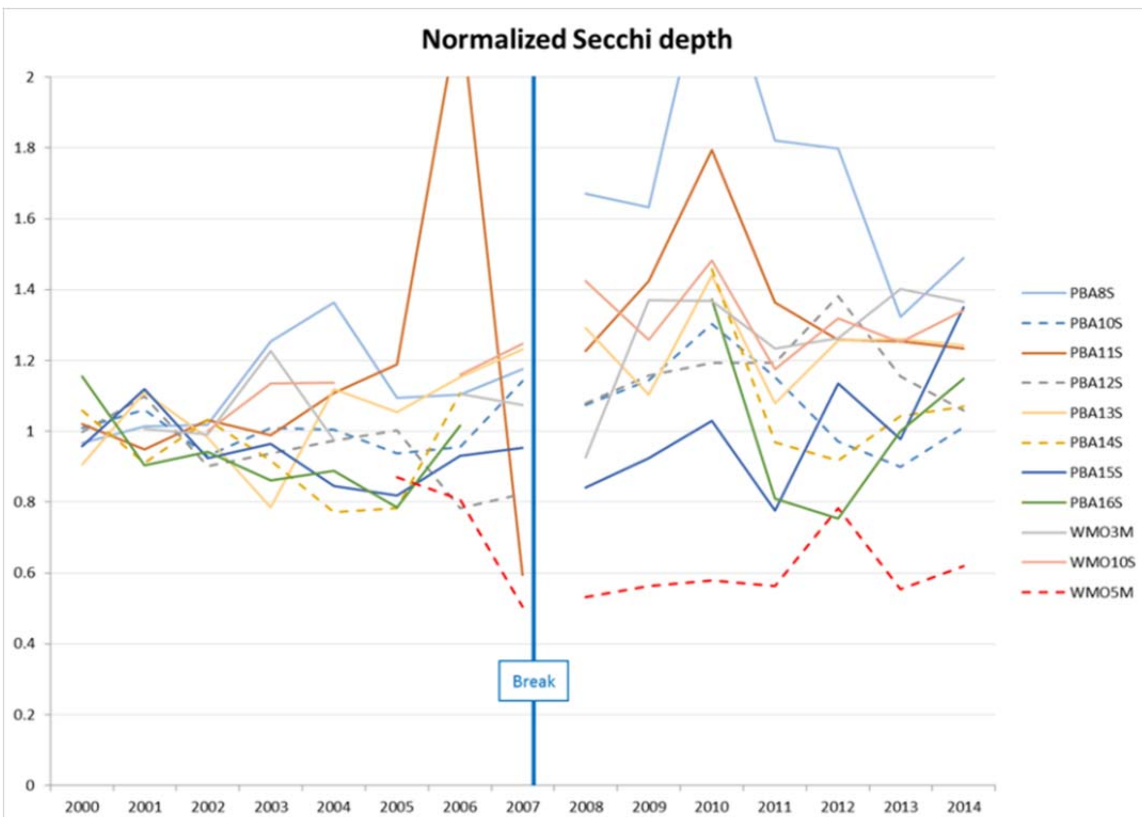


Figure 10: Normalized Secchi Depth

The Figures presented in this TM for Nauset Harbor include standard deviation bars for each site. The trend analysis for Pleasant Bay (2015) does not show the internal variation in the annual averages plotted and fit to a trend line. A hallmark of water quality data is the wide variability in data values. The MEP-approved technique of averaging the approximately five sample values taken over a season to establish an annual value yields standard deviation that are typically around 20 percent and often over 30 percent. Figure 11 shows Standard Deviation for representative sites:

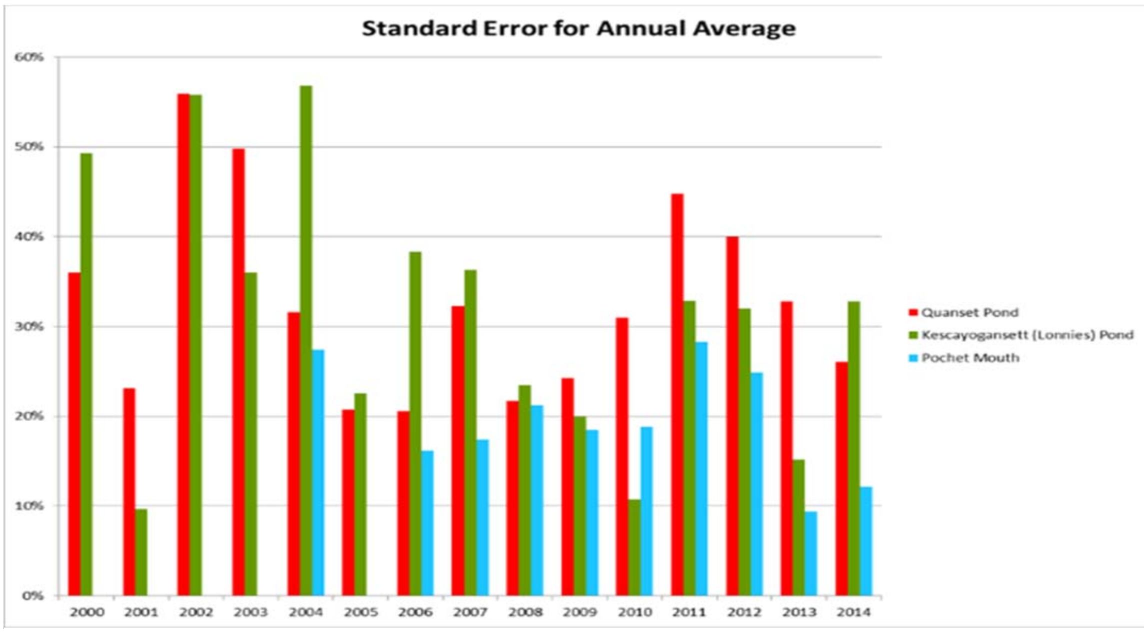


Figure 11: Standard Deviation for Select Sites

f. Pleasant Bay Data: Individual Site Assessment

As shown in Table 2, Orleans stations are grouped based on three action items:

- Confirm system health
- Determine why inconsistent;
- Treat as impaired.

Confirming system health is recommended when the station is below the TMDL for BioN and other water quality parameters such as total pigments show improved conditions that reflect acceptable BioN concentrations. Five of thirteen stations are in this category. Determining why parameters are inconsistent is suggested for sites where either BioN is at or near the TMDL, but other parameters indicate impairment, or BioN is above the TMDL but other parameters seem to show that the system is in good condition. Five of thirteen sampling stations are in this category. Treating systems as impaired is designated for sub-embayments where the range of water quality parameters consistently show degraded conditions. Three of thirteen stations are in this category.

Ecosystems are impacted by many different variables. Trend observations from fifteen years of Pleasant Bay data underscores this complexity. For this reason, the MEP recommends quantifying several indicators of health, including water quality, benthic environment and key species such as eelgrass and macroalgae. Implications for a long term monitoring program based on this data analysis follow in Section 7: Findings.

7. Findings/Recommendations

A review of data from monitoring programs in both Pleasant Bay and Nauset Harbor reveal a significant variability in water quality data. There are several key implications of this analysis:

- Establishing current baseline conditions requires additional sampling locations in Nauset Harbor, and additional study of the biogeochemical processes impacting nutrient cycling in select sub-embayments of Pleasant Bay;
- Establishing baseline conditions that will enable the effect of demonstration projects to be quantified requires site-specific monitoring with high spatial and temporal resolution to capture the localized range in values for water quality and benthic parameters; and
- A recalibration and rerun of the Massachusetts Estuaries Project (MEP) model for Pleasant Bay is warranted based on the changes in physical conditions and measured nutrient concentrations.

A detailed monitoring program, including assignment of responsibility for accomplishing program tasks, will be provided in TM 4.a.2: *Long Term Waterbody Monitoring Program*. The following findings provide the framework for this subsequent TM:

a. Utility and Recommendations for Existing Station Locations

There are currently three stations monitored in Nauset Harbor. Based on the analysis detailed in Section 6, additional monitoring locations, such as the original fifteen MEP stations, are recommended in order to accurately assess this estuary.

There are currently twenty-four stations monitored in Pleasant Bay. Based on the analysis detailed in Section 6, these station locations may be adequate. However, the stations in Orleans where water quality parameters do not show consistent trends are recommended for further evaluation. This study of ecosystems response to TMDL-compliance may require additional stations in Pleasant Bay.

b. Recommended Monitoring Frequency, Parameters, and Analyses

Recommended additional monitoring and evaluations include:

- Additional sampling dates;
  - Spring (March/April)
  - Fall (Sept/October)
- DIN and PON concentrations sorted by temperature, based on additional sampling;
- Macroalgae populations and nutrient flux;
- DON changes due to reduced atmospheric deposition;

- Pigment assessments based on Chl-*a* only;
- Continuous DO and Chl-*a* monitoring at Sentinel Stations;
- Benthic assessments; and
- Data triggers.

Based on the analysis presented in Section 6, sampling dates in early spring (March/April) and fall (October/November) should be added for several reasons. Samples collected in the spring are recommended because the nitrogen associated with biologic activity within the ecosystem is minimized and the human-derived component can be more easily quantified. DIN is assimilated during July and August when biologic activity is at its maximum, therefore samples taken during this timeframe likely underestimate DIN, therefore BioN concentrations are inaccurate. Conversely, PON and DON concentrations may be higher during the summer because they are a by-product of biologic activity from salt marshes and macrophytes.

The July and August sampling period was established over a decade ago because it was believed that eutrophic conditions were peaking, but monitoring before peak conditions may facilitate discerning trends. The other benefit of early and late season monitoring is that it will capture peaks, and will show data before and after these peaks. In this way, nitrogen species can be better correlated to their sources, and PON and DON cycling can be captured. The large variability in data values, as shown by the standard deviation of annual averages, has implications for the number of sampling events that should be occurring. Additional sampling should be grouped according to water temperature to assess the impact of temperature on trends.

If the hypothesis that DIN is assimilated into macroalgae is correct, then water sampling should be supplemented with assessment of macrophytes in the water column, as well as in bottom sediments. Macrophyte surveys (macroalgae and eelgrass) are recommended for both Pleasant Bay and Nauset Harbor. Macroalgae consume DIN but release PON. Because pigments seem to be decreasing as DIN increases in some sub-embayments, macroalgae should be surveyed and quantified as a possible sink for DIN and a source of PON. Because taxa respond differently, identifying macrophyte species can help evaluate changes in nitrogen regimes. Macroalgae may be impacting the nitrogen budget in ways that would otherwise seem contradictory by looking at water quality parameters alone.

The TMDL for Pleasant Bay and its sub-embayments is based on BioN because the DON fraction that comes from atmospheric sources is approximately 70 percent of TN (Figure 8). Recent research in Waquoit Bay suggests that the amount of DON contributed by atmospheric sources has declined over 50 percent since 2000 (Valiela, in press). Data from Pleasant Bay shows that since the breach, DON has been decreasing at a significantly lower rate than before the break. There is reason to believe that contributions from atmospheric sources were higher before the breach and have continued to decrease since (Valiela, in press). The stalling of the DON decrease may be due to contributions from the decay of microorganisms. If this is the case, it is a significant problem for the health and future of the Pleasant Bay ecosystem. Because DON is a major contributor to the total nitrogen that stimulates biologic activity (Bronk, 2007), this hypothesis should be confirmed.

In addition, BioN as defined in the TMDL includes DIN and PON. To understand ecosystem loading, tracking DIN separately from PON during the early spring is advised. In addition, characterizing PON as well as DON cycling and fluxes in the Pleasant Bay system may explain some of the inconsistencies in the parameter trends for water quality. Laboratory analysis of water samples for nitrogen fractions of nitrate, ammonium, DON, and PON should continue. Organic fractions should not be determined arithmetically.

The Chl-a fraction of total pigments should be evaluated for trends. Continuous DO monitoring is recommended for all sentinel stations because the cycling of this parameter is more indicative of ecosystem functioning than a grab sample that is only a snapshot in time. While additional water quality parameters are not necessary, DIN, DON and PON should be evaluated in the context of nutrient cycling, macroalgae growth, and reduced atmospheric deposition.

Baseline data analysis indicates that it may improve water quality evaluations if data triggers were instituted. When values exceed a certain threshold, in-depth monitoring of these outlier events could be undertaken. For example, a ten-fold increase in Chl-a between samples could trigger the deployment of sensors with high temporal and spatial resolution to confirm algae blooms. DO falling below 2 mg/L could trigger evaluation of the duration of anoxic events. Another trigger could be weather-related. Periods of overcast conditions could trigger additional sampling to collect data that yields process information used to assess sensitivity of ecosystems to nutrient loads. This would require connecting sampling efforts to near-real-time sample processing and data analysis. Over time, this documentation of algal blooms and sustained periods of anoxia could provide an additional set of baseline conditions. As projects are implemented to reduce nutrient loading, the frequency and duration of these events could be compared to this baseline. This would serve as an additional, perhaps more representative tool for evaluating ecosystems health in response to load reduction.

c. Recommended Additional Demonstration Monitoring

As described in Section 5, demonstration monitoring requires data collection at high spatial and temporal resolution. Standard deviation has implications for the number of sampling events that are needed for evaluating a demonstration project that removes modest amounts of nitrogen. Current data sets are not adequate for establishing a baseline to which the impact of demonstration projects can be compared. A detailed monitoring program for evaluating demonstration projects is the subject of TM 4.a.3: *Non-Traditional Technology Performance Monitoring* (task 4.a.3) which will present the specifics of a recommended monitoring program for each demonstration site.

d. Recommended Monitoring Coordination, Compilation and Review of Data

There are valuable data collection programs occurring across water bodies in Orleans. To maximize the benefit of these efforts, annual compilation, review and analysis is recommended. In addition, it is suggested that reports present figures in a way that allows the data points to be known. Increasing the number of monitoring stations in Nauset Harbor will require a higher level of volunteer coordination. Meeting the personnel and technical support requirements is an important aspect of the overall monitoring program in Orleans.

8. References

Bronk, DA., 2007. DON as a Source of Bioavailable Nitrogen for Phytoplankton, Biogeosciences 4, 238-296.

Center for Coastal Studies, 2014. A Study of Cedar Pond and the Rock Harbor Estuary, p. 3.

Center for Coastal Studies, 2012. How is Our Bay? Five Years of Environmental Monitoring of Cape Cod Bay, p.8.

Hein, M, Pedersen, M, and Sand-Jensen, K., 1995. Size Dependent Nitrogen Uptake in Micro- and Macroalgae, Marine Ecology Progress Series, 118: 247-253.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, Kelley, S, Ramsey, J and Detjens, P 2012. Massachusetts Estuaries Project: Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Nauset Harbor Embayment System Towns of Orleans and Eastham, Massachusetts. 188 pp.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, Kelley, S, Ramsey, J and Detjens, P, 2006. Massachusetts Estuaries Report: Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster and Harwich, Massachusetts.

Pleasant Bay Alliance 2015. Water Quality Monitoring Program: Statistical Analysis of 2000-2014 Water Quality Monitoring Data, Cadmus Group.

Pleasant Bay Alliance 2010. Water Quality Monitoring Program: Statistical Analysis of Multi-Year Water Quality Monitoring Data, Cadmus Group.

Valiela, I, and Lloret, J., Eutrophication of Cape Cod estuaries: Effect of Decadal Changes in Global-Driven Atmospheric and Local-Sscale Wastewater Nutrient Loads, Ecosystems Center, Marine Biological Laboratory, Woods Hole MA 02543, USA (submitted).