

Memorandum

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Michael Domenica, PE, Program Manager

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Subject **Town of Orleans, MA**
Water Quality and Wastewater Planning
Task Number 4.a.1 – Adaptive Management Plan
Technical Memorandum on Draft 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 02/08/16

1. Background

The estuaries in Orleans have been studied for decades. Now, the town is planning to implement nutrient remediation measures to improve ecologic conditions in these degraded systems. Ongoing monitoring efforts should be able to quantify changes and trends in water quality and benthic parameters that result. The town's monitoring program should be sufficient to accomplish the following:

- Establish 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

The purpose of this Technical Memorandum (TM) is to evaluate the adequacy of sampling locations and sampling methodology (protocols and parameters) for establishing the baseline conditions as stated above. To make this assessment, existing water quality data sets for Orleans have been consolidated and reviewed, and missing data elements have been identified. In addition, ten plus years of water quality information, collected and detailed in the Massachusetts Estuaries Project (MEP) reports, is compared to baseline monitoring data from these reports and trends have been documented. Findings and recommendations for additional monitoring to meet the goals have been outlined. 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-Structural 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.

2. Introduction

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

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

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, field dissolved oxygen, field dissolved oxygen percent saturation, field water temperature, laboratory salinities, laboratory conductivity, phosphate (PO₄), ammonium (NH₄), nitrate (NO_x), dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), total dissolved nitrogen (TND), particulate organic carbon (POC), particulate organic nitrogen (PON), total organic nitrogen (TON), total nitrogen (TN), chlorophyll a and pheophytin. 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 (NH₄): a molecule with a positive charge containing nitrogen and hydrogen.

Nitrate (NO_x): a molecule with a negative charge containing nitrogen and oxygen.

Bioactive Nitrogen (BioN): the sum of Dissolved Inorganic Nitrogen + Particulate Organic Nitrogen.

Dissolved Inorganic Nitrogen (DIN)/Total Inorganic Nitrogen: the sum of the concentrations of nitrate 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.

Dissolved Oxygen (DO): the amount of elemental oxygen, O₂, 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.

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.

Phosphate (PO₄): an inorganic molecule in the environment that influences the growth rate of organisms.

Total Dissolved Nitrogen (TDN): is the sum of DON and DIN.

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.

Total Organic Nitrogen: the sum of DON and PON.

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

4.1 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) or boatyard docks, town landings and 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-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 6:00AM - 9:00AM 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 samplers 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 – mid September, when lowest DO levels can be identified and nutrient related water quality is typically lowest.

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 affects. Surface water samples are collected at 15 centimeters below the surface, and bottom water samples 30 - 50 cm above the bottom. These depths have been determined by SMAST as representative of estuary water quality that is important to ecosystems health. Collection of a sample 15 cm below surface prevents entrainment of the overlying air into DO samples, and keeps floating material from fouling nutrient samples. Sampling 30-50 cm above bottom prevents stirring of the bottom sediments and subsequent contamination of the nutrient sample.

Bacterial sampling for sources such as waterfowl can be conducted in parallel with the nutrient sampling, with samples typically collected from the surface. In addition, stormwater bacteria sampling may be conducted which focuses upon land-based point inputs, primarily from direct stormwater 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 stormwater 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 only 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 – 2012 (Howes et al, 2012). The continuous sonde data for DO that is reported in the MEP report was collected using optical sensors.

4.2 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 this 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).
- Provincetown Center of Coastal Studies: Ongoing monitoring in Pleasant Bay, Nauset Harbor, Rock Harbor/Cedar Pond, and Cape Cod Bay.
 - 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 approximately 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 (4) additional stations were added in 2012. Data and analysis is presented in a final report (Center for Coastal Studies, 2014).
 - 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 right whale season (January - May) and monthly from February - October. Aerial surveys for right whales 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 dredge of Nauset estuary (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 – 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 1 meter square quadrat), birds (species, abundance and behavior within delineated area) and salinity (pore and surface water).
- APCC Study of Rock Harbor marsh in 2006 that is restricted by Dyer Prince Road includes pore and surface water salinity measurements, plant identification and percent cover estimated within 1 meter square quadrats. Bird monitoring 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: 2006 field study of Rock Harbor marsh off of Rock Harbor Road included pore and surface water salinity measurements, 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: 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 1 meter square quadrats, and pore and surface water salinity measurements were taken.
- US Geologic Survey: 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: ongoing technical support to Orleans regarding diadromous fish populations (Pilgrim Lake and Cedar Pond).
- Cape Cod 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 8600 kg N/year, while the Town Cove sub-embayment target load reduction is approximately 6700 kg N/year. Since these estuarine systems circulate and mix, 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. This is accomplished by positioning monitoring stations upstream, instream and downstream of the project location, with high spatial resolution. Water quality samples are then analyzed for different nitrogen fractions, including DIN, 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 2003-2004, with sporadic data 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 error 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. However, in order to quantify a small change in nitrogen that is removed from a shellfish or floating wetland installation, data points taken in close proximity 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 be developed with high spatial and temporal resolution sampling within the project area, and input from experts as part of the water quality and wastewater planning process. TM4.a.3: Non-Structural 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

6.1 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.

The charts in Figure 4 compare the values from the MEP Report (2001-2004 averages) to the years 2003 – 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.

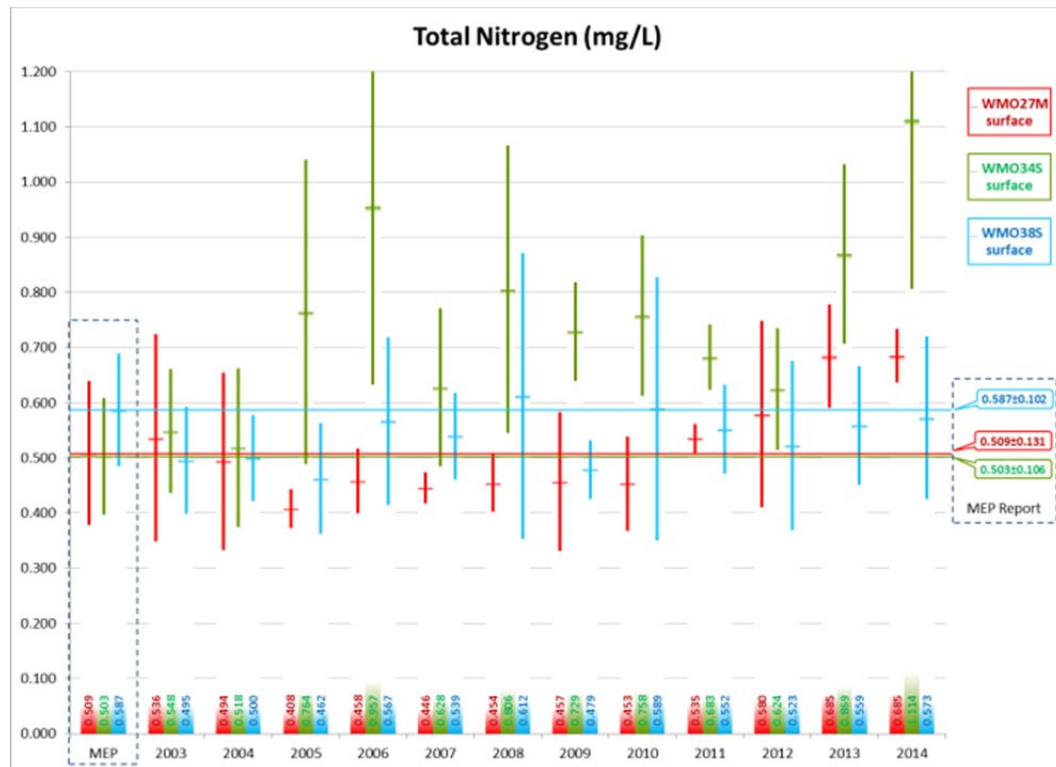


Figure 4 (a)

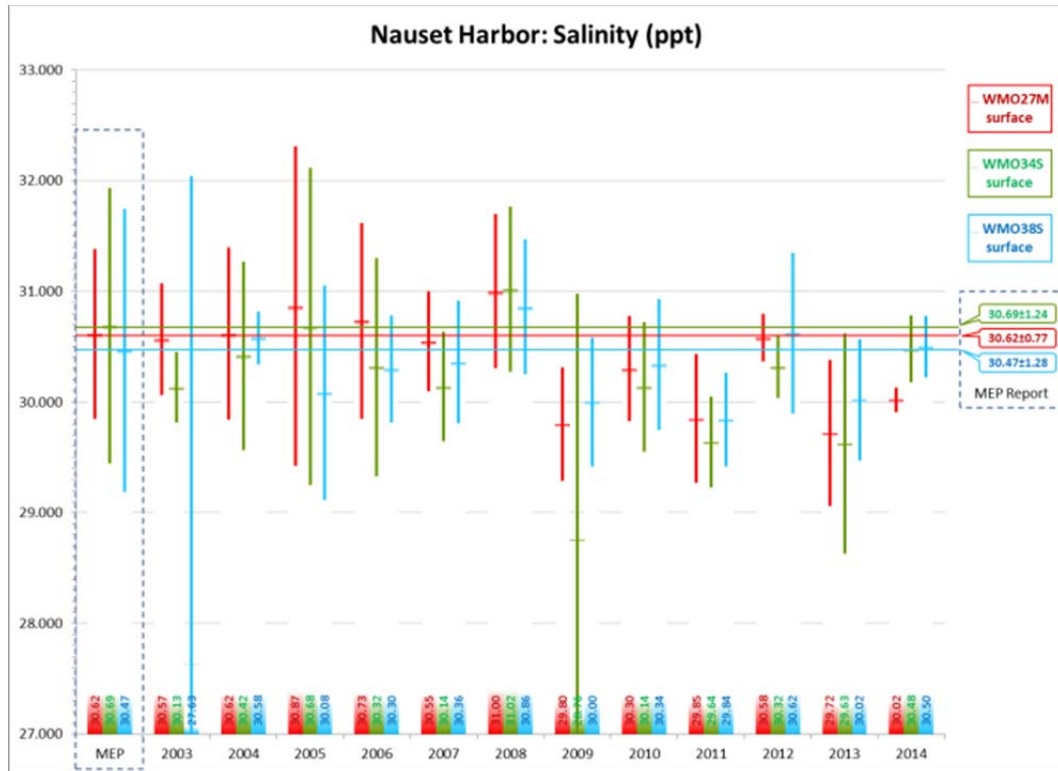


Figure 4 (b)

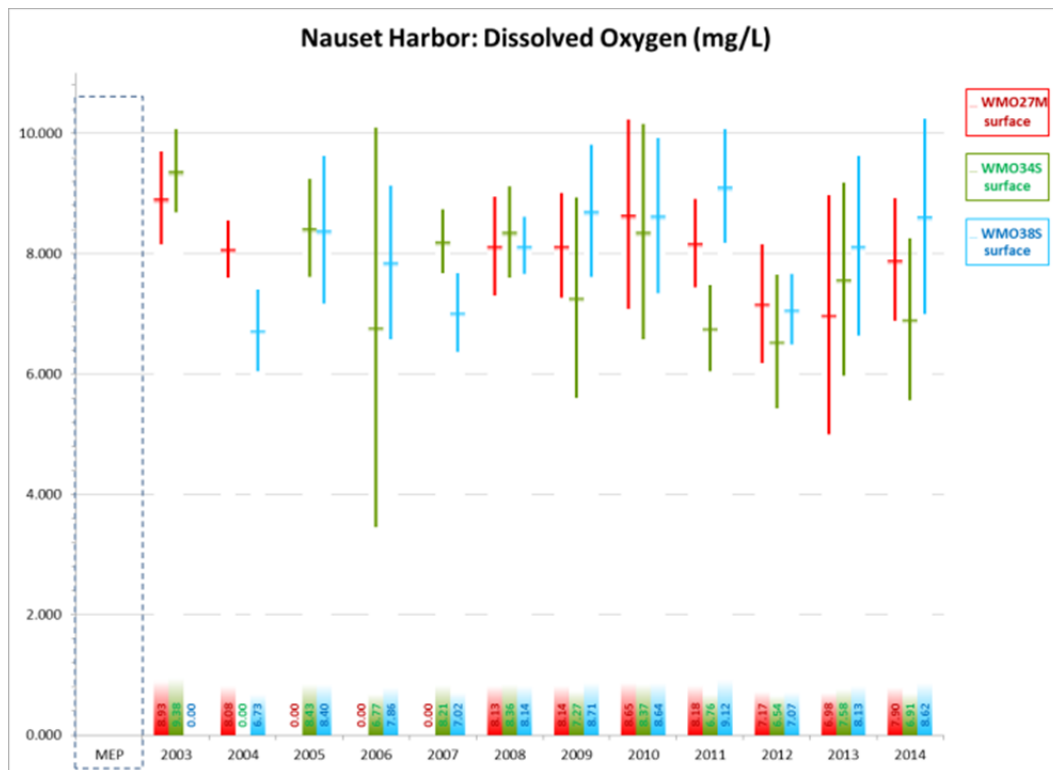


Figure 4 (c)

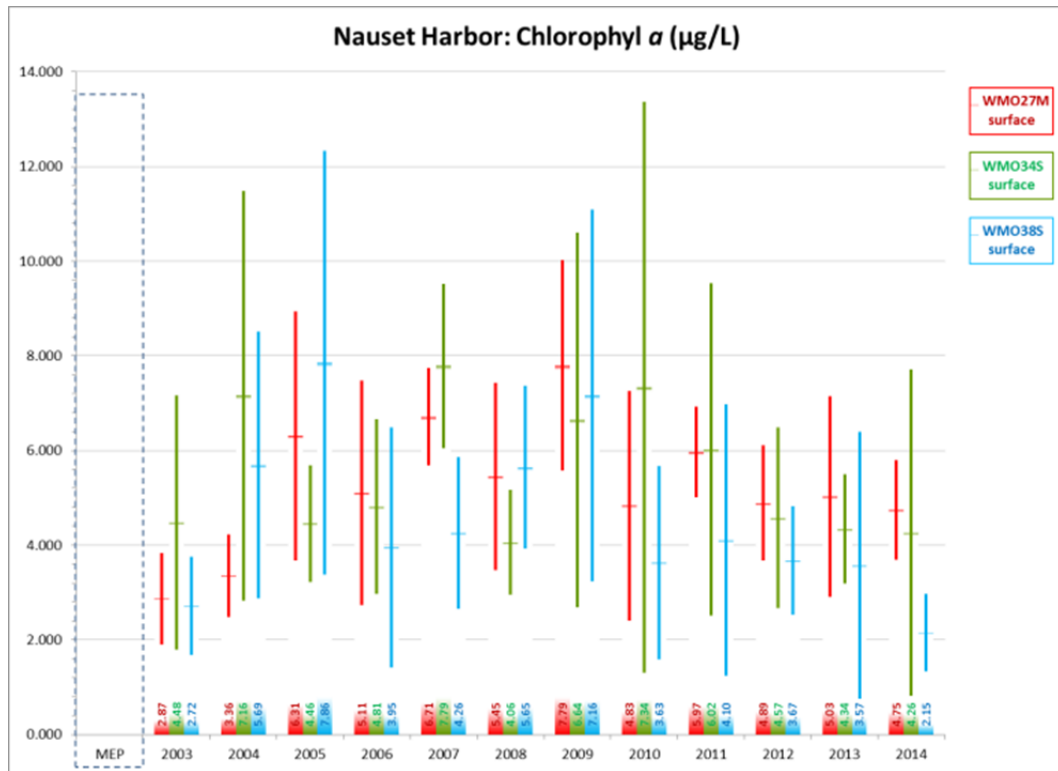


Figure 4 (d)

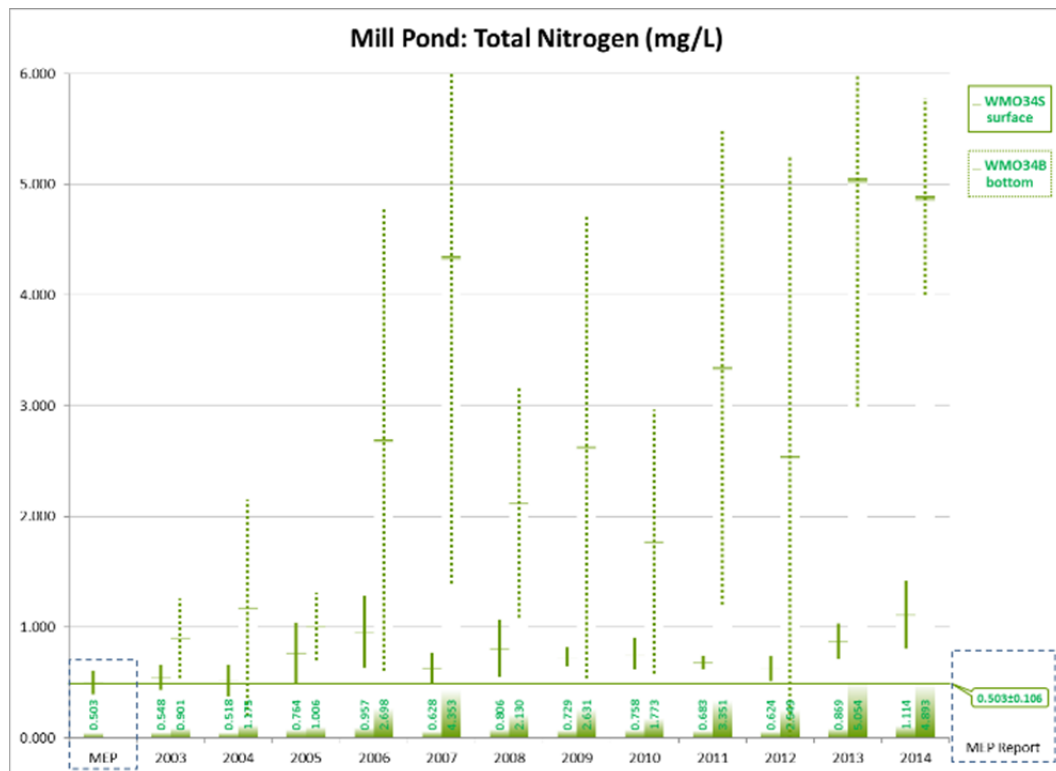


Figure 5 (a)

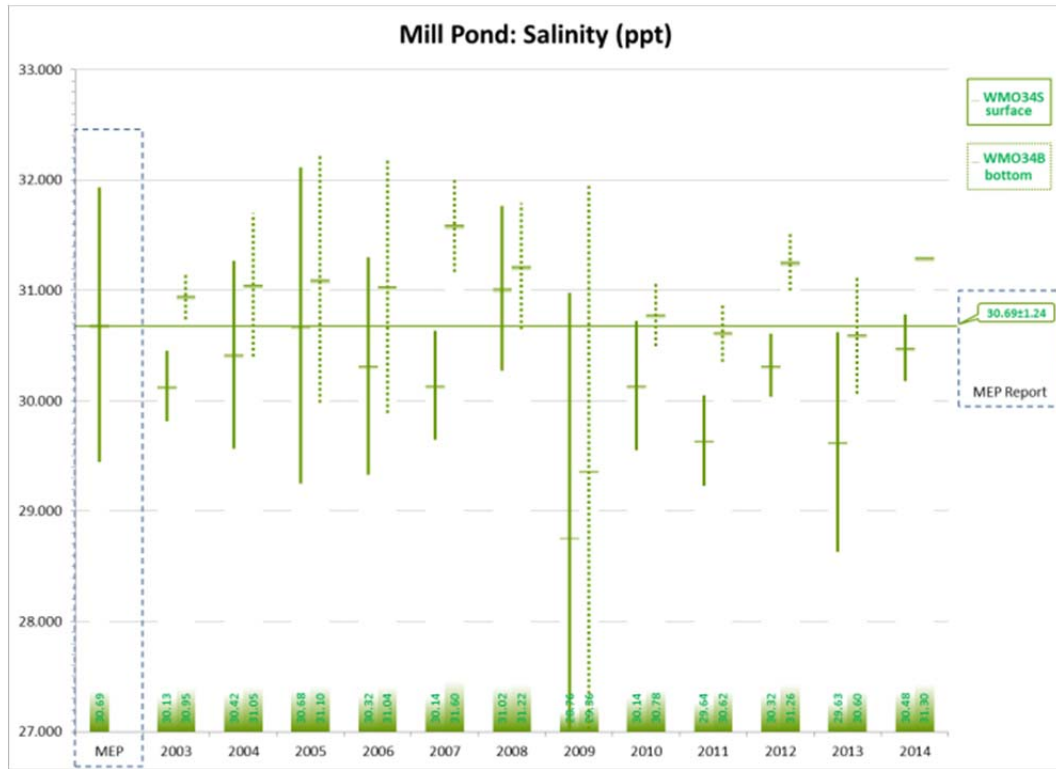


Figure 5 (b)

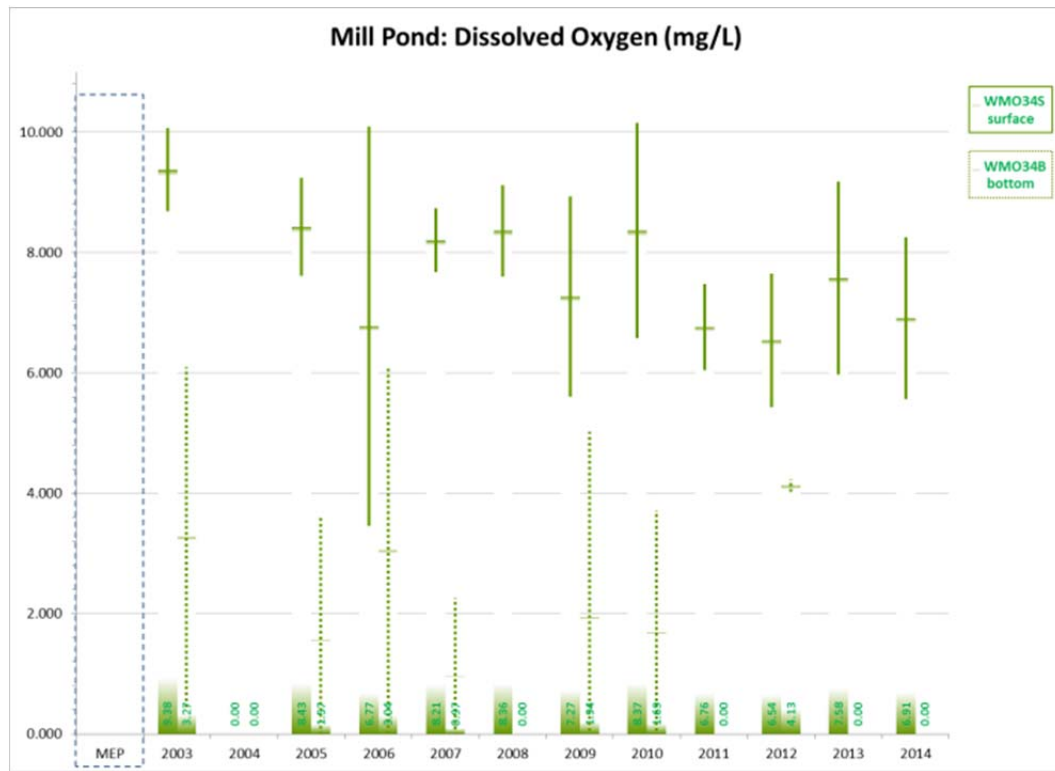


Figure 5 (c)

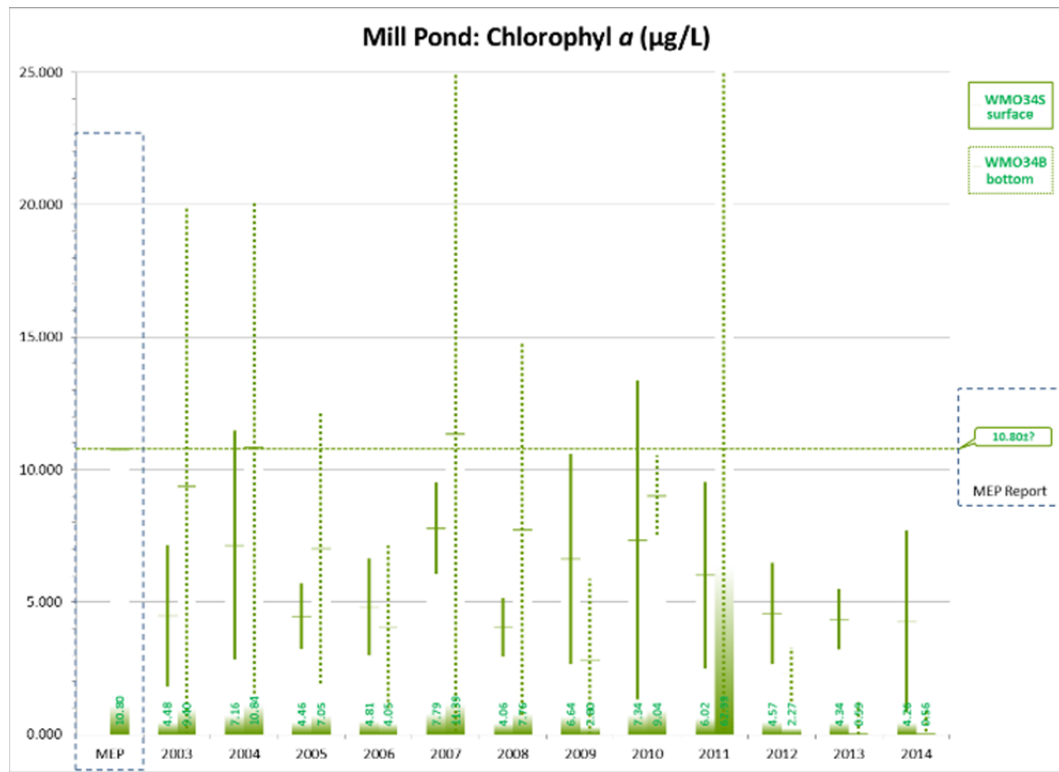


Figure 5 (d)

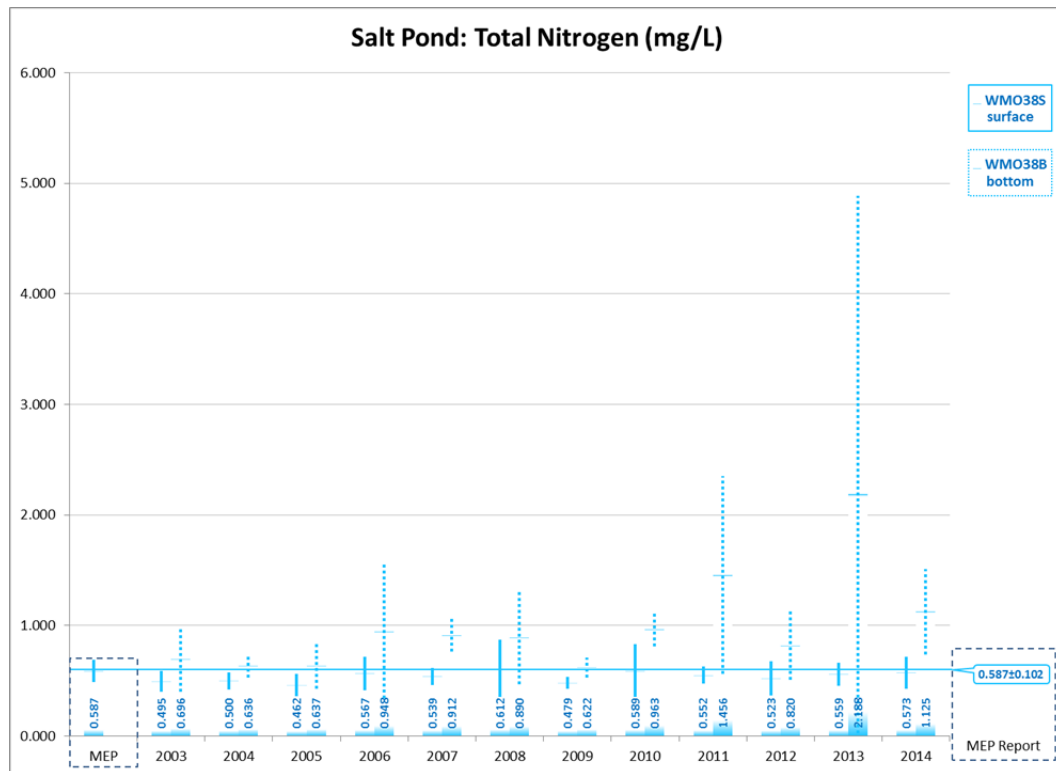


Figure 6 (a)

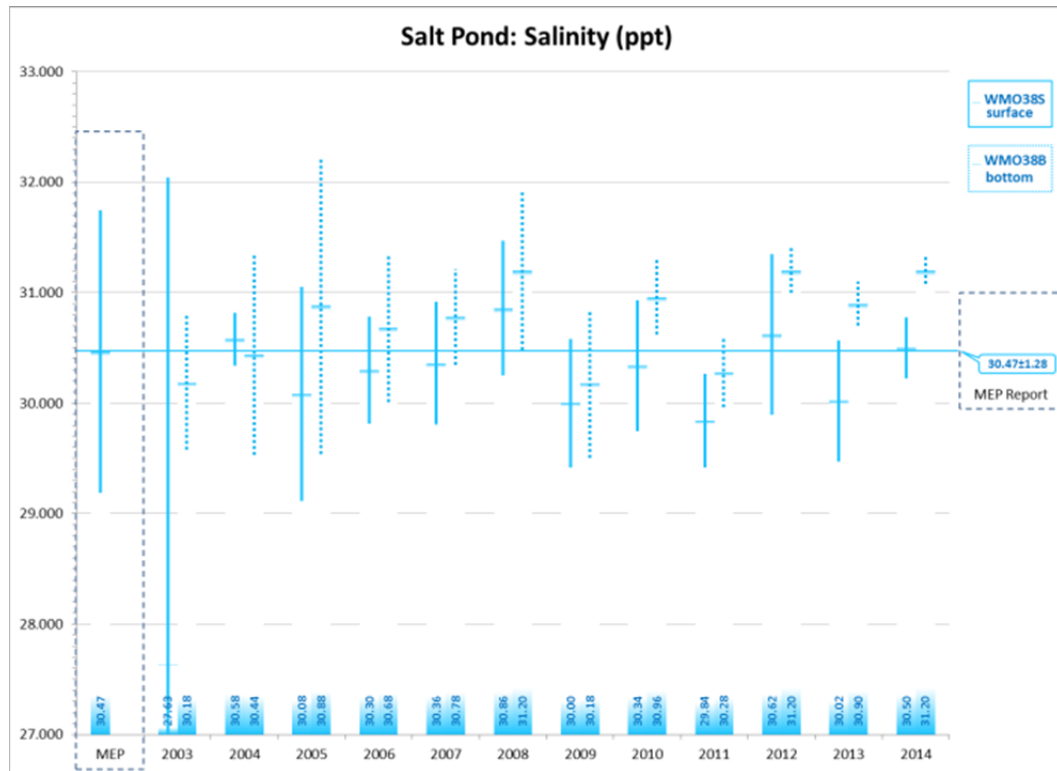


Figure 6 (b)

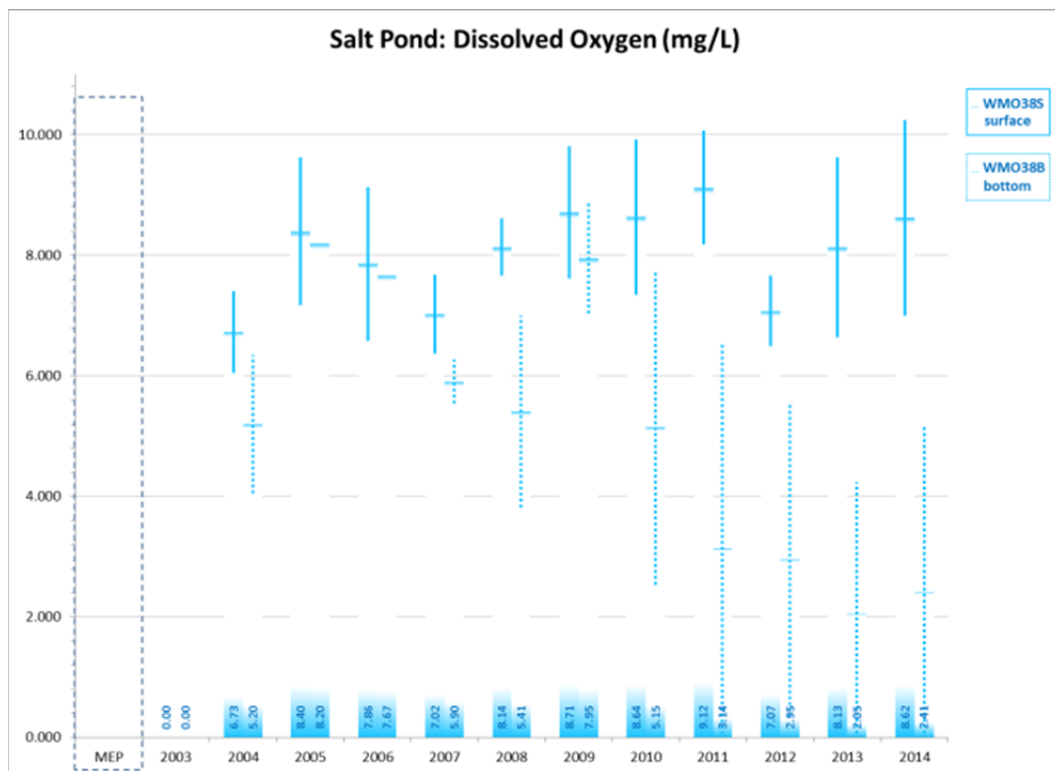


Figure 6 (c)

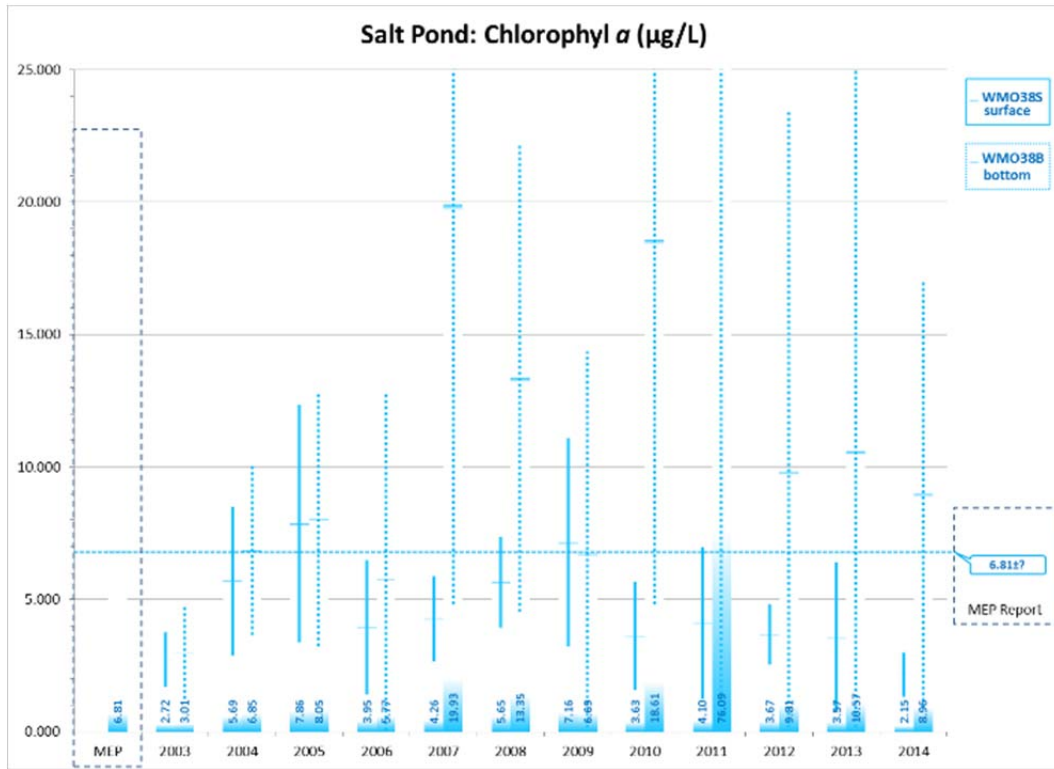


Figure 6 (d)

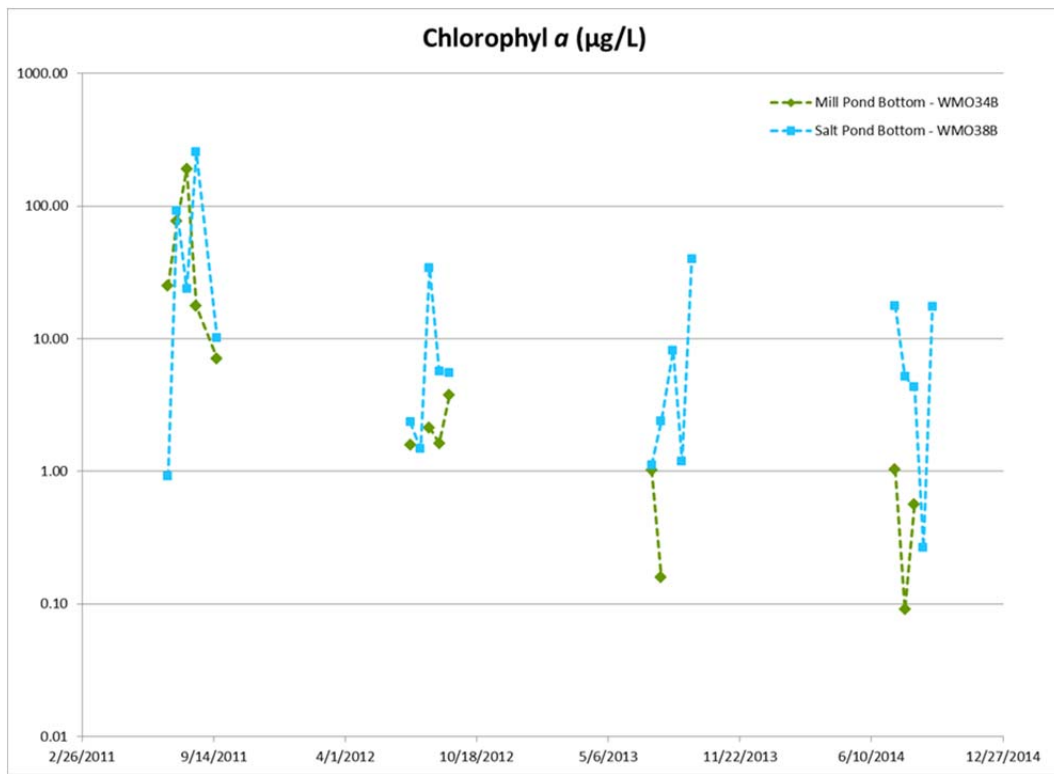


Figure 6 (e)

6.2 Nauset Harbor Assessment

Figure 4 compares the MEP report to recently published 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 value; Mill Pond has been consistently higher than the MEP baseline value since 2010; and since 2011, Salt Pond has been consistently lower than the MEP baseline value, 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.

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 .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 errors for the 2001 bottom Chl-a data. Plotting each measurement as a function of time (Figure 6) 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.

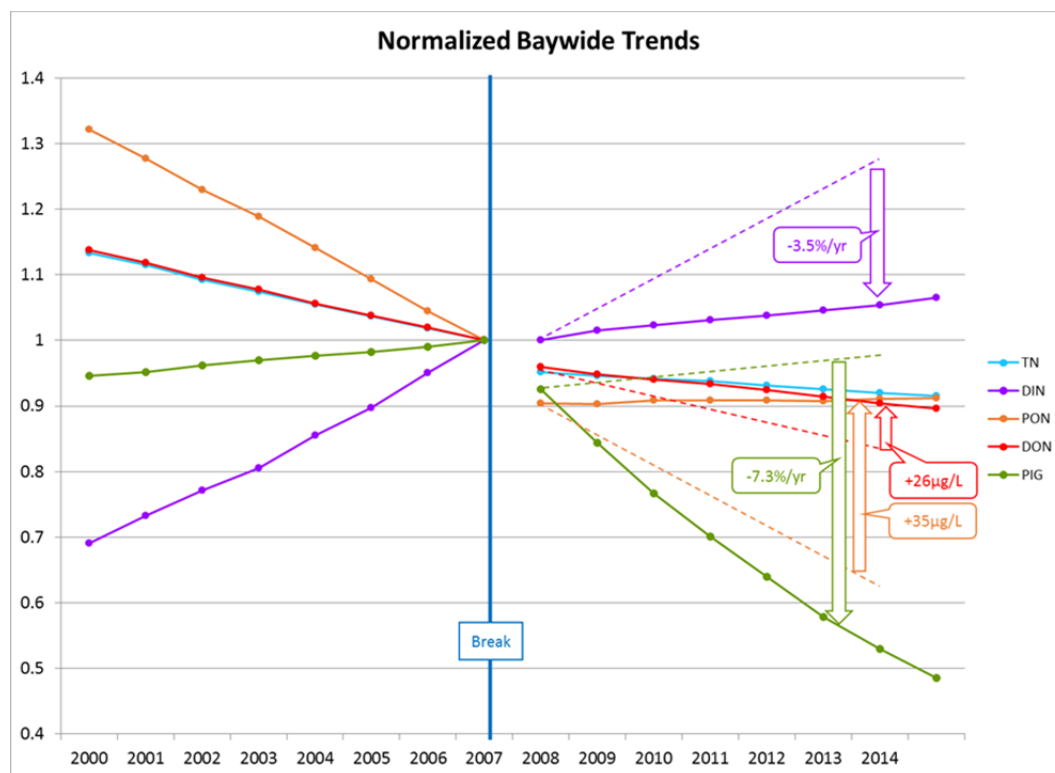


Figure 7: Normalized Trends in Nitrogen Species and Phytopigments

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. 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 6 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, or an atypical event. For the purpose of this analysis, two anomalies for DO concentration, likely data entry errors, were corrected 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 error 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.

6.3 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. 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, but North Inlet was formed in 2007, 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, PO₄ not considered statistically significant; and
- Increased salinity.

Figure 7 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 8, grey area at the top indicates DON contribution). BioN is used for the TMDL because it only includes DIN (anthropogenic sources) and PON.

6.4 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 7, 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 $\mu\text{g/L}$ to 434 $\mu\text{g/L}$, a reduction of 50 $\mu\text{g/L}$. If this rate continued from 2008 to 2014, the expected decrease would have been from 408 $\mu\text{g/L}$ to 358 $\mu\text{g/L}$. Data shows a 24 $\mu\text{g/L}$ reduction in the concentration of DON, to 384 $\mu\text{g/L}$. Thus, there is 26 $\mu\text{g/L}$ 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 $\mu\text{g/L}$, the value that would have been measured if the pre-breach trends continued. If this change in BioN were due to increased flushing and water quality improvements, accelerated decreases in PON and DON should be observed, but this is not the case.

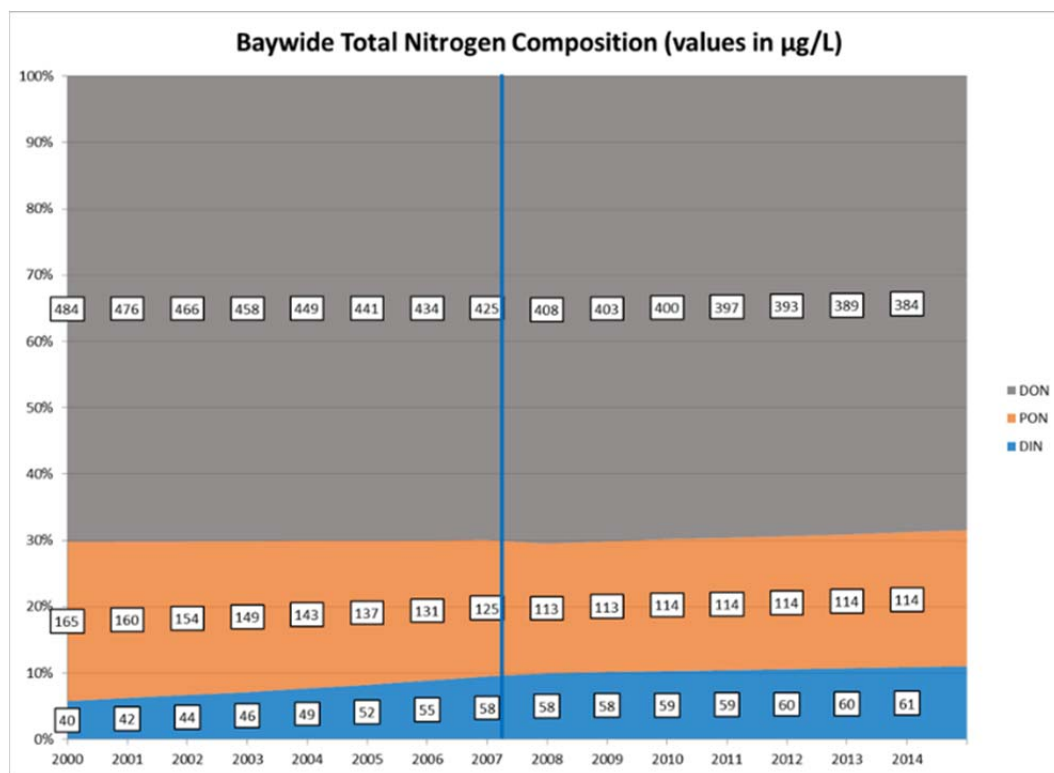


Figure 8: Nitrogen Species as a Percent of Total Nitrogen

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. This explanation 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 $\mu\text{g/L}$ more PON and DON combined than would have been expected if pre-breach trends continued, 35 $\mu\text{g/L}$ and 24 $\mu\text{g/L}$ 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; and
- 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 7 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. Benthic analysis is needed. 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 could also indicate inversions.

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.

6.5 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 15 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 (PO₄), 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)
- Little Quanset Pond (WMO-12)

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

- Pochet (mid): WMO-4
- The River (mid): WMO-8
- Namequoit River (mouth) WMO-7
- Round Cove: WMO- 9
- Pleasant Bay north of Round Cove: PBA-7

WMO-4 and 7 have not been sampled since 2004, WMO- 9 does not have data from 2006 to 2013, and WMO-8 and PBA-7 do not have data after 2005, with data collection resumed at WMO-8 in 2013. 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. A no statistically significant trend may also indicate that there is insufficient sample data. Based on a 5 percent significance level, there are no consistent trends in water quality parameters across the 20 Bay-wide monitoring stations that were analyzed. For each of the Pleasant Bay sites in Orleans, no statistically significant trends (at 95 percent confidence) were found for the parameters shown in Table 1.

Location	ID	DIN	BioN	TN	PO4	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
Arey's Pond	(PBA-14)	X	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
Pochet Upper	(WMO-5)	X	X	X				X
Quanset Pond	(PBA-10)						X	X
Little Quanset Pond	(WMO-12)				X	X		

Table 1: Water Quality Parameters with No Trends (based on Cadmus 2015)

From Table 1, DIN, PO4, DO and salinity data is not trending with statistical significance for stations in Orleans. Another observation for Orleans sites (Cadmus 2015) is that when BioN has a statistically significant trend, it is decreasing. 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 PO4 may be a function of the sampling period being restricted to summer when biologic activity is widely variable. In addition, sampling for BioN during times of peak biologic activity is likely to both underestimate DIN and result in wide variation due to the cycling of PON and DON as DIN is assimilated. Sampling during the spring may provide data that shows trends in DIN, PO4 and BioN with more statistical significance.

Table 2 presents stations in Orleans for which there are parameters with trends (Cadmus 2015).

Location	ID	GOOD						BAD		
		BioN Below TMDL	BioN Near TMDL	Pigments Below 5 µg/L or Decreasing	Turbidity Decreasing	DO Increasing	DIN Decreasing	BioN Above TMDL	DO Decreasing	DIN Increasing
Namequoit South	(PBA-12)	X		X	X	X				
Namequoit North	(PBA-13)	X		X	X					
Namequoit Mid	(WMO-6)		X	X						
LPB Near Quanset (Big Bay NE)	(PBA-8)		X	X	X					X
Pochet Mouth	(WMO-3)	X		X	X					X
Meetinghouse Pond	(PBA-16)	X		X						
The River at Rattles Dock	(WMO-10)			X	X	X		X		
Kescayogansett Pond (Lonnie's)	(PBA-15)			X	X			X		
Paw Wah Pond	(PBA-11)	X		X	X					
Pochet Upper	(WMO-5)		X	X		X				
Little Quanset Pond	(WMO-12)			X				X	X	X
Arey's Pond	(PBA-14)							X	X	
Quanset Pond	(PBA-10)			X				X		X

Table 2: Water Quality Parameters with Trends (based on Cadmus 2015)

From Table 2, BioN is at or near TMDL for eight 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 Arey’s Pond. This unexpected decrease in BioN and Pigments was further evaluated by reviewing Secchi depth (turbidity) data and calculating the standard error for select sites (Figure 9 and 10). Secchi depth was normalized to the average depth from years 2000 – 2002. In Figure 9, the solid lines indicate stations where Secchi depth is increasing, (turbidity is decreasing), and that water clarity is improving.

Data from Figure 7 shows decreasing pigments, which matches data in Figure 9, 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. 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 yet continue to degrade because nitrogen fractions are cycling in new ways in response to environmental changes.

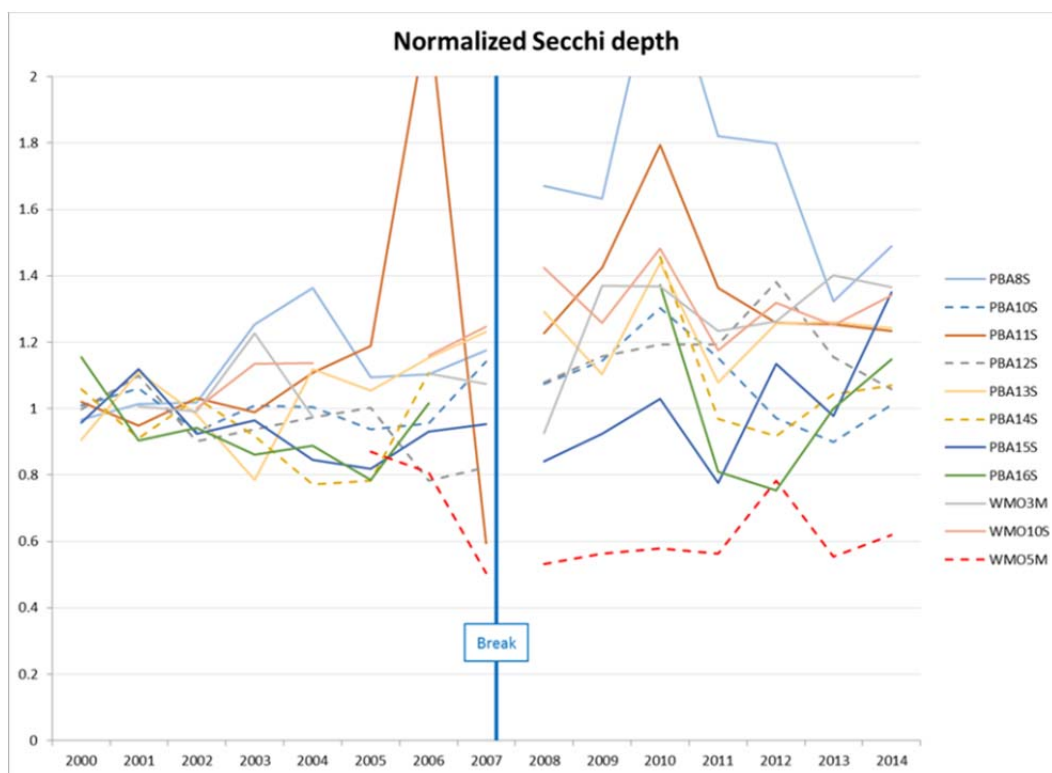


Figure 9: Normalized Secchi Depth

The Figures presented in this TM for Nauset Harbor include standard error 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 5 sample values taken over a season to establish an annual value yields standard errors that are typically around 20 percent and often over 30 percent. Figure 10 shows Standard Error for representative sites:

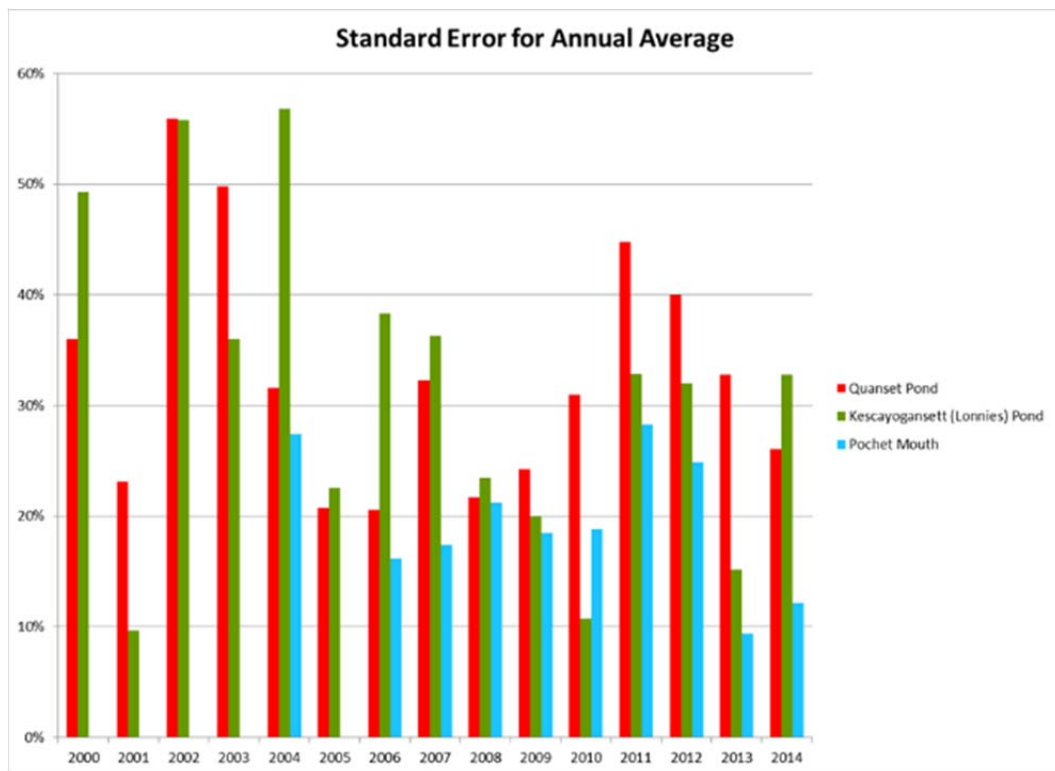


Figure 10: Standard Error for Select Sites

6.6 Pleasant Bay Data: Individual Site Assessment

Table 3 presents the findings from Table 2, and recommends actions to be taken, depending on the consistency of these trends.

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

Table 3: Water Quality Parameters with Trends and Action Items

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 show improved conditions that reflect acceptable BioN concentrations. Three 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. Seven 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 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.

7.1 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 (15) 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.

7.2 Monitoring Frequency, Depths and Parameters

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
- 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. In addition, as water temperatures warm, and climates change, the dates when eutrophic conditions are at their worst may shift. 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 error 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.

7.3 Demonstration Monitoring

As described in Section 5, demonstration monitoring requires data collection at high spatial and temporal resolution. Standard error 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-Structural Technology Performance Monitoring (task 4.a.3), which will present the specifics of a recommended monitoring program for each demonstration site.

7.4 Monitoring Coordination

There are valuable data collection programs occurring across 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.

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