Town of Orleans
Lonnie's Pond Aquaculture and Nitrogen Management Plan

A Partnership with
Coastal Systems Program
School for Marine Science and Technology
University of Massachusetts Dartmouth

Quality Assurance Project Plan 2019-2021

Prepared by:

Coastal Systems Program
School for Marine Science and Technology
University of Massachusetts Dartmouth

Prepared for:

Massachusetts Department of Environmental Protection

April 2019

1.0 PROJECT MANAGEMENT

1.1 Title and Approval Page

Town of Orleans: Lonnie's Pond Aquaculture and Nitrogen Management Plan

Town of Orleans, Department of Public Works and Natural Resources and
Coastal Systems Program, SMAST/University of Massachusetts Dartmouth and
Massachusetts Department of Environmental Protection QAPP Review

Town Project Manager: _____ Date 5/28/19

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APPENDIX F: Boston University Stable Isotope Laboratory Shellfish N Content Assay SOP

1.3 Distribution List

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D. Aquaculture Contractor: Ward Aquafarms, LLC

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North Falmouth, MA. 02556
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1.4. Program Organization

Title	Responsibilities
Town Project Manager	Manage finances, coordinate with Aquaculture Contractor, Town Administrator and file necessary regulatory compliance documents. Will post project results and reports on the town's public access website. Town Project Manager: Natural Resources Officer, Nathan Sears
Monitoring Contractor	Coastal Systems Program, School for Marine Science and Technology University of Massachusetts Dartmouth
CSP Field Manager	Responsible for ensuring collection, handling, and transporting all samples to matrix-specific laboratories within timeframes required by assay methods, including those collected by volunteers. Field Manager: Coastal Systems Program PM, Amber Unruh
CSP Project Manager/Data Manager	Will prepare drafts Semi-Annual Technical Memorandum and a Lonnie's Pond Aquaculture/TMDL Annual Report with the assistance of the Aquaculture Contractor and final versions following review and comment by Town. Data from the Lab and field data are collated and reviewed to ensure QA standards are met. Data is maintained by Project Manager/Data Manager and shared with Town Project Manager. Project Manager/Data Manager: Coastal Systems Program, Brian Howes
CSP Technical Advisors	Assist with development of program objectives, data quality objectives, and methods, facilitate implementation of action plans when possible, use data and case studies to inform state water policies where appropriate. Assist with data analysis. Brian Howes, David Schlezinger and Sara Sampieri Horvet
CSP Laboratory	Coastal Systems Analytical Facility Laboratory, School of Marine Science and Technology (SMAST) provides analysis of water samples specifically for nutrients and nutrient-related constituents at the low concentrations typically found in surface waters. Lab will provide appropriate sample containers and coolers for sample collection and transport. Handle and analyze samples using standard methods and performs all quality control checks as required by their QAPP. Provide results of analysis in a timely fashion. Work with CSP Project and Field Managers, and others as appropriate, to resolve any issue that may arise during the sampling season. Director; Sara Sampieri, Analytical Facility Manager
Town Volunteers	Volunteer samplers coordinated through the Town of Orleans Marine and Fresh Water Quality Committee will continue to sample using previously approved sampling procedures. CSP/SMAST Field Manager will coordinate with chair of committee to ensure that sampling procedures and regular training are consistent and will coordinate to ensure delivery of samples to the laboratory according to QAPP procedures. Current Orleans MFWQC Chair: Carolyn Kennedy
Aquaculture Contractor	Responsible for: a) purchasing, transporting, installing, maintaining and removing the shellfish and b) coordinating any water quality or shellfish sampling with CSP/SMAST (Monitoring Contractor). Aquaculture Contractor: Daniel Ward, Ward Aquafarms, LLC

1.5. Problem Definition/Background

The Town of Orleans is working on options to reduce nitrogen loads to its estuaries through a variety of strategies, including improved wastewater treatment, but also through lower-cost, non-traditional approaches. These efforts reflect an understanding of the community and economic links to healthy ecosystems and clean water, but also strive to attain reductions required by the Massachusetts Department of Environmental Protection (MassDEP) through their adoption of Total Maximum Daily Loads (TMDLs) for impaired waters under the federal Clean Waters Act.

In 2007, MassDEP finalized TMDLs for Pleasant Bay that identified portions of the estuary, including Lonnie's Pond, as having excessive nitrogen.[1] The Massachusetts Estuaries Project report for Pleasant Bay[2], which is the technical basis for the TMDLs, suggested that the nitrogen load to Lonnie's Pond would need to be lowered by 300 kg N/yr to mitigate the impairments.

In 2016, the Town began a non-traditional nitrogen reduction approach using oyster aquaculture in a demonstration project in Lonnie's Pond. This approach is part of the Town of Orleans examination of several non-sewering approaches to nitrogen management. The Lonnie's Pond Demonstration Project was planned as a three-year effort to evaluate the water quality impacts and determine any implementation issues associated with enhanced aquaculture for nitrogen reduction as part of achievement of the TMDL without sewering within the Pond watershed. Monitoring during the demonstration project found significant removal of nitrogen and some water quality improvements due to shellfish growth and bio-deposition.[3]

In 2018, the Town approved the Lonnie's Pond Aquaculture and Nitrogen Management Plan[4] to transition from an oyster aquaculture demonstration project to long-term implementation of nitrogen removal by oyster aquaculture for TMDL compliance. The Management Plan (included as **Appendix A**) detailed the logistical, regulatory, monitoring, and public coordination components needed for long-term use of aquaculture as part of the Town's nitrogen management program for its estuaries.

This QAPP has been prepared to ensure that the Town and MassDEP are in agreement regarding sampling procedures and analysis techniques that will be used for defining Town nitrogen removal credits for TMDL compliance under the Lonnie's Pond Aquaculture and Nitrogen Management Project.

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[1] MassDEP. 2007. FINAL Pleasant Bay System Total Maximum Daily Loads For Total Nitrogen (Report # 96-TMDL-12, Control #244.0). 53 pp.

[2] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

[3] Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth, Lonnie's Pond Shellfish Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment. September 2018. 75 pp.

[4] Howes, B. and E. Eichner. 2018. Town of Orleans Lonnie's Pond Aquaculture and Nitrogen Management Plan. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth. New Bedford, MA. 128 pp.

1.6. Project/Task Description and Schedule

The Town has hired an Aquaculture Contractor (Ward Aquafarms, LLC) and a Monitoring Contractor (Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth) to implement the Lonnie's Pond Aquaculture and Nitrogen Management Plan. The specific responsibilities for each contractor are described in the Management Plan, but generally the Aquaculture Contractor is responsible for purchasing, transporting, installing, maintaining and removing the shellfish, while the Monitoring Contractor is responsible for all the planned monitoring, review of monitoring results, and reporting on result findings. See Table 1-1 for details the planned schedule for the Plan.

The Town plans on completing three monitoring tasks: a) measurement of N removed by shellfish harvest, b) measurement of water column water quality improvements, and c) measurement of enhanced sediment denitrification because of aquaculture operations. The Town intends initially to only use the N removal by shellfish harvest measurements for the purposes of TMDL compliance in Lonnie's Pond, but will complete the other monitoring to assess whether the planned aquaculture will eventually also provide documentation for additional N removal and accompanying improvements in water quality.

1.7 Quality Objectives and Criteria for Measurement Data

Data collected through the Lonnie's Pond Aquaculture and Nitrogen Management Plan are used to assess progress towards TMDL compliance and restoration of acceptable water quality conditions in Lonnie's Pond. Water quality monitoring and sediment sampling will follow criteria used in previous MEP and Demonstration Project measurements, the previously-approved MEP QAPP and the previously-approved Town water column monitoring QAPP. Precision and accuracy of the data collected each year will similarly follow details discussed in these previously-approved QAPPs. Shellfish monitoring will follow procedures documented in the Demonstration Project. Data quality objectives and criteria for water quality and sediment chemical analyses are included in the previously-approved QAPPs and are noted where appropriate throughout this QAPP, while shellfish monitoring data quality objectives and criteria are noted in more detail herein.

1.7.1 Objectives and Project Decisions

Monitoring in Lonnie's Pond will be completed in order to provide the Town with TMDL compliance documentation. TMDL nitrogen levels were established in the MassDEP Pleasant Bay TMDL[5] based on baseline information developed in the Pleasant Bay Massachusetts Estuaries Project (MEP) report.[6] MassDEP assigned a target Lonnie's Pond nitrogen TMDL target of 3 kg/d, which is composed of watershed loads, atmospheric loads, and benthic inputs. The MEP report suggested that 300 kg/yr of the annual nitrogen load to Lonnie's Pond would have to be removed to mitigate the documented impairments and achieve the TMDL target.

[5] MassDEP. 2007. FINAL Pleasant Bay System Total Maximum Daily Loads For Total Nitrogen (Report # 96-TMDL-12, Control #244.0). 53 pp.

[6] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Town will be using measurement of nitrogen incorporated into shellfish during the growing season to document nitrogen removal when shellfish are removed from Lonnie's Pond. Town will also collect water quality and sediment data to measure impact of shellfish on water column conditions and potential permanent nitrogen removal by sediment processes due to the aquaculture effort. Collectively, monitoring will focus on the nitrogen TMDL limit and MassDEP numeric standards for dissolved oxygen (≥ 6 mg/L) and temperature (< 29.4°C).[7] Monitoring will also review progress toward the bioactive N threshold of 0.21 mg/L recommended as a secondary check in the MEP report to restore the impaired benthic community in Lonnie's Pond, but this will not be a primary goal. The Town has initially decided to focus on partial nitrogen removal credit for TMDL compliance through the focus on nitrogen incorporation into shellfish. The Town will also use the collected data to further evaluate options for nitrogen removal credit by sediment processes if monitoring results support this approach. Initial goal is to remove 75 kg of total nitrogen via shellfish growth and removal.

Data quality objectives (DQOs) establish acceptable quantitative criteria on the quality and quantity of the data to be collected, relative to the ultimate use of the data. These criteria are known as performance or acceptance criteria, or DQOs. DQOs represent the overarching quality objectives of the study, including that collected data meet measurement quality objectives (MQOs).

Given that monitoring will focus on three media (shellfish, water, and sediments), DQOs for this project are to:

1. Shellfish: collect sufficient shellfish to document N content at the time of deployment and the time of removal. Based on information developed in the Demonstration Project, 100 shellfish will be collected, weighed and analyzed for nitrogen at the time of deployment and the time of removal.
2. Water Quality: a total of 18 water quality samples will be collected at a central pond location between June 15 and September 15 each year. Grab samples will be collected at a shallow and deep depth every two weeks, but may be reduced to once a month if monitoring results becomes sufficient documented and less frequent sampling is deemed sufficient for compliance by MassDEP. Field measurements for total depth, temperature and dissolved oxygen profiles, and clarity/Secchi will also be recorded during each site visit. Two continuous monitoring devices will also be installed at two depths (0.5 m and 3.5 m). Both devices will have the following probes: dissolved oxygen, depth, salinity, temperature, and chlorophyll-a and will be programmed to record readings every 15 minutes.
3. Sediments: Eight (8) cores will be collected and incubated twice a year to determine the amount and forms of nitrogen cycled under a selected portion of the shellfish area. Cores will be collected in June/July and early October to determine N2 release as an additional removal of nitrogen associated with the aquaculture deployment. Four (4) cores under the floating bags and 4 cores at a "control" area adjacent (>15 m outside) the floating bags will be collected during each core collection run.

[7] 314 CMR 4

All collected samples will be analyzed, using standard methods as in the demonstration project, to obtain data that meet MQOs described below and are comparable to previous study results.

1.7.2 Action Limits/Levels

The initial target for the nitrogen removal goal under the Lonnie's Pond Aquaculture and Nitrogen Management Plan is based on monitoring and aquaculture installations completed during the Lonnie's Pond Demonstration Project. The initial goal for nitrogen removal during the Management Plan is 75 kg N/yr. Nitrogen removal mass is based on removal weight and N content of shellfish minus the initial deployment weight and N content of the shellfish. Based on monitoring completed during the Demonstration Project, 23,400 kg of net live biomass (shell + tissue), should be sufficient to achieve the target goal of 75 kg nitrogen removal.

Water column grab sampling will occur based on monitoring completed during the Lonnie's Pond Demonstration Project. All sampling methods and sample handling followed and will continue to follow previously approved Town and MEP QAPP procedures. Continuous monitoring will also occur during the same period as the grab sampling based on previously-approved MEP procedures. All water column data is being collected to provide supplemental and independent datasets to assess the impacts of the aquaculture installation and separately address the nitrogen concentrations cited in the Lonnie's Pond portion of the Pleasant Bay MEP assessment.

Sediment core sampling will also be conducted to measure the forms and amount of nitrogen deposited to the sediments by the shellfish during a given growing season. All sediment nitrogen content assay methods will follow those described in the Demonstration Project and the MEP QAPP procedures. The amount of N removed will be part of the TMDL compliance reporting, but the Town does not intend to initially seek credit for sediment N removal. Comparison of the forms of nitrogen in the pre- and post-growing season samples and in the various redox conditions of the cores will be considered with the water quality data to estimate the amount of nitrogen that has been removed via denitrification.

1.7.3 Measurement Performance Criteria/Acceptance Criteria

Monitoring will include sampling of water quality, shellfish nitrogen content, and sediment N content. Monitoring will occur at different frequencies depending on the source being sampled. Data Quality Indicators (DQIs) which include precision, accuracy, and completeness are listed in Table 2-4. All laboratory DQIs are addressed in the SMAST Coastal Systems Analytical Facility Quality Assurance Plan (2003). Each of these factors is briefly discussed below:

Precision

The precision of each laboratory chemical assay needs to have been determined from duplicate assays of five standards and this is part of standard laboratory practices. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R2 of the linear regression of each set of standards (N>5). Precision for the planned continuous recordings are based on the manufacturer specifications of the recording sensors.

Accuracy
Accuracy of laboratory assays is determined from the analysis of standards for the standard curves, analysis of the matrix spikes and use of Performance and Evaluation (PE) Samples. Accuracy is determined as the RPD of the assay of five standards run as samples within a series of analytical runs. This is compared to the RPD of five sets of Performance and Evaluation Samples. In addition, the accuracy of the method within the sample matrix is determined from the RPD of five matrix spikes experiments (standard additions), where appropriate.

Measurement Range
The usable measurement range for each of the laboratory assays is determined by the method and development of standard curves. Sample dilutions may be required for initial results outside of the curve range; dilutions will strive to attain the middle of the standard curve range. Ranges of field measurements are based on performance parameters established for each instrument and largely determined by the factory.

Representativeness
The goals of the monitoring program are to provide data needed to evaluate overall water quality conditions in Lonnie's Pond and to determine changes over the long-term as a result of the aquaculture program. The sampling program is designed to collect spatial and temporal water quality data sufficient to measure the changes. Previous data collection will provide a baseline to check for the representativeness of the data.

Comparability
Since the data methods, analytical facility, personnel, and equipment are the same as collected during the Demonstration Project, data collected through the Lonnie's Pond Aquaculture and Nitrogen Management Plan will be directly comparable. Since these procedures are also the same as those used for Pleasant Bay monitoring, the Management Plan data will also be comparable to data collected since 2001 for Lonnie's Pond.

Completeness
The ultimate goal for monitoring is to obtain acceptable measurements for all parameters and assays attempted. Completeness is gauged as the number of actual measurements used divided by the number of planned measurements times 100%.

1.8 Special Training Requirements/Certification

Since water column monitoring and sample collection will follow the same procedures documented in the Town Estuary Monitoring QAPP[8] and utilized by volunteers coordinated through the Marine and Fresh Water Quality Committee for many years, these highly trained volunteers will continue to collect the planned grab samples. Sediment sampling and coordination of the continuous water quality recordings will be completed by professional staff and students under the direction of professional staff from Coastal Systems Program, School for

[8] Town of Orleans Estuary Monitoring Quality Assurance Project Plan: Namskaket, Little Namskaket, Rock Harbor, Nauset and Upper Pleasant Bay Systems. 2006. Prepared by B. Howes and R. Samimy, Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 50 pp.

Marine Science and Technology, University of Massachusetts Dartmouth. All staff, students, and volunteers shall be under the direction of Brian Howes, who was the principal investigator and project coordinator for the Massachusetts Estuaries Project and the directed the monitoring during the Lonnie's Pond Demonstration Project.

1.9 Documents and Records

This QAPP and any subsequent updates will be distributed to the Town, including listed staff, CSP-SMAST staff, the Aquaculture contractor, and appropriate MassDEP staff. The Town will also post the QAPP and any subsequent updates on the Town website.

As specified in the Aquaculture Management Plan, a Semi-Annual Status Update and Annual Report will be prepared each year. The Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update will be a technical memorandum prepared by the Monitoring Contractor by the end of the July and will summarize initial insights from shellfish deployment and ecosystem monitoring (including dates of installation, maintenance, and monitoring) and information and data collected by the Aquaculture Contractor, but will not significantly review any monitoring data. The Lonnie's Pond Aquaculture/TMDL Annual Report will, at a minimum, include summaries of the following:

1) Aquaculture summary, including shellfish counts, size, and weight at initial deployment and at removal, and notes on maintenance and care,
2) Shellfish nitrogen mass removal based on comparison of average weight and nitrogen content at the time of delivery and upon removal at the end of the growing season,
3) Progress toward meeting TMDL and MassDEP surface water standards based on water quality results (both continuous records and grab samples), shellfish nitrogen removal, and sediment core results, and
4) Recommendations for refinements in any Project procedures and likely changes in costs for refinements.

Both the Semi-Annual Status Update and Annual Report will be submitted to Town Natural Resource Manager (or designee) and the Shellfish and Waterways Improvement Advisory Committee and presented by the CSP-SMAST staff at a Committee meeting. CSP-SMAST shall provide summaries of all data in the Semi-Annual Status Update and Annual Report and shall provide a spreadsheet copy of field and laboratory water quality data to the Town with the Annual Report. CSP-SMAST shall maintain all raw data, including field log books, copies of chain-of-custody forms, QC sample results, and Instrument Calibration data for at least a decade.

2.0 DATA GENERATION AND ACQUISITION

2.1 Sampling Design

Sampling in support of the Lonnie's Pond Aquaculture and Nitrogen Management Plan will focus on shellfish, water quality, and sediments to document nitrogen removal and associated water quality improvements and sediment nitrogen processes by aquaculture activities. Rationale for each of these matrices is:

1. Shellfish: collect sufficient shellfish to document N content at the time of deployment and the time of removal.
2. Water Quality: collect water column grab samples at shallow and deep depths and field measurements every two weeks at a long-term, historic, central pond location (Figure 2-1) between June 15 and September 15 each year. Supplement these samplings with shallow and deep continuous monitoring devices recording dissolved oxygen, depth, salinity, temperature, and chlorophyll-a readings every 15 minutes.
3. Sediments: Collect and incubate eight (8) sediment cores in June-July and early October to determine the amount and forms of nitrogen and loss through N2 release under the aquaculture deployment and an adjacent control area (Figure 2-2).

Table 2-1 describes more details for the sampling design and rationale, while Table 2-2 summarized the field and QC samples to be collected.

2.2 Sampling Methods

Water quality and sediment core incubation methods are the same as those documented in the Town of Orleans estuarine sampling QAPP and the MEP QAPP, respectively (these are included in Appendix B and C, respectively). Analysis of shellfish weight and N content will follow the same procedures utilized in the Lonnie's Pond Aquaculture Demonstration Project (Appendix D). Table 2-3 summarizes Analytical Methods, Containers, Preservation, and Holding Times Requirements for collected water samples, while the shellfish nitrogen assay SOP is included in Appendix F.

2.3 Sample Handling and Custody

Sample handling and custody of water quality and sediment core incubation methods are the same as those documented in the Town of Orleans estuarine sampling QAPP and the MEP QAPP, respectively (these are included in Appendix B and C, respectively). Water samples are collected, held, and transported to the laboratory on the same day they are collected. The analysis is done according to procedures previously approved by MassDEP and/or US EPA criteria (See Table 2-3). Handling and custody of samples for shellfish weight and N content will follow the same procedures utilized in the Lonnie's Pond Aquaculture Demonstration Project.

2.4 Analytical Methods

Table 2-3 summarizes analytical methods utilized for all planned CSP/SMAST Analytical Facility assays, while Appendix F includes the shellfish nitrogen assay methods. Measurement methods for field parameters are the same as those utilized in the Town of Orleans estuarine sampling QAPP and the MEP QAPP**.** Water quality assays and sediment core incubations will

be completed at the CSP/SMAST Analytical Facility at the University of Massachusetts Dartmouth. The CSP/SMAST Analytical Facility is accepted[9] for the parameters listed in this QAPP via the SMAST Coastal Systems Analytical Facility Quality Assurance Plan (2003) and through a variety of MassDEP and EPA regulatory decisions.

2.5 Quality Control Requirements

Laboratory assay QC checks are based on standard procedures described in the SMAST Coastal Systems Analytical Facility Quality Assurance Plan (2003).

At least one duplicate field samples is required for each sampling run (9 sampling runs per season; > 10% of the total number of samples). A unique identifier will be assigned to each duplicate and noted in the field sampling sheet/chain of custody form (see Appendix E). Depths for duplicate samples will be selected and coordinated between the CSP/SMAST field coordinator and the rest of the monitoring team. Duplicate samples are collected at the same location and depth as the primary sample. Duplicate samples are collected by using the same sampling procedures twice sequentially by the same sampler and filling the same sequence of sample bottles. The duplicate sample bottles will have the same labeling as the primary sample with the addition of "DUP" and will be subject to the same laboratory assays as the primary sample.

Duplicate field readings of dissolved oxygen and temperature profiles and Secchi measurements will also be collected at least once during the sampling season (>10% of readings). These readings will be noted on the same field sampling sheet/chain of custody form as the duplicate water quality sample is noted.

Upon receipt of duplicate results, the CSP/SMAST QA Officer will review to ensure samples are within an acceptable range, normally $\pm$20%. If data is outside of acceptable range, the CSP/SMAST QA Officer will seek to verify all procedures for the questionable results, including field, sample transfer, and laboratory tasks and comparison to other results from the same sampling, to try to determine potential causes. If the results cannot be reconciled, the questionable results will not be included in the database that will be submitted to the Town and the exclusion will be noted in the metadata associated with the database.

Field blanks will be prepared every sampling day using distilled/deionized water and sampling equipment prior to each sampling runs. Blanks will be prepared at the CSP/SMAST Analytical Facility and subject to all sample transfer and analysis procedures, including reporting, to ensure sampling and lab procedures are not adding bias to results. CSP/SMAST staff will strive to utilize the same blank preparation techniques used over the course of many years. The field blank bottle will be labelled with date of collection, sampling program name, and "field blank." A separate field sampling sheet/chain of custody form will be prepared for each field blank.

[9] The facility has run blind samples from DEP, and has been reviewed by USGS for inorganic N species and gone through laboratory intercalibration on the estuarine inorganic N assays for the Town of Chatham; the laboratory was accepted for the Merrimack River TMDL assays, Department of Defense Ashumet Pond Assays and for the regulatory Massachusetts Estuaries Project (fresh and salt water nutrients), Alkalinity for CC PALS. Data has been published in over 50 peer reviewed journal articles and 100+ technical reports for various agencies, including MassDEP, etc.

2.6 Instrument/Equipment Testing, Inspection, and Maintenance

All field and analytical facility instruments and tools for water quality and sediment incubation will be tested, inspected, and maintained by CSP/SMAST staff according to manufacturer instructions and SMAST Coastal Systems Analytical Facility Quality Assurance Plan SOPs. All analytical facility instruments and tools for shellfish N content will be tested, inspected, and maintained by Coastal Systems Analytical Facility staff according to manufacturer instructions and the procedure SOP (see Appendix F).

2.7 Instrument/Equipment Calibration and Frequency

All field and analytical facility instruments and tools for water quality and sediment incubation will be calibrated regularly by CSP/SMAST staff according to manufacturer instructions and SMAST Coastal Systems Analytical Facility Quality Assurance Plan SOPs. All analytical facility instruments and tools for shellfish N content will be calibrated regularly by Coastal Systems Analytical Facility staff according to manufacturer instructions and the procedure SOP (see Appendix F). Normally instruments are calibrated before each sample series with standards embedded in the sample train and run as unknowns for QA.

2.8 Inspection/Acceptance Requirements for Supplies and Consumables

All details on inspection and acceptance of supplies and consumables (*e.g.*, standard materials and solutions, filters, pumps, tubing, sample bottles, glassware, reagents, calibration standards, electronic data storage media, etc.) used at CSP/SMAST are listed in the Coastal Systems Analytical Facility Quality Assurance Plan.

2.9 Data Acquisition Requirements (Non-Direct Measurements)

Data collected during the MEP assessment of Pleasant Bay, including Lonnie's Pond, and during the Lonnie's Pond Aquaculture Demonstration Project will be used for comparison/baseline purposes. These datasets include sediment incubation results, water column grab samples, continuous water quality monitoring, and shellfish N content. Water quality, water column, and sediment data in these datasets were collected according to the same procedures previously approved in the MEP QAPP and the Town of Orleans water column monitoring QAPP that will be used during the current project. Water quality, water column, shellfish and sediment data in these datasets were also collected according to the same procedures that will be used during the current project and are documented in the associated project reports.

2.10 Data Management

All collected and generated data will be organized, synthesized, and stored by CSP/SMAST staff. CSP/SMAST staff will also be responsible for any updates to historic data that are found during synthesis and summary of the data. Data entry or synthesis errors that are found will be noted in all subsequent stored data, including spreadsheets. All data will be stored in both original formats (*e.g.*, field notes) and in electronic forms (*e.g.*, spreadsheets). Data summaries will be provided in the Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update and Annual Report. Water column grab sample data, both laboratory and field, will be collected in an electronic spreadsheet and provided to the Town at the time of the Annual Report.

3.0 ASSESSMENT AND OVERSIGHT

3.1 Assessments/Oversight and Response Actions

CSP/SMAST staff will be responsible for the monitoring and reporting aspects of the Lonnie's Pond Aquaculture and Nitrogen Management Plan and will report to the Town of Orleans Natural Resources Manager. Professional CSP/SMAST staff will coordinate the sampling schedule, ensuring the use of proper sampling and assay techniques, review of reported results, preparation of summary reports to the Town and coordination with the Town-selected Aquaculture Contractor.

Results from each sampling run will be reviewed by an appointed CSP/SMAST professional and any notable results will be discussed with the CSP/SMAST Director. If any corrections are required in procedures or protocols, those will be discussed and implemented with all involved CSP/SMAST staff.

3.2 Reports to Management

As specified in the Lonnie's Pond Aquaculture and Nitrogen Management Plan, a Semi-Annual Status Update and Annual Report will be prepared each year and submitted to the Town. Any day to day project operations will be coordinated between CSP/SMAST staff and the Town Natural Resource Manager (or designee).

The Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update will be a technical memorandum prepared by the Monitoring Contractor by the end of the July and will summarize initial insights from shellfish deployment and ecosystem monitoring (including dates of installation, maintenance, and monitoring) and information and data collected by the Aquaculture Contractor, but will not significantly assess any monitoring data.

The Lonnie's Pond Aquaculture/TMDL Annual Report will include, at a minimum, summaries of the following:

1) Aquaculture summary, including shellfish counts, size, and weight at initial deployment and at removal, and notes on maintenance and care,
2) Shellfish nitrogen mass removal based on comparison of average weight and nitrogen content at the time of delivery and upon removal at the end of the growing season,
3) Progress toward meeting TMDL and MassDEP surface water standards based on water quality results (both continuous records and grab samples), shellfish nitrogen removal, and sediment core results, and
4) Recommendations for refinements in any Project procedures and likely changes in costs for refinements.

Both the Semi-Annual Status Update and Annual Report will be submitted to Town Natural Resource Manager (or designee) and the Shellfish and Waterways Improvement Advisory Committee and presented by the CSP-SMAST staff at a Committee meeting. CSP-SMAST shall provide summaries of all data in the Semi-Annual Status Update and Annual Report and shall provide a spreadsheet copy of field and laboratory water quality data to the Town with the Annual Report.

4.0 DATA REVIEW AND USABILITY

4.1 Data Review, Verification, and Validation Requirements

All collected data will be reviewed and verified for inclusion in the analysis and synthesis and reporting in the Semi-Annual and Annual Report. Data will be reviewed for consistency with past historic data, projected results based on the aquaculture installation, and internal consistency among various parameters within the dataset. Generally, data points outside of two standard deviations for their specific characteristics (*e.g.*, depth, time of the year, etc.) will be identified as potential outliers and then reviewed to assess whether that datapoint can be accounted for by assessing mitigating factors, such as data entry issues, sampling or holding time problems or can be resolved by re-running the assay, etc. All datapoints subject to additional review and the subsequent determinations will be noted in the datasheets.

4.2 Verification and Validation Methods

Collected data will be reviewed based on standard protocols (*e.g.*, statistical analysis, identification of outliers, etc.) and comparison to previously collected data (*e.g.*, MEP and Demonstration Project). Internal consistency of datasets will also be evaluated (*e.g.*, comparison of field DO concentrations and readings from continuous loggers). Verification and validation steps will be multi-tiered and will include regular review of staff following standard laboratory and field procedures, review of field monitoring results directly after the completion of monitoring events, and comparison of collected data to previously collected data. Efforts will be made to clarify any questionable/suspect data, including review of procedures, data entry, relationship to other parameters, equipment maintenance, etc. Details of laboratory procedures are include in the SMAST Coastal Systems Analytical Facility Quality Assurance Plan.

4.3 Reconciliation with User Requirements

Verified and validated data will be included in the synthesis of data and preparation of the Semi-Annual and Annual Reports. The Annual Report will focus on Town progress toward meeting TMDL and MassDEP surface water standards based on water quality results (both continuous records and grab samples), shellfish nitrogen removal, and sediment core results). Depending on the results, the Town may change the aquaculture practices while continuing to monitor the impact.

5.0 REFERENCES

Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth, Lonnie's Pond Shellfish Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment. September 2018. 75 pp.

Howes, B. and E. Eichner. 2018. Town of Orleans Lonnie's Pond Aquaculture and Nitrogen Management Plan. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth. New Bedford, MA. 128 pp.

Howes, B. and R. Samimy. 2003. Quality Assurance Project Plan, Year One Final: the DEP/SMAST Massachusetts Estuaries Project. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth. New Bedford, MA. 400 pp.

SMAST Coastal Systems Program, Analytical Facility, Laboratory Quality Assurance Plan.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 245 pp.

MassDEP. 2007. FINAL Pleasant Bay System Total Maximum Daily Loads For Total Nitrogen (Report # 96-TMDL-12, Control #244.0). 53 pp.

Town of Orleans Estuary Monitoring Quality Assurance Project Plan: Namskaket, Little Namskaket, Rock Harbor, Nauset and Upper Pleasant Bay Systems. 2006. Prepared by B. Howes and R. Samimy, Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 50 pp.

FIGURES:

Figure 1-1. Program Organization Flow Chart
Figure 2-1. Lonnie's Pond Water Quality Monitoring Sampling Location
Figure 2-2. Lonnie's Pond Oyster Aquaculture Deployment Areas

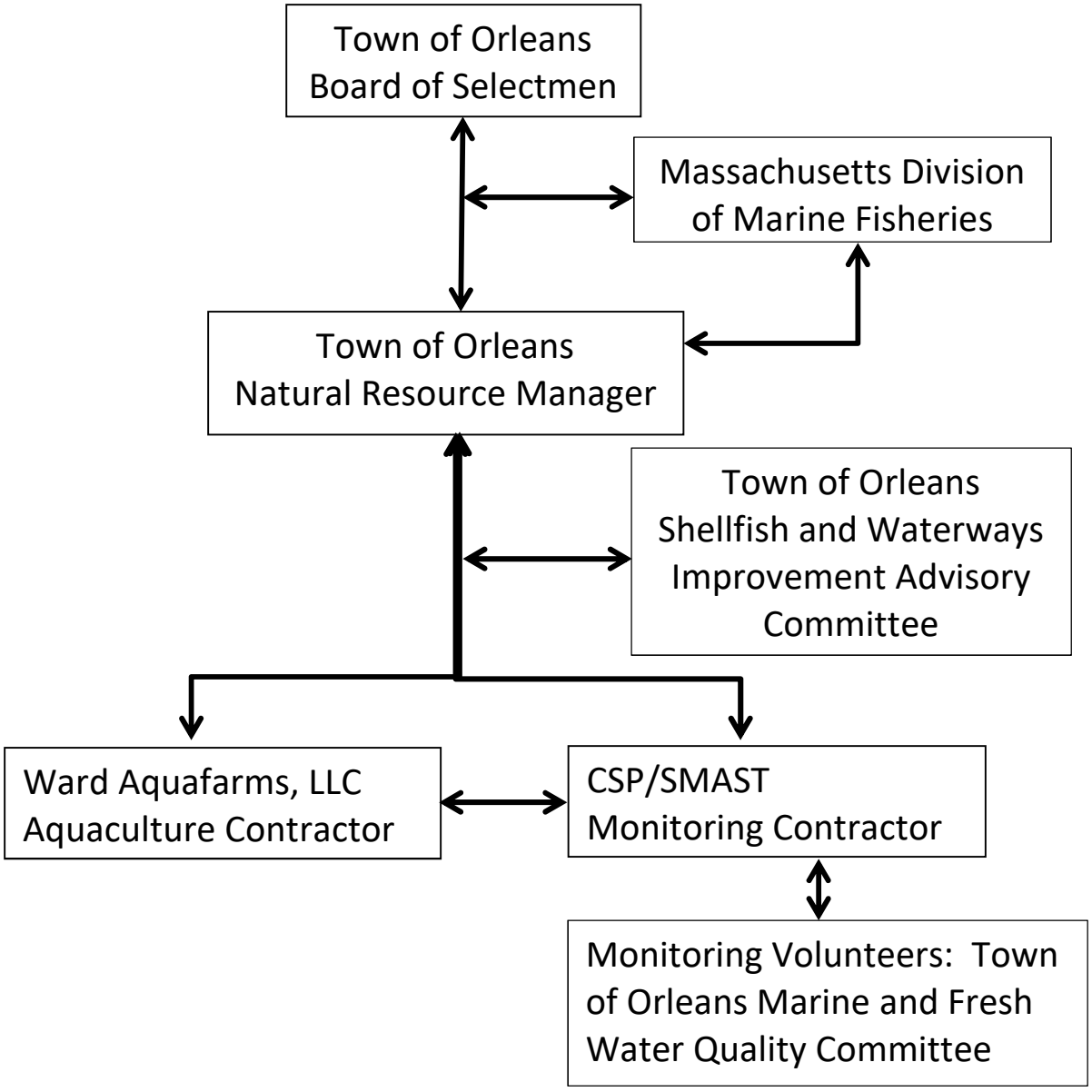


Figure 1-1. Program Organization Flow Chart

The Town of Orleans through its Board of Selectmen is responsible for TMDL compliance and approval of the Lonnie's Pond Aquaculture and Nitrogen Management Plan funding. The Massachusetts Division of Marine Fisheries regulates shellfish aquaculture under Massachusetts regulations and, as such, will be a regulatory partner in guiding the regular permitting of the Aquaculture Contractor. The Town Shellfish and Waterways Improvement Advisory Committee provides a forum for regular public discussion and updates on Plan activities. CSP/SMAST (the Monitoring Contractor) is responsible for regular monitoring to document N removal from the Town Marine and Fresh Water Quality Committee. Aquaculture and Monitoring Contractor responsibilities are detailed in the Lonnie's Pond Aquaculture and Nitrogen Management Plan and are briefly summarized in Table 1.1.



Figure 2-1. Lonnie's Pond Water Quality Monitoring Sampling Location. Mid-pond sampling location indicated with green bullseye.

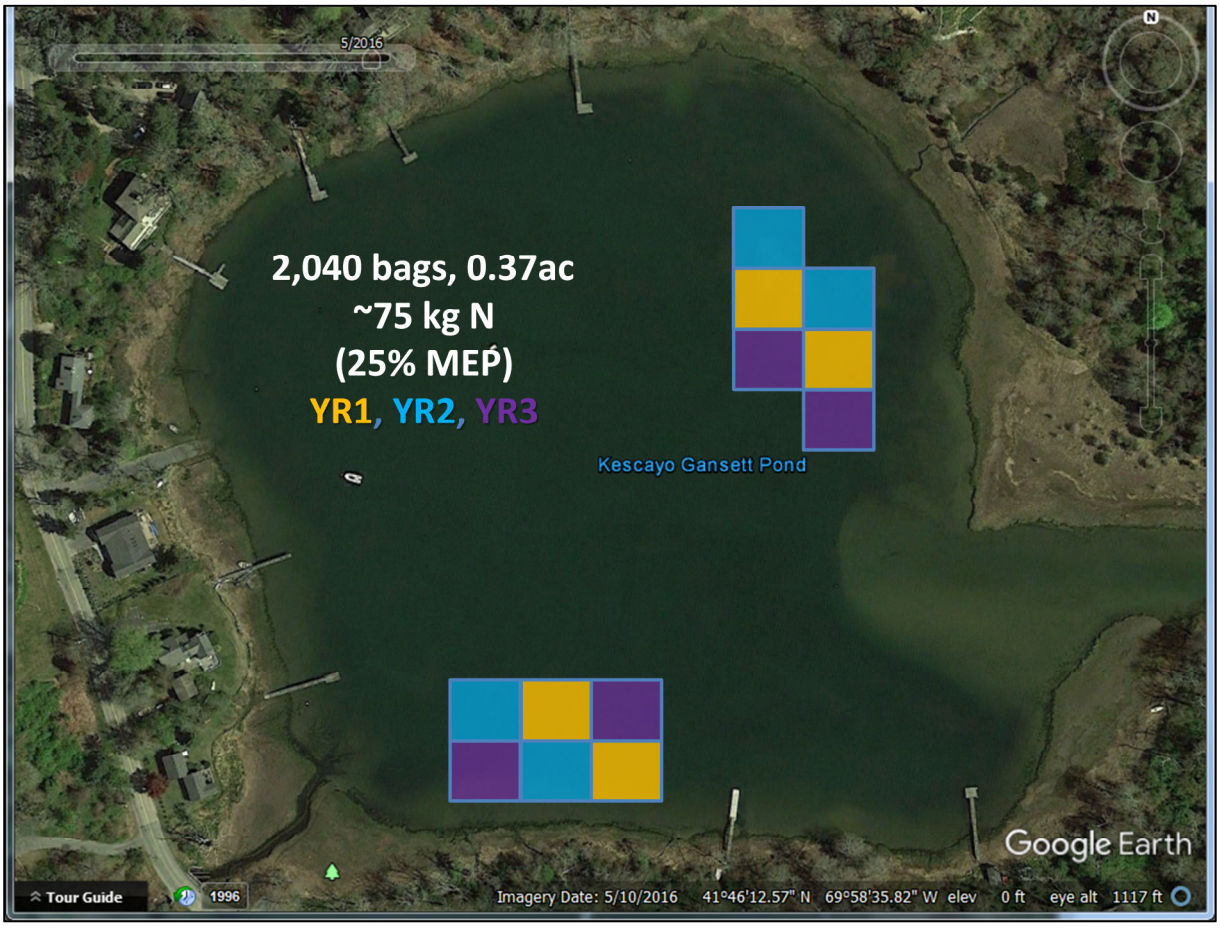


Figure 2-2. Lonnie's Pond Oyster Aquaculture Deployment Areas.
During Year 1, the deployment will be within the four boxes shaded yellow shown above, which have an area of 0.37 acres (or 2% of the pond area). This area is the same surface coverage as utilized during the Demonstration Project. During Years 2 and 3, the deployment area will remain 0.37 acres, but will shift to other boxes within the overall deployment area as shown. Rotation of deployment areas will occur to encourage additional nitrogen reductions and will try to avoid use of the same areas for more than two consecutive years. Deployment areas will be adjusted and reviewed annually based on the oyster count needed to attain N removal.

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Table 1-1. Lonnie's Pond Aquaculture and Nitrogen Management Plan Schedule
Table 2-1. Sampling Design and Rationale
Table 2-2. Summary of Field and QC Samples to Be Collected
Table 2-3. Analytical Methods, Containers, Preservation, Holding Times Requirements
Table 2-4. Data Quality Indicators: Range, Sensitivity, Precision, Accuracy, and Completeness

Table 1-1 Lonnie's Pond Aquaculture and Nitrogen Management Plan Schedule		
Action	Date	Frequency
Town Actions		
Town publicly advertises Aquaculture Contractor RFP	November	YR1 and as needed
Town holds Aquaculture Contractor pre-bid conference to review available, used Lonnie's Pond Aquaculture gear	November	YR1 and as needed
Town selects Aquaculture Contractor	December 1	YR1 and as needed
Town publicly advertises Monitoring Contractor RFP	January	YR1 and as needed
Town grants license to Aquaculture Contractor following MassDMF certification of the Town license	January/February	YR1 and as needed
Town and Aquaculture Contractor obtain RDA or NOI from Conservation Commission	January/February	YR1 and as needed
Town selects Monitoring Contractor	February 15	YR1 and as needed
Aquaculture Contractor Actions		
Aquaculture Contractor confirms to Town that sufficient Year 1 seed oysters will be delivered	By December 31	Annually
Aquaculture Contractor deploys oysters	no later than June 1 (Scenario A) or July 1 (Scenario B)	Annually
Aquaculture Contractor removes oysters and gear	Between November 15 and December 15	Annually
Monitoring Contractor Actions		
Monitoring Contractor completes and submits Nitrogen Management QAPP to Town and MassDEP	February/March	Every 3 years
Monitoring Contractor measures initial shellfish N content through coordination with Aquaculture Contractor	Collection at time of deployment	Annually
Monitoring Contractor completes sampling every two weeks	June 15 to September 15	Annually
Monitoring Contractor installs and maintains continuous monitoring devices	Late May/early June to September	Annually
Monitoring Contractor submits and publicly presents Lonnie's Pond Aquaculture/Semi-Annual Status Update	By July 30	Annually
Monitoring Contractor measures sediment N removal	August	Annually
Monitoring Contractor measures harvest shellfish N content	Late Fall	Annually
Monitoring Contractor measures sediment N removal	October	Annually
Monitoring Contractor submits and publicly presents draft Lonnie's Pond Aquaculture/TMDL Annual Report	By December 31	Annually
Monitoring Contractor submits final Lonnie's Pond Aquaculture/TMDL Annual Report	By January 31	Annually

Table 2-1. Sampling Design and Rationale

Sampling Location/ID Number	Matrix/ Media	Depth	Analytical Parameter	Rationale for Sampling Design
Central WQ Station	Water – Grab Samples	0.25 m 0.5 m off the bottom	nitrate+nitrite, ammonium, total dissolved nitrogen, particulate nitrogen, ortho-phosphorus, chlorophyll a, pheophytin a, and particulate carbon	Long-term sampling station used during Aquaculture Demonstration Project & MEP; parameters are those specified in Lonnie's Pond Aquaculture and Nitrogen Management Plan and will provide characterization of various nitrogen species, including bioactive N utilized in the MEP assessment and the subsequent TMDL; independent confirmation of continuous monitoring
Central WQ Station	Water – Field Data	Water column	Dissolved oxygen and temperature profiles; Secchi and station depth	Long-term sampling station used during Aquaculture Demonstration Project & MEP; parameters are those specified in Lonnie's Pond Aquaculture and Nitrogen Management Plan and will provide complementary data to the grab sample results and comparison to MassDEP surface water standards (314 CMR 4)
Central WQ Station	Water – Continuous Recording	0.5 m 3.5 m	dissolved oxygen, depth, salinity, temperature, and chlorophyll-a	Long-term sampling station used during Aquaculture Demonstration Project & MEP; parameters are those specified in Lonnie's Pond Aquaculture and Nitrogen Management Plan and will provide continuous characterization of factors measured in grab sample events, including numeric standards for DO and temperature specified in MassDEP surface water standards (314 CMR 4)
Shellfish	Whole Shellfish	n/a	N content/weight	A sample of 100 shellfish will be collected, weighed, and analyzed for nitrogen prior to and at the end of the growing season. Shellfish will be separated into 5 groups, screened by size and analysis will be of whole shellfish. Net N mass removed will be based on weight and N content and compared to TMDL N reduction goal.
Sediment cores (locations to be finalized)	Sediment	n/a	Time series incubation: N species (including N_2), ortho-P, SOD (see Appendix D for details)	8 cores will be collected and incubated twice to determine the amount and forms of nitrogen under a selected portion of the shellfish area and in control areas. Core incubations will determine N2 release as an additional removal of nitrogen associated with the aquaculture deployment.

Table 2-2. Summary of Field and QC Samples To Be Collected								
Matrix/ Media	Analytical Parameter	Number of Sampling Locations	Depth	Number of Field Blanks	Inorganic Analyses Number of:		No. of PE Samples	Total Number of Samples per season
					Dup	MS		
LABORATORY ANALYSES:								
Water	nitrate+nitrite, ammonium, total dissolved nitrogen, particulate nitrogen, ortho-phosphorus, chlorophyll a, pheophytin a, and particulate carbon	1 (deep mid-pond)	0.25 m	9	9	b	b	27
Water	nitrate+nitrite, ammonium, total dissolved nitrogen, particulate nitrogen, ortho-phosphorus, chlorophyll a, pheophytin a, and particulate carbon	1 (deep mid-pond)	0.5 m off bottom	9	9	b	b	27
Sediment	Time series incubation: N species (including N2), ortho-P, SOD (see Appendix D for details)	8	bottom	n/a		b	b	Incubation typically requires many samples (usually in triplicate) to establish nutrient release curves
Shellfish	Total nitrogen (whole oysters)	1	n/a	n/a	10%	b	b	10 (minimum) from 100 shellfish
FIELD MEASUREMENTS:								
Water	DO, Temp	1 (deep mid-pond)	profiles	1				Readings ≈ 80
Water	Clarity /Secchi	1 (deep mid-pond)		1				Readings ≈ 10
Water	DO, depth, salinity, temp,, and chlorophyll-a	1 (deep mid-pond)	0.5 m					Readings ≈ 11,000
Water	DO, depth, salinity, temp,, and chlorophyll-a	1 (deep mid-pond)	3.5 m					Readings ≈ 11,000

NOTES:

a. **No organic analyses planned**
b. **PE and MS samples are part of standard laboratory analyses/practices and number required will be adjusted based on sample results and lab procedures. Lab practices are discussed in SMAST Coastal Systems Analytical Facility Quality Assurance Plan.**

Table 2-3. Analytical Methods, Containers, Preservation, Holding Times Requirements					
Analytical Parameter or Field Measurements	Analytical Method	Ref	Containers	Preservation Requirements	Maximum Holding Times[3]
ANALYTICAL PARAMETERS FOR WATER					
Carbon, particulate organic Nitrogen, particulate organic	Kirsten, W., 1983	1	1L HDPE acid-washed	collect on filter, dry and store in desiccator	90 days
Chlorophyll *a*/ Phaeophytin *a*	Parsons and others, 1989	2	1L HDPE acid-washed	Store on ice in dark	24 hrs (4°C)
Nitrogen, ammonium	Scheiner 1976	3	60 ml HDPE acid-washed	Field filter, store on ice in dark	24 hrs (4°C)
Nitrogen, nitrate+nitrite	Wood, Armstrong, & Richards 1967	4	60 ml HDPE acid-washed	Field filter, store dark at -30°C	Frozen, 60 days[6]
Nitrogen, total	Method 4500	5	1L HDPE acid-washed		Frozen, 60 days[6]
Nitrogen, total dissolved organic	Method 4500-Norg-D	6	1L HDPE acid-washed	Field filter, store on ice in dark	Frozen, 60 days[6]
Phosphorus, ortho	Method 4500-P-E	7	1L HDPE acid-washed	Field filter, store on ice in dark	24 hrs (4°C)
FIELD MEASUREMENTS FOR WATER					
Temperature	YSI DO Meter Range: -5 to 45°C		n/a	n/a	n/a
Dissolved Oxygen	YSI DO Meter Range: 0 to 20 mg/L		n/a	n/a	n/a
Water Clarity	Secchi Disk disappearance/reappearance meters		n/a	n/a	n/a

Method notes:

1. Kirsten, W. 1983. Organic Elemental Analysis: Ultramicro, Micro, and Trace Methods. Academic Press/Harcourt Brace Jovanovich, New York.
2. Chlorophyll a/phaeophytin a: Parsons, T.R., Y. Maita and C. Lalli. 1989. Manual of Chemical and Biological Methods for seawater analysis. Pergamon Press, 173 pp. Analysis using Turner Designs - AU-10.
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5. Total N: Standard Methods 19th Edition, Method 4500-Norg-D D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.
6. Standard Methods 19th Edition, Method 4500-Norg-D; D'Elia, C.F., Steudler, P.A., & Corwin, N. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22, 760e764
7. Standard Methods 19th Edition, Method 4500-P-E. Ascobic Acid Method.
8. Avanzino, R. J., and V. C. Kennedy (1993), Long-term frozen storage of stream water samples for dissolved orthophosphate, nitrate plus nitrite, and ammonia analysis, *Water Resour. Res.*, 29(10), 3357–3362, doi:10.1029/93WR01684

Table 2-4. Data Quality Indicators: Range, Sensitivity, Precision, Accuracy, and Completeness								
Parameter	**Method**	**Units**	**Range**	**Sensitivity**	**Precision**	**Accuracy**	**Calibration**	**Completeness Goal**
Water: Field Parameters								
Temperature	Thermometer	°C	-5° to +40°	0.5	±0.5	1	Certified thermometer over temperature range	>95%
Temperature	Meter Thermistor	°C	-5° to +40°	0.1	±0.1	0.2	Factory calibration & Certified Thermometer	>95%
Salinity	Conductivity Meter	ppt	0 to 35	0.1	±0.1	0.2	Certified Conductivity Stds	>95%
Dissolved Oxygen	Meter	mg/L	0 to 16	0.5	±0.5	1	Dissolved gas stds	>95%
Water Clarity	Secchi Disk Std methods	m	0 to 15	0.01	±0.1	0.2	n/a	>95%
Chlorophyll	Sonde sensor	µg/L	~ 0 – 400	0.1	±0.1	0.2	Factory calibration	>95%
Depth	Sonde sensor	m	0 to 9.1	0.001	±0.018	0.02	Factory calibration	>95%
Dissolved Oxygen	Sonde sensor	mg/L	0 to 50	0.01	±0.1	0.1 or ±1%, whichever is greater	Factory calibration	>95%
Salinity	Sonde sensor	ppt	0 to 70	0.01	±0.1	0.1 or ±1%, whichever is greater	Factory calibration	>95%
Temperature	Sonde sensor	°C	-5° to +50°	0.01	±0.15	0.2	Factory calibration	>95%
Water: Analytic Facility Parameters								
Chlorophyll a	Parsons and others, 1989	µg/l	0.1 - 120[10]	0.1	<20% RPD	75% to 125% of matrix spike	Standard practices in SMAST Coastal Systems Analytical Facility QAP	>95%
Pheophytin a	Parsons and others, 1989	µg/l	0.1 - 120[2]	0.1	<20% RPD	75% to 125% of matrix spike		>95%
Carbon, particulate	Kirsten, W., 1983	µM	>5[2]	0.1	<20% RPD	75% to 125% of matrix std		>95%
Nitrogen, ammonia	Scheiner 1976	µM	>0.05[2]	0.05	<20% RPD	75% to 125% of matrix spike		>95%
Nitrogen, nitrite/nitrate	Wood, Armstrong, & Richards 1967	µM	>0.05[2]	0.05	<20% RPD	75% to 125% of matrix spike		>95%
Nitrogen, particulate	Kirsten, W., 1983	µM	>1[2]	0.1	<20% RPD	75% to 125% of matrix std		>95%
Nitrogen, total dissolved	Method 4500-Norg-D	µM	>1[2]	0.1	<20% RPD	75% to 125% of matrix spike		>95%
Phosphorus, Ortho	Method 4500-P-E	µM	>0.05[2]	.05	<20% RPD	75% to 125% of matrix spike		>95%

[10] The upper limit is not relevant as the samples can be diluted or for particulates, less sample is filtered.

APPENDICES

APPENDIX A. Lonnie's Pond Aquaculture and Nitrogen Management Plan

APPENDIX B. Town of Orleans Estuary Water Quality Sampling QAPP

APPENDIX C. Massachusetts Estuaries Project QAPP

APPENDIX D. Lonnie's Pond Aquaculture Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment Report

APPENDIX E. Lonnie's Pond Water Quality Sampling Sheet/chain of custody form

APPENDIX F. Boston University Stable Isotope Laboratory Shellfish N Content Assay SOP

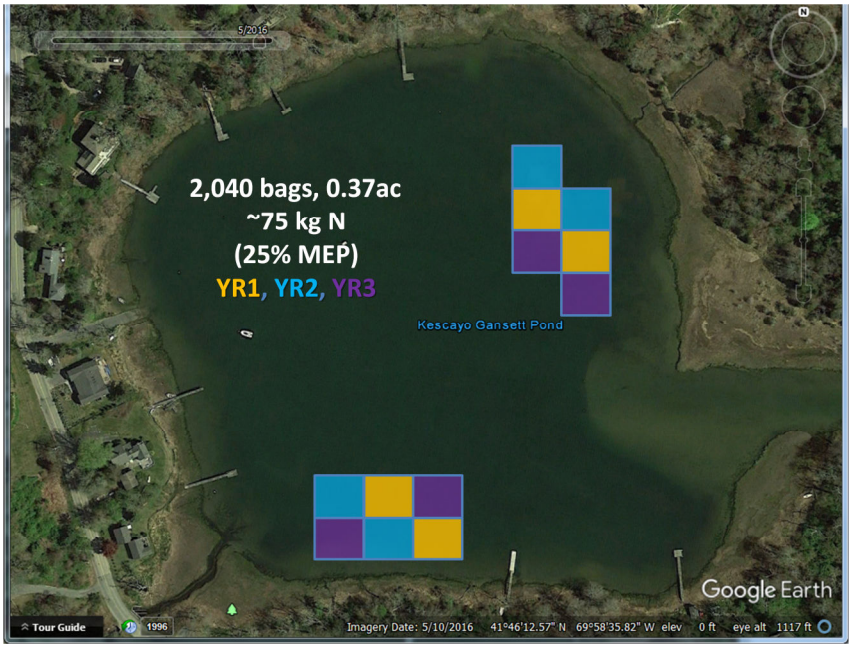
APPENDIX A: Lonnie's Pond Aquaculture and Nitrogen Management Plan

Lonnie's Pond Aquaculture and Nitrogen Management Plan

FINAL

October 2018

Town of Orleans



Prepared by:

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University of Massachusetts Dartmouth
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Lonnie's Pond Aquaculture and Nitrogen Management Plan

FINAL
October 2018

Prepared for

Town of Orleans

Prepared By

Brian Howes, Director CSP/SMAST
Ed Eichner, Senior Water Scientist/Project Manager

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Town of Orleans
Nathan Sears and George Meservey
Shellfish and Waterways Improvement Advisory Committee

Science Wares, Inc.
Eric Karplus

Lonnie's Pond Aquaculture and Nitrogen Management Plan

FINAL

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Appendix A. AECOM Lonnie's Pond Aquaculture Management Plan. Final. January 2018

Appendix B. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth, Lonnie's Pond Shellfish Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment. September 2018

I. Introduction

The Town of Orleans is working on options to reduce nitrogen loads to its estuaries through a variety of strategies, including improved wastewater treatment, but also through lower-cost, non-traditional approaches. These efforts reflect an understanding of the community and economic links to healthy ecosystems and clean water, but also strive to attain reductions required by the Massachusetts Department of Environmental Protection (MassDEP) through their adoption of Total Maximum Daily Loads (TMDLs) for impaired waters under the federal Clean Waters Act.

In 2007, MassDEP finalized TMDLs for Pleasant Bay that identified portions of the estuary, including Lonnie's Pond, as having excessive nitrogen.[1] The Massachusetts Estuaries Project report for Pleasant Bay[2], which is the technical basis for the TMDLs, suggested that 300 kg/yr of nitrogen would need to be removed from Lonnie's Pond to mitigate the impairments.

In 2016, the Town began a non-traditional oyster aquaculture demonstration project in Lonnie's Pond as part of examining innovative non-sewering approaches to nitrogen management. The aquaculture project was planned as a three-year effort to evaluate the water quality impacts and implementation issues associated with enhanced aquaculture for nitrogen reduction and potential achievement of the TMDL without sewering within the Pond watershed.

Monitoring during the Lonnie's Pond Demonstration Project has found significant removal of nitrogen due to shellfish growth and bio-deposition and some water quality improvements. However, as the amount of nitrogen removal by oyster aquaculture is becoming clear, focus has shifted to the logistical, regulatory, monitoring, and public coordination components that are needed for its long-term use in the Town's nitrogen management program for its estuaries.

This Lonnie's Pond Aquaculture and Nitrogen Management Plan provides a detailed framework for the long-term use of oyster aquaculture in this basin. Its goal is ensuring the reliability of regular oyster aquaculture for nitrogen removal. The overall concept of the plan is that the Town will partner with private contractors to oversee and implement the Plan. An Aquaculture Contractor will be responsible for purchasing, installing, maintaining, and removing oysters deployed in floating bags started as seed and then grown from spring to removal in early winter. A separate, Monitoring Contractor will coordinate with the Aquaculture Contractor to complete nitrogen monitoring of both the shellfish and water quality. The Monitoring Contractor will also work with the Town Natural Resource Manager (or designee) to provide an annual aquaculture report detailing the number and amount of shellfish grown, the amount of nitrogen removed and resulting water quality relative to compliance with the TMDL. This Plan will be coordinated initially through the Shellfish and Waterways Improvement Advisory Committee to ensure that start-up information is publicly shared and available. After initial start-up, the Town Natural Resource Manager (or designee) will be ensure regular public sharing of project performance.

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[1] MassDEP. 2007. FINAL Pleasant Bay System Total Maximum Daily Loads For Total Nitrogen (Report # 96-TMDL-12, Control #244.0). 53 pp.

[2] Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2006). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Pleasant Bay, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

The Plan includes shellfish and water quality management decision points and their likely schedule within each year, a communications plan to ensure that all Town decision makers and citizens understand the in-pond activities, results, and responsibilities for costs and associated contingencies, such as dealing with catastrophic loss/death of oysters. This Plan also includes details such as the ideal number of oysters, their sizes, their deployment areas, and their ultimate use/sale.

II. Lonnie's Pond Aquaculture Deployment

To initiate the Aquaculture portion of the Lonnie's Pond Aquaculture and Nitrogen Management Plan, an Aquaculture Contractor will be selected by the Town through a public procurement process in November for a 3 year renewable contract. The Aquaculture Contractor will be responsible for purchasing, installing, maintaining, transporting, and harvesting the shellfish. The Aquaculture Contractor will be provided access to the available aquaculture gear previously developed and used during the demonstration project, including 680 floating spat bags and 2,040 6 mm diamond mesh floating bags. A floating bag setup similar to that used in the Demonstration Project is to be used, although the oyster density may be varied based on growth results.

II.A. Aquaculture Contractor: Selection, Responsibilities

II.A.1. Aquaculture Contractor: Selection

The selection of an Aquaculture Contractor for Lonnie's Pond will be completed through a public procurement process, including the development of a Request for Proposals (RFP). The Town will publicly advertise a RFP in November of each year a new contractor is needed and select the Aquaculture Contractor by December 1. A pre-bid conference will be held by the Town to allow inspection of the gear previously developed and used during the demonstration project; details for the pre-bid conference will be included in the RFP. The RFP will follow standard Town procurement requirements and include the following criteria for review:

1) Experience in oyster aquaculture, both on Cape Cod and within Orleans.
2) Experience deploying more than 2 million oyster seed prior to June 1.
3) Certification of access to approved upweller space and experience in growing seed in an upweller or ability to provide the required amount of oyster seed.
4) Experience with use and maintenance of existing Town gear or equivalent.
5) Description of planned oyster deployment, including specific shellfish deployment areas, shellfish care between installation and harvesting, maintenance, and any additional equipment that will be deployed (see II.B for details of deployment); alternative strategies for oyster counts and management to attain the required N removal will be considered,
6) Description of planned use of public facilities, such as the boat ramp, including anticipated time of day and frequency of access
7) Description of how the Contractor will minimize visual, noise and traffic relative to abutters
8) Documentation of liability insurance
9) Presentation of any necessary regulatory documents

II.A.2. Aquaculture Contractor: Contractor Responsibilities

The Aquaculture Contractor will be responsible for purchasing, transporting, installing, maintaining and removing the shellfish. Associated details of Aquaculture Contractor responsibilities include:

1) Creation of 23,400 kg of net weight of oysters by the time the oysters are removed (based on Demonstration Project results, this should remove 75 kg of total nitrogen). This growth will be achieved by selecting either of the following scenarios:

   Scenario A:

   - acquisition and deployment of a minimum of 5.5 million Year 1 seed oysters (2 to 3 mm) by June 1 in floating spat bags;
   - then selecting and transferring the best growing oysters to 2,040 6 mm mesh bags, such that there will be 1,000 oysters per bag;
   - then allowing these oysters to grow and removing them between November 15 and December 15

   OR

   Scenario B:

   - acquisition and deployment of a minimum of 2.1 million Year 1 seed oysters (10 to 25 mm) by July 1 in 2,040 6 mm mesh bags, such that there will be 1,000 oysters per bag;
   - then allowing these oysters to grow and removing them between November 15 and December 15

   If monitoring results show that this amount of oysters needs to be reduced or increased in subsequent years, it will be addressed in annual modifications and/or a future contract.
2) providing documentation to the Town by December 31 that adequate supply of Year 1 seed oysters has been ordered and planned delivery is prior to June 1. The Aquaculture Contractor will ensure that oysters are certified disease-free and obtained from a certified facility.
3) providing (or fabricating) any additional gear necessary for oyster installation and necessary trucks or alternatives for transport of shellfish. All bags shall be black to minimize visual aesthetics, anchoring of gear shall use of telescoping auger system (helix anchors) or equivalent, and other gear equivalent to the current Demonstration Project will be required. Note that if screw anchors (augers) are used to anchor the deployment, no Army Corps of Engineers permit is needed, but the Contractor should confirm with Massachusetts Division of Marine Fisheries (MassDMF).
4) boats and other equipment for installation, movement, maintenance, and collection of the bags and racks,
5) an acceptable plan for restoring shellfish if oysters die or are lost before August 1 in any given year, including the time needed for re-deployment. The Aquaculture Contractor should identify potential mid-season suppliers of Year 1 oysters as part of the replacement plan. If shellfish are lost the Aquaculture Contractor must submit a brief memorandum documenting the reason for the loss, the timing of loss and reinstallation (including costs to contractor) and how it will be avoided in the future,
6) installation and removal of gear in spring and fall with gear removed by 2 weeks after harvest each year, but no later than December 15, except with permission of the Natural Resource Manager (or designee),

7) ensuring that oysters are certified disease-free prior to their removal from Lonnie's Pond and obtaining permission from MassDMF and the Natural Resource Manager (or designee) to move the oysters to a new site.
8) storage of all gear used and emergency backup gear over the course of the contract,
9) notifying the Town of any survival or growth concerns, including signs of disease,
10) coordinating any water quality or shellfish sampling with Monitoring Contractor,
11) providing all necessary information to the Monitoring Contractor for the completion of the Lonnie's Pond Aquaculture/TMDL Annual Report,
12) coordinating response to any catastrophic events (*e.g.*, significant shellfish die-off, significant gear destruction) with Town and Monitoring Contractor, and
13) providing a plan for the oyster sale or the transfer to other sites independent of town funding or liability.
14) obtaining a renewable annual permit from MassDMF for the oyster deployment.
15) providing a commitment to work to address abutters concerns as much as possible, including visual impacts, minimizing noise, restricting work hours, and minimizing vehicle parking at the boat ramp.

II.A.3. Aquaculture Contractor: Town Responsibilities

II.A.3.a. Regulatory Approvals

Following the selection of the Aquaculture Contractor, the Town will work with the Aquaculture Contractor to secure: 1) a Board of Selectmen license from the Town, 2) a Division of Marine Fisheries certification of the Town license, 3) a Notice of Intent (NOI) or Request for Determination of Applicability (RDA) from the Town Conservation Commission. These permitting steps will be completed prior to Spring deployment. The Town will also ensure that the Aquaculture Contractor has obtained a renewable annual permit from MassDMF for the oyster deployment. If any other regulatory approvals are required, the Town will work with the Aquaculture Contractor to obtain necessary approvals.

II.B. Shellfish: Deployment Details

II.B.1. Shellfish: Type, Quantity

Shellfish will be deployed with the purpose of removing a Net Live Biomass (shell + tissue) of 23,400 kg (removal weight minus deployment weight) to yield a Net Nitrogen Removal of 75 kg N per year following one of the two acceptable scenarios below:

Scenario A:

- acquisition and deployment of a minimum of 5.5 million Year 1 seed oysters (2 to 3 mm) by June 1 in floating spat bags;
- then between July 1 and July 20, transferring seed to 2,040 6 mm mesh bags, such that there will be 1,000 oysters per bag;
- then allowing these oysters to grow and removing them between November 15 and December 15.

OR

Scenario B:

- acquisition and deployment of a minimum of 2.1 million Year 1 seed oysters (10 to 25 mm) by July 1 in 2,040 6 mm mesh bags, such that there will be 1,000 oysters per bag;
- then allowing these oysters to grow and removing them between November 15 and December 15.

If monitoring results show that this amount of oysters needs to be reduced or increased in subsequent years, it will be addressed in annual modifications and/or a future contract. The target population will be sustained with documentation of any replacements until at least November 15. All oysters and accompanying gear must be removed from Lonnie's Pond no later than December 15 with certification that the shellfish are disease-free prior to their removal from Lonnie's Pond and with permission from MassDMF and Natural Resource Manager to move the Year 1 oysters to a new site. The Aquaculture Contractor shall complete both the initial shellfish deployment and end of season removal within seven days.

II.B.2. Shellfish: Deployment Locations

The maximum extent of the deployment locations will be approximately 0.37 acres, similar to the area used during the Demonstration Project in 2017 and 2018 (Figure 1**)**. It is anticipated that a rotational deployment strategy will be implemented where the same site is not used for more than two consecutive years. Locations will be finalized with the Town Natural Resource Manager (or designee) assisted by the Monitoring Coordinator who will provide GPS coordinates, before submission for Conservation Commission review.

II.B.3. Shellfish: Density and Care

Based on estimates developed through the Demonstration Project, after the shellfish reach the size where they can be deployed in the 6 mm mesh bags, the density will be approximately 1,000 oysters per bag from July to removal. Installation will be similar to the Demonstration Project setup with 800 floating bags along lines approximately 10 ft apart within each of the 80 ft X 120 ft areas (as shown in Figure 1). As the oysters grow, it is anticipated that actual growth conditions may require adjustments by the Contractor. The final number of bags is anticipated to be approximately 2,040 bags based on information developed during the Demonstration Project (see Appendix A). The number of spat bags in Scenario A is flexible, but must fit in the deployment footprint.

Bags will be flipped on a weekly basis at the beginning of the growing season and bi-weekly later in the season; this practice was deemed to be sufficient to prevent tunicate (sea-squirt) and algal growth and help extract feces and pseudofeces. Dead oysters should be removed, at a minimum, when bags are split. Gear will be inspected and repaired if necessary during these visits. Aquaculture activities on the pond shall be performed between the hours of 7 AM and 6 PM Monday through Friday, except in preparation for storms.

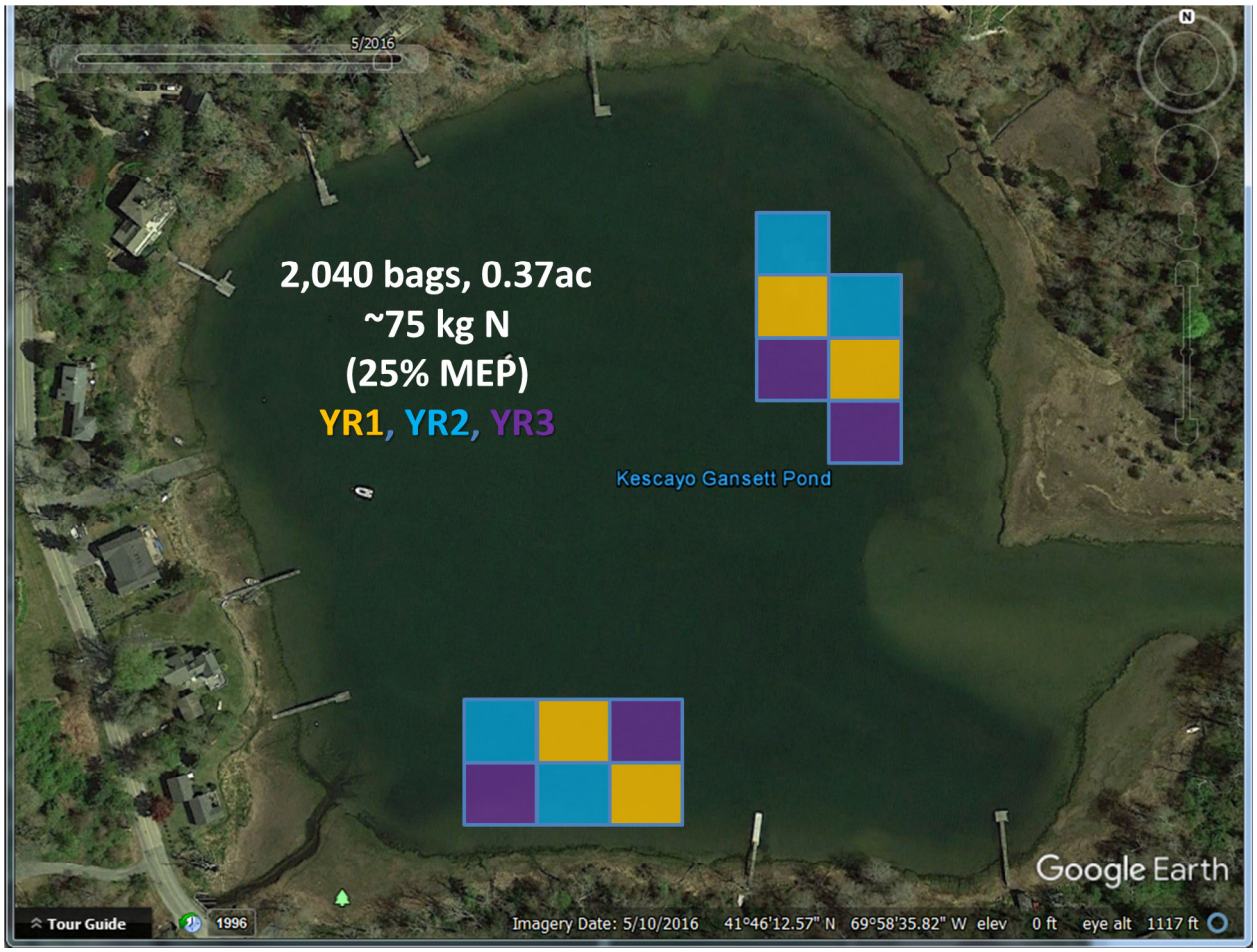


Figure 1. Lonnie's Pond Oyster Aquaculture Deployment Area. During Year 1, the deployment will be within the four boxes shaded yellow shown above, which have an area of 0.37 acres (or 2% of the pond area). This area is the same surface coverage as utilized during the Demonstration Project. During Years 2 and 3, the deployment area will remain 0.37 acres, but will shift to other boxes within the overall deployment area as shown. Rotation of deployment areas will occur to encourage additional nitrogen reductions and will try to avoid use of the same areas for more than two consecutive years. Deployment areas will be adjusted and reviewed annually based on the oyster count needed to attain N removal.

II.B.4. Shellfish: Catastrophic Loss (Death) or Equipment Loss

The timing of replacement noted herein is based on the maximum deployment being spring (no later than June 1 in Scenario A and July 20 in Scenario B) to December 15 each year, with no overwintering of oysters in Lonnie's Pond. Once oysters are removed from Lonnie's Pond by the Aquaculture Contractor, they are solely the responsibility of the Aquaculture Contractor.

In the event of a catastrophic loss of the shellfish population (defined as more than 50% of the initial annual population), the Aquaculture Contractor shall strive to replace the population as soon as replacements are available if the loss occurs in April, May, June, or July. If the loss

occurs in August, September, October, November, or December, the Aquaculture Contractor will not be required to replace the population.

In the event of a significant gear loss due to a storm or theft during April, May, June, or July, the Aquaculture Contractor will be responsible to replace the gear at their cost and strive to install the replacement gear within the same month. If significant gear loss due to a storm or theft occurs during August, September, October, November, or December, the Aquaculture Contractor will be responsible to replace the gear at their cost, but re-installation of the replacement gear will not be required until normal spring deployment the following year.

III. Lonnie's Pond Nitrogen and Ecosystem Monitoring

Monitoring in Lonnie's Pond will be completed in order to provide the Town with TMDL compliance documentation. Monitoring will include sampling of water quality, shellfish nitrogen content, and sediment N content. Monitoring will occur at different frequencies depending on the source being sampled. It is anticipated that the Town will select a Monitoring Contractor to complete the ecosystem monitoring tasks.

III.A. Monitoring Contractor: Selection, Responsibilities

III.A.1. Monitoring Contractor: Selection

The selection of a Monitoring Contractor for Lonnie's Pond will be completed through a public procurement process, including the development of a Request for Proposals (RFP). The Town will publicly advertise a RFP in January prior to the first year of deployment for a 3 year duration (same as Aquaculture Contractor, also renewable) and select the Monitoring Contractor by February 15. The RFP will follow standard Town procurement requirements and include the following criteria for review:

1) Experience in water quality sampling, both on Cape Cod and within Orleans
2) Experience with types of sampling required for Lonnie's Pond, including potentially use and coordination of volunteers, shellfish sampling, and sediment sampling
3) Description of planned sampling strategy, including anticipated laboratories for assays, detection limits, and how procedures may differ from those used during the Demonstration Project and the MEP.
4) Documentation of applicable insurance
5) The Monitoring Contract must also demonstrate acceptability of data produced for regulatory agencies (*i.e.*, compliance)

III.A.2. Monitoring Contractor: Contractor Responsibilities

The Monitoring Contractor will be responsible for collecting, handling, and transporting all samples to matrix-specific laboratories within timeframes required by assay methods (see Sections III.B and III.C). The Monitoring Contractor will select the laboratories and ensure that assay methods and detection limits are comparable or superior to those used during the Demonstration Project. The Monitoring Contractor will submit a Lonnie's Pond Nitrogen Management QAPP to the Town and, following Town review, to MassDEP for approval to ensure MassDEP acceptability of results for TMDL compliance. The Monitoring Contractor will also be responsible for preparing both a Semi-Annual Technical Memorandum and a Lonnie's Pond Aquaculture/TMDL Annual Report with the assistance of the Aquaculture Contractor (see Section IV). Each of these reporting documents will be submitted to the Town for review and final approval before being submitted to MassDEP. Monitoring activities on the pond shall be

performed between the hours of 6 AM and 6 PM Monday through Friday, except in preparation for storms.

III.B. Water Quality Sampling

Water quality sampling will include both grab samples and continuous monitoring and will focus on summer months, which are the primary focus for TMDL compliance. Sampling methods and chemical assays will generally be the same as previous MEP and Town samplings and comparability to historic data is required.

III.B.1. Water Quality Grab Sampling

Water quality grab sampling will be conducted every two weeks between June 15 and September 15 in each of the three years. A reduction in sampling to only once a month may be allowed in future years if system variability within the monitoring results becomes sufficient documented and less frequent sampling is deemed sufficient for compliance by MassDEP. The Monitoring Contractor will participate in any discussion about sampling with the Town and MassDEP. Water quality samples will be collected during the morning (6 AM to 9 AM) on the outgoing (ebb) tide. Sampling dates will be selected so that sampling occurs at approximately mid-ebb tide (1 hr before to 1 hr after). Since these are the same procedures utilized in the Demonstration Project and the volunteer sampling coordinated through the Marine and Fresh Water Quality Committee, it is envisioned that volunteers will continue to collect this portion of the Lonnie's Pond sampling.

Samples will be collected at two depths:

- one sample at 0.25 meters below the surface (the "surface" sample).
- one sample from 0.5 meters above the bottom (the "bottom" sample)

Field measurements for total depth, temperature, dissolved oxygen, and clarity/Secchi will also be recorded at the same location (Figure 2). All sampling methods and sample handling will follow previously approved Town and MEP QAPP procedures and the project-specific Lonnie's Pond Nitrogen Management QAPP.

Collected grab samples will be assayed for the following parameters: nitrate+nitrite, ammonium, total dissolved nitrogen, particulate nitrogen, ortho-phosphorus, chlorophyll a, pheophytin a, and particulate carbon. All assay methods will follow those described in previously approved Town and MEP QAPP procedures and the project-specific Lonnie's Pond Nitrogen Management QAPP.

III.B.2. Water Quality Continuous Monitoring

Two continuous monitoring devices will be installed at two depths (0.5 m and 3.5 m). Both devices will have the following probes: dissolved oxygen, depth, salinity, temperature, and chlorophyll-a. The devices will be installed in late May/early June and removed in September to coincide with the critical compliance period. The device will be programmed to record readings every 15 minutes.

III.B.3. Contingency Monitoring

Funding will be reserved to address "emergency" monitoring associated with extreme events that are anticipated to occur rarely during the growing season, including harmful algal blooms, signs of shellfish disease, and hurricanes.

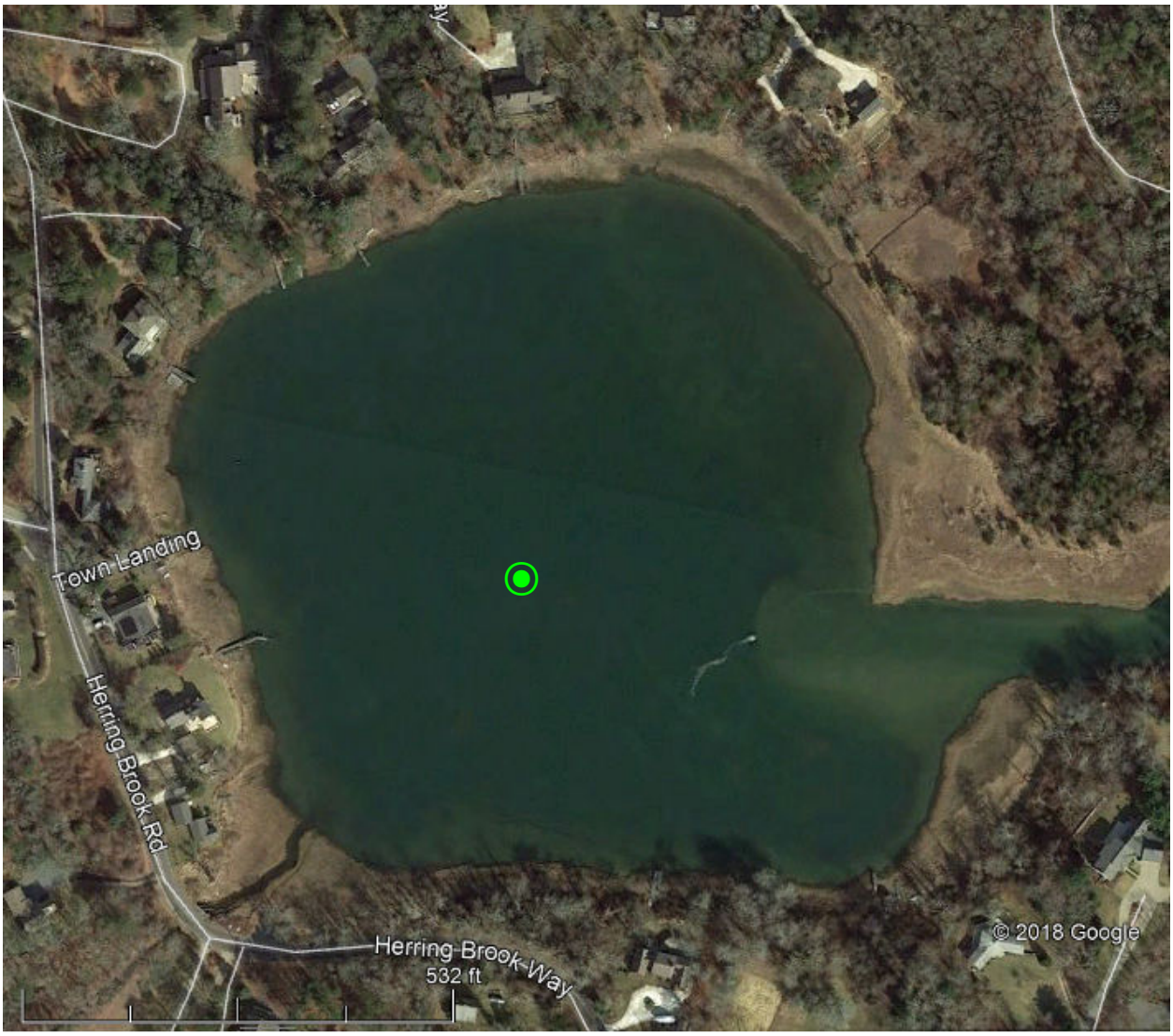


Figure 2. Water Quality Monitoring Sampling Location. Location indicated with green bullseye.

III.C. Shellfish Sampling

Shellfish sampling will be conducted by the Monitoring Contractor to measure the amount of nitrogen retained and removed through removal of oysters at the end of each growing season. This sampling will be coordinated with the Aquaculture Contractor. The amount of nitrogen removed will be part of the TMDL compliance reporting, as will the size and number of oysters harvested.

At the beginning of the growing season, the Aquaculture Contractor will coordinate with the Monitoring Contractor to measure the total weight and estimate the total population of oysters deployed in Lonnie's Pond. At the end of the growing season, the Aquaculture Contractor will coordinate with the Monitoring Contractor to weigh all the oysters as they are removed from Lonnie's Pond.

A representative sample of one hundred (100) shellfish will be collected, weighed, and analyzed for nitrogen twice during the shellfish season in batches of no more than 10 oysters, once at the beginning of the growing season prior to deployment and once at the end of the growing season. If seed are being assayed, screening for size can be used, and groups of seed can be weighed and analyzed as long as at least 5 groups are assayed. Analysis will be completed on whole shellfish. End of season oysters will be measured individually. Comparison of the nitrogen content in the pre- and post-growing season samples combined with the weight and post-growing count will determine the amount of nitrogen removed by shellfish in Lonnie's Pond. All nitrogen content assay methods and sampling procedures will follow those described in the Demonstration Project (see Appendices A and B).

III.D. Sediment Sampling

Sediment sampling will be conducted to measure the forms and amount of nitrogen deposited to the sediments by the shellfish during a given growing season. The amount removed will be part of the TMDL compliance reporting.

Eight (8) cores will be collected and incubated twice to determine the amount and forms of nitrogen under a selected portion of the shellfish area. Cores will be collected in August and early October to determine N_2 release as an additional removal of nitrogen associated with the aquaculture deployment. Four (4) cores under the floating bags and 4 cores at a "control" area adjacent (>15 m outside) the floating bags will be collected during each core collection run. Core collections will follow procedures used during the demonstration project (Appendix B). Core data will be reviewed each year to assess the need for additional sampling in the following year (agreement between the Town, Monitoring Contractor and MassDEP). Water column sampling at each meter will also be conducted at the time of core collection to determine the water column nitrogen forms. Comparison of the forms of nitrogen in the pre- and post-growing season samples and in the various redox conditions of the cores will be considered with the water quality data to estimate the amount of nitrogen that has been removed via denitrification. All nitrogen content assay methods will follow those described in the Demonstration Project (see Appendix B).

IV. Lonnie's Pond Reporting and Communication

The Lonnie's Pond Aquaculture Management Project will include two primary communication pathways: a) reporting to state agencies and b) reporting to Orleans decisionmakers, citizens, and staff. Two documents will be prepared by the Monitoring Contractor with cooperation from the Aquaculture Contractor and analytical facilities and will be the main focal points for providing updates on Project status: 1) Lonnie's Pond Aquaculture/TMDL Annual Report and 2) Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update Technical Memorandum. However, these formal reports do not take the place of on-going communication between the Aquaculture Contractor, Monitoring Contractor, the Natural Resource Manager (or designee) and the Shellfish and Waterways Improvement Advisory Committee.

IV.A. Lonnie's Pond Reports: Annual Report and Semi-Annual Status Update

The Lonnie's Pond Aquaculture/TMDL Annual Report will, at a minimum, include summaries of the following:

1) Aquaculture summary, including shellfish counts, size, and weight at initial deployment and at removal, and notes on maintenance and care,
2) Shellfish nitrogen mass removal based on comparison of average weight and nitrogen content at the time of delivery and upon removal at the end of the growing season,
3) Progress toward meeting TMDL and MassDEP surface water standards based on water quality results (both continuous records and grab samples), shellfish nitrogen removal, and sediment core results, and
4) Recommendations for refinements in any Project procedures and likely changes in costs for refinements.

The Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update will be a technical memorandum prepared by the Monitoring Contractor by the end of the July and will summarize initial insights from shellfish deployment and ecosystem monitoring (including dates of installation, maintenance, and monitoring), but will not significantly review any monitoring data. The Semi-Annual Status Update will incorporate information and data collected by the Aquaculture Contractor. The Update will be submitted to Natural Resource Manager (or designee) and the Shellfish and Waterways Improvement Advisory Committee and presented by the Monitoring Contractor at a Committee meeting.

IV.B. Lonnie's Pond Reports: Delivery Dates and Public Presentations/Outreach

The Lonnie's Pond Aquaculture/TMDL Annual Report will be prepared by the Monitoring Contractor with cooperation from the Aquaculture Contractor and analytical facilities. The Annual Report will be publicly presented in draft form at a forum acceptable to both the Town and the Monitoring Contractor in December and a final form will be delivered to the Town in January following the receipt of any comments. The Lonnie's Pond Aquaculture/TMDL Semi-Annual Status Update Technical Memorandum will be delivered to the Town in July and will be publicly presented at a forum acceptable to both the Town and the Monitoring Contractor. The Town will mail agendas and any meeting materials to Lonnie's Pond abutters and other concerned citizens prior to the presentations on both the Semi-Annual Status Update and the Annual Report. Both the Technical Memorandum and the Annual Report will be available on the Town website, as will any presentation materials.

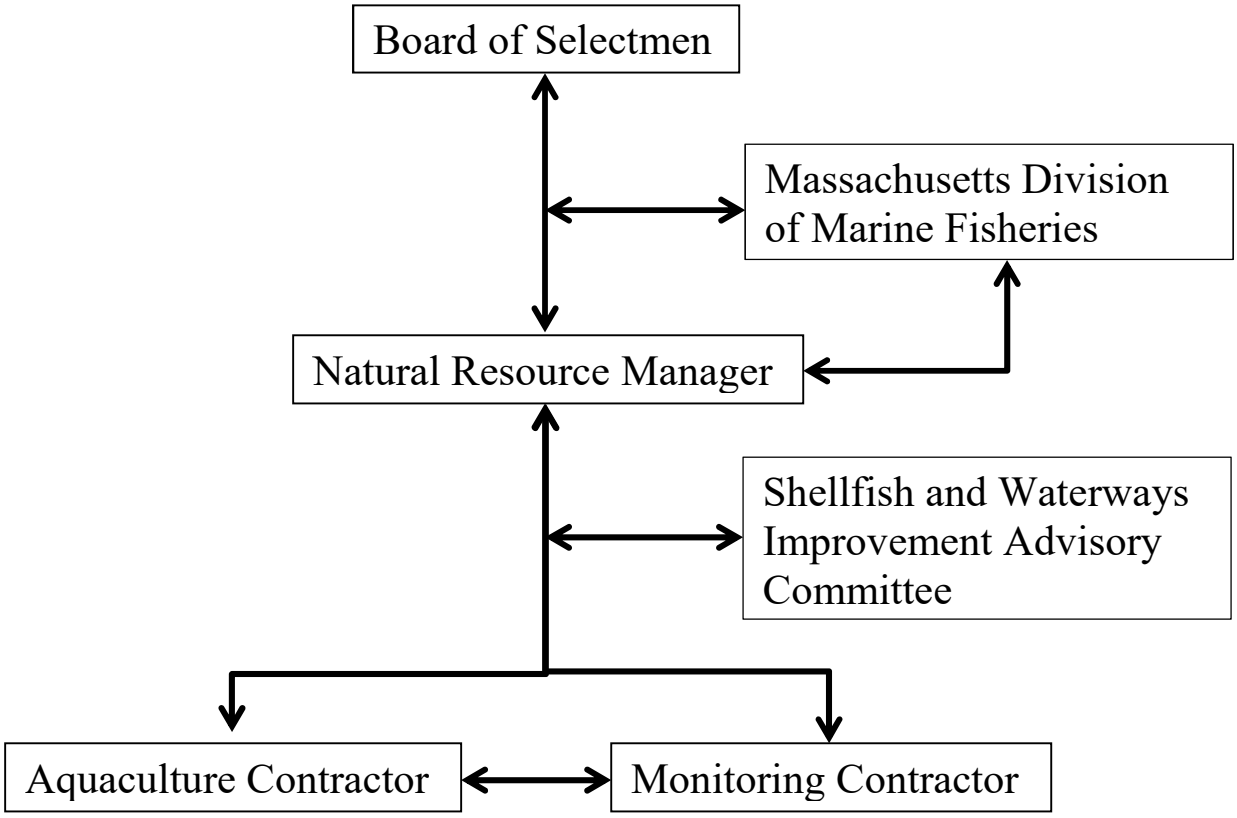
IV.C. Lonnie's Pond Reports: Regulatory Reporting

The Town, with support from the Monitoring Contractor, will submit the Lonnie's Pond Aquaculture/TMDL Annual Report to MassDEP in support of TMDL and Surface Water Quality Standards compliance. A copy of the Annual Report will also be submitted to MassDMF and the Town.

V. Lonnie's Pond Aquaculture and Nitrogen Management Plan Schedule

Action	Date	Frequency
Town Actions		
Town publicly advertises Aquaculture Contractor RFP	November	YR1 and as needed
Town holds Aquaculture Contractor pre-bid conference to review available, used Lonnie's Pond Aquaculture gear	November	YR1 and as needed
Town selects Aquaculture Contractor	December 1	YR1 and as needed
Town publicly advertises Monitoring Contractor RFP	January	YR1 and as needed
Town grants license to Aquaculture Contractor following MassDMF certification of the Town license	January/February	YR1 and as needed
Town and Aquaculture Contractor obtain RDA or NOI from Conservation Commission	January/February	YR1 and as needed
Town selects Monitoring Contractor	February 15	YR1 and as needed
Aquaculture Contractor Actions		
Aquaculture Contractor confirms to Town that sufficient Year 1 seed oysters will be delivered	By December 31	Annually
Aquaculture Contractor deploys oysters	no later than June 1 (Scenario A) or July 1 (Scenario B)	Annually
Aquaculture Contractor removes oysters and gear	Between November 15 and December 15	Annually
Monitoring Contractor Actions		
Monitoring Contractor completes and submits Nitrogen Management QAPP to Town and MassDEP	February/March	Every 3 years
Monitoring Contractor measures initial shellfish N content through coordination with Aquaculture Contractor	Collection at time of deployment	Annually
Monitoring Contractor completes sampling every two weeks	June 15 to September 15	Annually
Monitoring Contractor installs and maintains continuous monitoring devices	Late May/early June to September	Annually
Monitoring Contractor submits and publicly presents Lonnie's Pond Aquaculture/Semi-Annual Status Update	By July 30	Annually
Monitoring Contractor measures sediment N removal	August	Annually
Monitoring Contractor measures harvest shellfish N content	Late Fall	Annually
Monitoring Contractor measures sediment N removal	October	Annually
Monitoring Contractor submits and publicly presents draft Lonnie's Pond Aquaculture/TMDL Annual Report	By December 31	Annually
Monitoring Contractor submits final Lonnie's Pond Aquaculture/TMDL Annual Report	By January 31	Annually

VI. Lonnie's Pond Aquaculture and Nitrogen Management Plan Organizational Chart



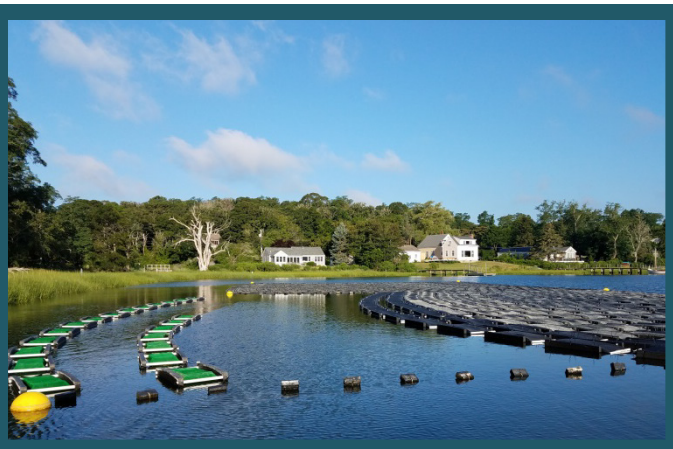
Appendix A. AECOM Lonnie's Pond Aquaculture Management Plan. Final. January 2018.

Appendix B. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth, Lonnie's Pond Shellfish Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment. September 2018.

Lonnie's Pond Aquaculture Management Plan

Town of Orleans, MA | Water Quality and Wastewater Planning

August 4, 2017
Revised December, 2017
Final January 2018



AECOM

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Executive Summary

In 2016, the Town of Orleans initiated a three year oyster Demonstration Project in Lonnie's Pond. The Demonstration Project is an outcome of planning efforts, including the Cape Cod Commission's 208 Plan Update, a Consensus Plan, and subsequent amendments to the Town's 2010 Comprehensive Wastewater Management Plan, which identified the need to improve water quality in coastal waters surrounding Cape Cod. The overall purpose of the Demonstration Project is to assess the effectiveness of using aquaculture to remove nitrogen from the water as a component of the Town's strategy to meet TMDL requirements and total nitrogen load reduction targets. Lonnie's Pond was identified as the preferred location for the town's first shellfish Demonstration Project based on a few key factors, including: the town's strong desire to improve the environmental conditions in the town's terminal ponds, many of which include anoxic, muddy sediments; and the expected ability to monitor water quality and other impacts caused by shellfish in this semi-closed sub-embayment.

The goals of this management plan are to summarize activity to date at Lonnie's Pond and identify management tasks between now and the end of the three-year Demonstration Project, including acquisition and disposition of shellfish, installation and monitoring of shellfish and water quality in Lonnie's Pond, budgeting, and long-term considerations for an aquaculture program in Lonnie's Pond.

Nearly 200,000 First Year (Y1) and Second Year 2 (Y2) oysters were deployed in Lonnie's Pond on June 22, 2016. Y1 are those oysters beginning the year as seed oysters approximately 2 to 3 mm in size and growing throughout one season. Y2 are those oysters that are in their second year of growth. The oysters were placed in floating bags containing 250 oysters each that were installed in an 80 foot by 120 foot system. Each bag contained 250 oysters. The bags were maintained on a weekly basis during the peak impairment season of July and August and then bi-weekly for the remainder of the growing season. Monitoring occurred every two weeks between June 2016 and December 2016. Monitoring consisted of assessing growth rate of 25 to 30 oysters that were randomly selected from each of seven tracking bags. The weight, length, and volume of the oysters were recorded. In addition, the oysters were monitored for mortality.

The oysters in the Lonnie's Pond demonstration grew well and at a rate that is typical for Cape Cod oysters during the first year of the demonstration. The Y1 oysters finished the season at an average length of about 74 mm (2.9 in) and an average weight of 35 g (1.23 oz.). The Y2 oysters finished at an average length of about 94 mm and an average weight of about 69 g (2.4 oz.). All of the Y2 oysters and approximately 80 percent of the Y1 oysters reached either petite or regular market size by the end of the Demonstration Project season, which started later than the normal growing season would. The live weight of the oysters increased from approximately 2,176 metric tons at the beginning of the project in June to approximately 10,091 metric tons at the end of the growing season (adjusted for 6.6 percent measured mortality prior to overwintering).

To measure the nitrogen content of the shell and dry weight tissue of the oysters, the samples were sent to the Boston University Stable Isotope Laboratory. The nitrogen content for Y1 and Y2 was 10.5 percent and 10.3 percent, respectively. The preliminary assessment indicates that the demonstration system removed 25.9 kg of nitrogen by uptake (increased biomass). The demonstration monitoring project in Lonnie's Pond provided data indicating that nitrogen reduction was achieved, which is a goal of the TMDL established by MassDEP for Lonnie's Pond.

Between 2016 and 2017, the oysters were overwintered in Lonnie's Pond in a system designed to keep oysters from sinking into soft sediment, avoid ice damage, maintain enough flow for the cold weather metabolic activity of oysters, and control mortality from predation. The oysters were resurfaced in mid-April 2017 and removed from the bags and assessed for mortality. Overall, the mortality rate for Y1 oysters from June 2016 through the resurfacing in 2017 was less (1.1 percent) than the Y2 oysters (10.9 percent). The total live weight of the oysters was measured and a representative sample of individuals was weighed and measured to assess growth during the winter period. These oysters were then used as a part of the second year demonstration. Year 2 oysters from the 2016 season, now three years old, were relayed to Falmouth, MA; approximately 113,000 oysters were relayed to Falmouth, MA with the intention that Falmouth, MA would return the same number of harvestable size oysters in fall 2017. However, due to oyster losses in Falmouth, MA, Orleans, MA and Falmouth, MA mutually agreed that 113,000 harvestable size quahogs would be returned in lieu of oysters. These quahogs were made available for residential family harvest.

The Demonstration Project was continued for a second year in late spring of 2017. Both Y1 and Y2 oysters were deployed in bags in a similar system as 2016. The population of oysters for the second demonstration year consisted of oysters from the first year of the Demonstration Project (former 2016 Y1 oysters), 480,000 two mm oyster seed from Mook Sea Farms, and 58,000 two inch oysters from Falmouth, MA. The total number of oysters deployed in the second year was approximately 607,000 oysters. Year 2 oysters were installed in 510 bags with a targeted final grown-out stocking density of 250 oysters per bag. Over the course of the 2017 growing season, the density of Y1 oyster bags was adjusted as their size increased, for a final grown-out density similar to the Y2 oysters.

Science Wares' monitoring in Year 2 included data collection to further refine the relationship between live wet weight and nitrogen content to provide a tool for quantifying estimated nitrogen removal by oysters without analyzing the nitrogen content of dry shell and tissue. These results will be included in the Year 2 report, due to be released in draft form in late January 2018.

The demonstration monitoring project in Lonnie's Pond data showed that oysters are achieving nitrogen reduction. The results from year one of the project indicate that oysters are removing nitrogen and could be used to meet part or all of the TMDL requirement in regard to nitrogen reduction. The oysters removed sufficient nitrogen through uptake alone. Mortality was low and the bag and line system and overwintering installation provided sufficient protection from predation and supported strong oyster growth. Year 2 and Year 3 of the Demonstration Project in Lonnie's Pond will provide additional data to evaluate the effectiveness of this non-traditional technology.

Year 3 of the demonstration project is proposed to be designed similarly as Year 1 and Year 2 but oysters in the Y1 field will be deployed in a system that is half the size of a full scale operation. These oysters are intended to validate the ability of Y1 focused scenarios to meet TMDL and MEP requirements. The field of Y2 oysters is proposed to remain the same as in 2017 with approximately 130,000 oysters. Maintenance and monitoring are proposed to be the same as in previous years, with bi-weekly measurements taken during the growing season. Samples will be sent to the BU laboratory for nitrogen analysis at the beginning and end of the demonstration year.

In fall of 2018, oysters that have been used for the Demonstration Project and are of harvestable size will be put out for harvest by residents, while smaller oysters are anticipated to be traded to Falmouth, MA for quahogs that will also be put out for harvest. It is necessary to remove these oysters from Lonnie's Pond because the oysters have incorporated nitrogen from the water column, and this nitrogen is only removed from the estuarine system when the oysters are removed from the pond.

The viability of oysters is impacted by a number of factors, including ocean acidification, predators, disease, algal blooms, biofouling and pests, storm damage, and theft. Environmental conditions should be monitored over the long term to ensure the health and survival of the oysters. Regular maintenance and the design of the system proved effective in controlling for predators and bio-monitoring to date. The overwintering system design protected from storm damage to date.

Biodeposition has not been approved by MassDEP as an approach to meet nitrogen targets. However, monitoring results indicated that it should supplement nitrogen removal by uptake. Further use of the biodeposition model to predict denitrification in Lonnie's Pond is warranted, however this management plan focuses on removal by direct uptake.

A number of scenarios are under consideration for full-scale implementation subsequent to 2018. It is estimated that the MEP nitrogen reducing goal for Lonnie's Pond (660 lbs/yr or 300 kg/yr) could be met by growing and harvesting Y1 oysters annually or by growing a combination of Y1 and Y2 oysters in a larger area of the pond, with oysters removed when they are of harvestable size. The selected scenario will be determined based on review of the last two years of data as well as the status of the MassDEP approval of aquaculture as part of a Watershed Permit and associated Watershed Management Plan.

1.0 Introduction

1.1 Background

1.1.1 Cape Cod Commission 208 Plan

Massachusetts Department of Environmental Protection (MassDEP) directed the Cape Cod Commission to update the 1978 Water Quality Management Plan in accordance with Section 208 of the federal Clean Water Act. The updated was necessary due to the impairment of water quality in coastal waters resulting from excess nitrogen. The plan was prepared by the Commission and approved by MassDEP and US EPA in 2015.

The 208 Plan Update identified a number of recommendations to improve water quality in coastal waters surrounding Cape Cod. Among these were a number of alternative technologies that should be considered to reduce nitrogen loadings from wastewater on the Cape, in addition to the consideration of traditional sewering, treatment, and effluent discharge approaches.

Following the update to the 208 Plan, a Consensus Agreement was developed under the guidance of the Orleans Water Quality Advisory Panel (OWQAP), which convened in 2014 to achieve consensus and build widespread community support for a customized, affordable water quality management plan for Orleans. The Consensus Agreement led to the preparation of an Amended Comprehensive Wastewater Management Plan,

1.1.2 Orleans Amended CWMP

In 2010, a Comprehensive Wastewater Management Plan (CWMP) was prepared that proposed to meet state and federal mandates through an expansion of the municipal sewer system under an Adaptive Management Plan.

The Amended CWMP was developed to provide the Town of Orleans with an alternative, more cost effective strategy for managing wastewater and reducing nitrogen in the Rock Harbor, Nauset Marsh, Pleasant Bay, Namskaket, and Little Namskaket Watersheds. This strategy included a hybrid approach to managing wastewater through a combination of traditional (sewered) technologies and several non-traditional technologies.

1.1.3 Non-Traditional Technologies

Non-Traditional nitrogen control strategies can reduce the volume of wastewater that requires treatment at wastewater treatment facilities and result in lower treatment costs for the Town. The Consensus Agreement recommended three Non-Traditional Technologies for use in key locations in Orleans' sub-watersheds in order to reduce nitrogen loading in the Town's coastal estuaries: Floating Constructed Wetlands (FCW), aquaculture/shellfish propagation, and permeable reactive barriers (PRB). An additional innovative Non-Traditional Technology, a Nitrogen Reducing Biofilter (NRB), was also considered for implementation in areas of Orleans.

1.1.4 Aquaculture/Shellfish Propagation

Orleans chose to include shellfish propagation as a means to reduce the amount of nitrogen entering watersheds where sewering was not currently planned. Four different Demonstration Projects were discussed and planned in order to obtain site specific information within Orleans' waterbodies and the viability of pursuing full-scale implementation. The Demonstration Projects were scaled to allow meaningful monitoring and quantifiable results, while expending only the minimal amount of necessary funds during this experimental phase. The purpose of the Orleans shellfish demonstrations is to both locally measure the nitrogen-removal benefits of shellfish cultivation as well as to demonstrate the practical applications of shellfish propagation and aquaculture expansion within the Town of Orleans.

1.1.5 Lonnie's Pond

Potential demonstration sites for non-traditional technologies were systematically evaluated and ranked using a site selection matrix that included criteria for site suitability, permitting, and project evaluation. Initially, Lonnie's Pond was not evaluated by the Shellfish Team during the site selection process because it was selected by as the best alternative for Floating Constructed Wetland implementation. Once the Town put implementation of the Floating Constructed Wetland technology on-hold until further refinement of estuarine nitrogen removal and costs were evaluated, Lonnie's Pond was identified as the preferred location for the town's first shellfish Demonstration Project. This selection was made based on two key factors: the town's strong desire to improve the environmental conditions in the town's terminal ponds, and the expected ability to monitor water quality and other impacts caused by shellfish in this semi-closed sub-embayment.

At the time of the preparation of this plan, Year 1 (Y1) of the oyster Demonstration Project at Lonnie's pond had been completed and the growing season of Year 2 (Y2) was underway. Work completed to date, including the installation, monitoring, overwintering, and analysis of 200,000 oysters, is summarized in the following sections of this management plan. The remaining work of the Demonstration Project includes monitoring and data collection for Y2, installation, monitoring, and data collection for Year 3 (Y3), and an assessment of considerations for full-scale aquaculture at Lonnie's Pond. A discussion of this work is included in the following sections of this management plan.

1.2 Goals and Organization of Document

The goals of the document are to summarize activity to date at Lonnie's Pond to date and identify remaining actions between now and the end of the three-year Demonstration Project. Remaining actions include:

- Important decision points such as acquisition of oysters for additional years of investigation;
- Disposition of shellfish at the conclusion of each season;
- Budgeting for the remaining years of the Demonstration Project; and
- Long-term considerations and next steps for maintaining an aquaculture program in Lonnie's Pond, and potentially other terminal ponds in Orleans.

The introduction of this document, Section 1, describes past plans and activities that led up to the planning and installation of a Demonstration Project at Lonnie's Pond. Section 2, Section 3, Section 4, and Section 5 provide an overview of the planning and implementation of the three year Demonstration Project. A description of the planning, installation, monitoring program and results, and overwintering for Y1 is included in this document. At the time this document was prepared (August 2017), Y2 of the demonstration at Lonnie's Pond was underway and sampling results were not yet available. Additional details about the demonstration field, installation, and monitoring can be found in the Technical Memorandums titled *Demonstration Project Year 1 Project Report* (2/17/17) and *Draft Aquaculture Full-Scale Implementation Program* (7/7/17).

A discussion of oyster viability considerations, including disease, pests, and environmental threats, is included in section 6 of this document. Section 7 provides an overview of the results of water quality monitoring from Year 1, which is described in more detail in the memorandum *Demonstration Project Year 1 Project Report.*

The final sections of this document review considerations for full scale aquaculture at Lonnie's Pond as well as other opportunities for shellfish aquaculture and coastal habitat restoration.

1.3 Town Organization

1.3.1 General

The Lonnie's Pond Demonstration Project and Full Scale Implementation is an outcome of planning efforts, including the Cape Cod Commission's 208 Plan Update, a Consensus Plan, and subsequent amendments to the Town's 2010 Comprehensive Wastewater Management Plan, which identified the need to improve water quality in coastal waters surrounding Cape Cod. The organization for the Project is shown on Figure 1-1.

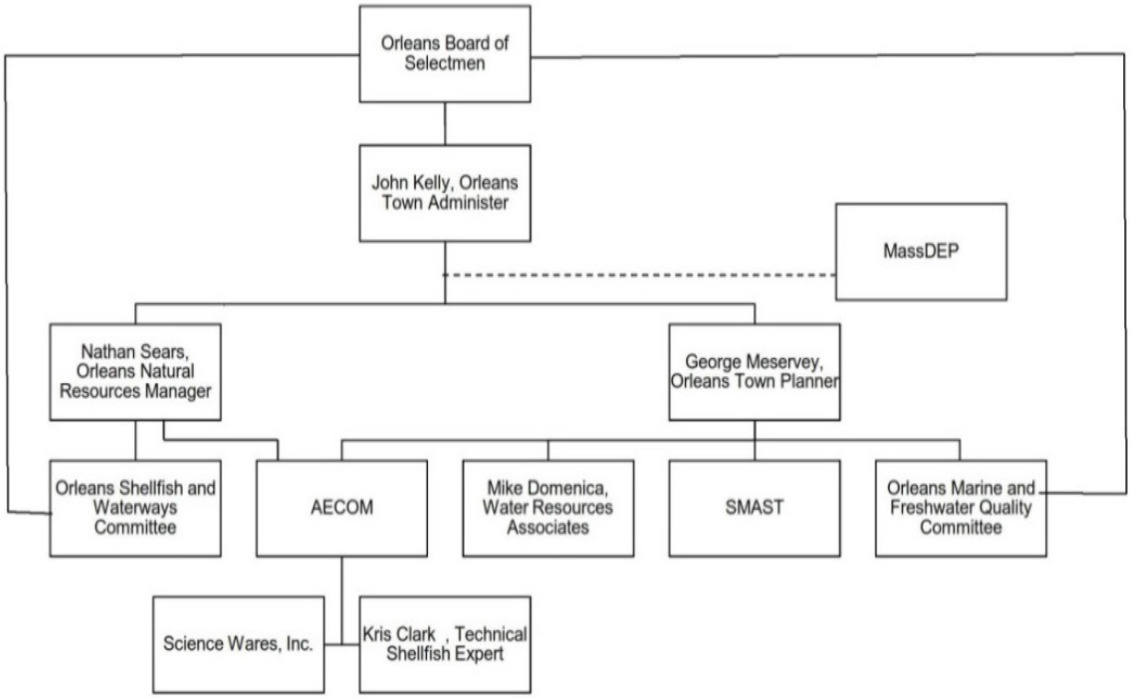


Figure 1-1 - Organizational Chart for Lonnie's Pond Demonstration

1.3.2 Board of Selectmen

The Board of Selectmen has a delegate who coordinates with the Committee and apprises the Board of status of the Lonnie's Pond aquaculture project, as well as any issues requiring decisions and resolution. The Board of Selectmen considered the Lonnie's Pond Management Plan in fall 2017 and voted to place an item on the Warrant for the fall 2017 Town Meeting for approval of funding for the spring 2018 portion of Y3 of the Demonstration Project. Prior to consideration of the budget at Town meeting, the Finance Committee reviewed the proposed budget and informed citizens of Orleans of its findings and recommendations. This is discussed in further detail in Section 5.7.

1.3.3 Shellfish and Waterways Improvement Advisory Committee Review

The Shellfish and Waterways Improvement Advisory Committee (the committee) serves as an advisor to the Town Administrator, Board of Selectmen, Harbormaster/Shellfish Constable, and other Town boards and committees. The Town calls upon this committee for issues related to preserving, protecting, managing, and enhancing natural resources, including shellfish and waterways. It is the committee's role to review the progress of, and provide recommendations as needed, in regard to the oyster Demonstration Project and Full Scale Implementation at Lonnie's Pond. The Committee provides recommendations to Nate Sears, Orleans Natural Resources Manager and the Board of Selectmen. In fall 2017, the Committee reviewed a draft version of the Management Plan and made a recommendation to Nate Sears and the Board of Selectmen to continue with Year 3 of the oyster Demonstration Project at Lonnie's Pond Board of Selectmen Review,

1.3.4 Town Meeting Budget Approvals

The Board of Selectmen submitted a Warrant Article for the fall Town Meeting, and citizens voted to approve the budget for spring 2018 Demonstration Project work on October 24, 2017. Ongoing budgets for the Lonnie's Pond aquaculture will be subject to approval at future Town Meetings as appropriate.

2.0 Lonnie's Pond Demonstration Project Planning

Orleans is pursuing oyster cultivation as the first demonstration because many scientific papers published in peer-reviewed journals demonstrate the nitrogen uptake and water quality improvements caused by oyster cultivation (Bricker 2015; Carmichael et al. 2004; Higgins et al. 2011; Kellogg et al. 2013, 2014; Nelson et al. 2004; Porter et al. 2004).

Oysters feed by filtering algae and other particles that contain nitrogen out of the water column. Through this filter-feeding process, oysters both improve water clarity and impact nitrogen concentrations (Newell et al. 2002, 2004, 2005; Officer 1982). Oysters remove nitrogen from the water column by filtering phytoplankton and other organic particles from the water. These inorganic materials are incorporated into the shell and soft tissue and are removed when the oysters are harvested. In the sediment, nitrogen compounds in the feces and pseudofeces are mineralized into inorganic nitrogen through oxidation to nitrates. Denitrification of nitrates releases nitrogen gas which leaves the system. A small fraction of the nitrogen is buried in the sediment and does not re-enter the water column.

Thus, the main pathways by which oysters remove the mass of nitrogen in an estuary are:

- Uptake into shell and soft tissue (which harvesting removes);
- Enhancement of sediment denitrification (nitrogen removed as a gas); and
- Packaging of particles into feces and pseudofeces (biodeposits), which sink into the estuary bottom and are not denitrified (burial).

It is important to remember that all of the nitrogen that is sequestered in the body of an oyster, as well as the nitrogen contained in biodeposits and excretions, comes originally from the water column. Therefore, following the principle of the conservation of mass, oysters do not contribute new nitrogen, but instead both sequester and reformulate the nitrogen already contained in an ecosystem. Biodeposition and excretion of inorganic nitrogen does not add any new nitrogen to the water column or estuary bottom. The nitrogen was already in the system.

Removing oysters that have grown in the water column directly removes a mass of nitrogen that was previously in the water. This nitrogen-removal value can be measured directly by weighing the shell and soft tissue and applying a measured value for the percent nitrogen contained therein. While the amount of nitrogen sequestered in the shell and tissue of adult oysters is reasonably consistent, rates of enhanced sediment denitrification vary widely and are highly site-specific (Kellogg et al. 2013). Therefore this management plan focuses on nitrogen removed via direct uptake.

There is a strong scientific basis for using oyster cultivation to decrease water column nitrogen concentration and improve water clarity. A Demonstration Projects focusing on oysters was seen as an important first step in order to validate the quantities of nitrogen removed through uptake in the body of the oyster. The Lonnie's Pond project provides the field-verified basis for including oyster cultivation in the Town's wastewater plans.

3.0 Lonnie's Pond Oysters Demonstration Project Year 1 (2016)

Two-hundred thousand (200,000) oysters between 1 and 2 inches in size were installed in floating bags in Lonnie's Pond in the summer of 2016. The oysters were maintained and monitored through the winter of 2016 and 2017. In April of 2017, the oysters were removed from the bags and evaluated for survival and growth. The work accomplished and results of Project Y1 are summarized below.

3.1 Field Installation

Oysters were deployed in Lonnie's Pond in an 80 foot by 120 foot system comprised of 800 floating bags that were installed along long lines spaced approximately 10 feet apart. Each floating bag contained 250 oysters. Volunteers, staff, and unpaid members of the shellfish technical team assisted with assembling and deploying the oysters, which were purchased from the Town of Falmouth, MA and Cape Cod Oyster (Table 3-1).

Table 3-1 - Oysters for Demonstration Year 1 (2016)

Size Classes	Number of Oysters	Source of Oysters	Number of Bags
Year 2 (2-inches)	127,000	Town of Falmouth, MA	560
Year 1 (1-inch)	11,700		
Year 1 (< 1-inch)	60,000	Cape Cod Oyster	240
TOTALS	**198,700**		**800**

3.2 Operation and Maintenance

In order to prevent fouling, bags were flipped on a weekly basis during the peak impairment period and bi-weekly as the growing season concluded. Tunicates (sea-squirts) and algae were found on several occasions but were controlled by the weekly flipping. Bags were flipped by boat at high tide to prevent disturbance to the bottom sediment and allow for SMAST to accurately determine denitrification rates. Flipping the bags also helped to prevent oysters from growing together and to trim edges, both of which are important for marketability. In addition, flipping the bags helps extract feces and pseudofeces.

Gear remained in-place all season and performed well overall. Minor repairs were performed as needed on the water, and primarily involved replacing broken zip-ties that held the side floats to some of the bags. On one occasion when there was a risk of a hurricane in the forecast, an additional 10-foot of length was temporarily added to the long lines to accommodate a possible storm surge increasing the water level.

The water level typically changed by several feet each the day. Scope between the end of the middle long line and the auger on each end was sufficient to allow the strings to withstand this range of water level change. On extreme tides, two to four bags located on the ends of the field would occasionally stand up on end, but the oysters would redistribute as the tide went out and the bags laid back down flat. Extended periods of wind and moon cycles could increase or decrease the average water height by about a foot. Regardless of the wind, the surface conditions were calm, and the gear was never at risk of damage due to wind or wave action.

3.3 Growing Season Monitoring

Seven floating bags were monitored for growth rates and mortality every two weeks between June and December, 2016 (total of 18 times). To assess growth rate, 25 to 30 oysters were randomly selected from each of the seven tracking bags and lightly scrubbed to remove surface fouling. Twenty-five oysters were placed on a scaled mat and photographed for measurement. The oysters were weighed as a group to determine an average weight. Individual oysters were also weighed to validate the averages. In addition, the total volume occupied by the sample was measured inside a cylindrical container with a gauge plate.

The entire oyster field was monitored for mortality during each session when bags were maintained and flipped. Two methods were used to assess oyster mortality: (1) visual inspection to look for open shells, and (2) audible inspection to listen for the distinctive rattle of a single oyster shell that could be heard when the bag was flipped. Mortality was noted during maintenance sessions, but dead oysters were not removed from the bags at that time.

The seven tracking bags were further inspected for mortality each time oysters were withdrawn for measurements, at which point any dead shells were inspected, counted, and removed. Mortality was first observed during these inspections of the tracking bags in mid-September. From mid-September through December, mortality counts were also made from additional representative bags during every other bag flip cycle. The final mortality assessment was made by counting live and dead oysters in four (4) bags of Y1 oysters and four bags of Y2 oysters that had not been previously counted. The overall final mortality rate prior to overwintering (December 2, 2016) was 6.6 percent.

3.4 Oyster Growth, Mortality, and Nitrogen Content

The oysters grew well and at rate typical of other Cape Cod locations. The Y1 oysters finished at an average length of about 74 mm (2.9 in) and an average weight of 35 g (1.23 oz.). The Y2 oysters finished at an average length of about 94 mm and an average weight of about 69 g (2.4 oz.). Approximately 80 percent of the Y1 reached harvestable size (76 mm / 3 in) in one shortened growing season (the typical season begins in May). The live weight of the oysters increased from approximately 2,176 metric tons at the beginning of the project on June 22, 2016 to approximately 10,091 metric tons at the end of the growing season (adjusted for 6.6 percent measured mortality). During the growing season, the volume requirement of the oysters increases, resulting in the need to split bags. The rate of change of volume requirement for Y1 and Y2 oysters is different, resulting in fewer bags on the water early in the season and during the critical impairment period of July and August for Y1 oysters as well as a lower visual impact from late June to early September.

Samples were sent to the Boston University Stable Isotope Laboratory to determine the nitrogen content of the shell and dry weight tissue. The nitrogen content for Y1 and Y2 was 10.5 percent and 10.3 percent, respectively Table 3-2). The preliminary assessment indicates that the demonstration system removed 17.3 kg of nitrogen by denitrification (about 67 percent of the amount removed through tissue and shell uptake) and 25.9 kg of nitrogen by uptake (increased biomass). A summary of oyster weights and nitrogen update from Y1 is displayed in

Location	Sample Time	Length (mm)	Whole Weight (g)	Dry Tissue Weight (g)	Total N, Shell and Tissue (g)	N as a percent of Dry Tissue Weight (%)
Y2 Lonnie's Incoming	Spring	62.9	17.73	0.66	0.0683	10.3
Y2 Lonnie's New Growth	Fall	100	80.4	2.49	0.257	10.3
Y1 Lonnie's New Growth	Fall	74.3	37.4	1.20	0.126	10.5

Table 3-3.

Table 3-2 - Total Nitrogen Content of Lonnie's Pond Oysters

Location	Sample Time	Length (mm)	Whole Weight (g)	Dry Tissue Weight (g)	Total N, Shell and Tissue (g)	N as a percent of Dry Tissue Weight (%)
Y2 Lonnie's Incoming	Spring	62.9	17.73	0.66	0.0683	10.3
Y2 Lonnie's New Growth	Fall	100	80.4	2.49	0.257	10.3
Y1 Lonnie's New Growth	Fall	74.3	37.4	1.20	0.126	10.5

Table 3-3 - Oyster Weights and Nitrogen Uptake from 2016 Demonstration by Installation Size Class

Oyster	Dry Tissue Weight (g)			N Uptake per Oyster (g)	Initial # of Oysters	Mortality	Total Uptake(kg)
	Initial	Final	Increase				
Y1	0.055	1.04	0.98	0.103	60,000	6.6%	5.81
Falmouth, MA Small	0.055	0.79	0.74	0.076	11,700	6.6%	0.84
Y2	0.562	2.12	1.56	0.160	126,690	6.6%	19.41
Totals					**198,390**	**6.6%**	**26.06**

The percent of total nitrogen contained in Lonnie's Pond oysters are typical for cultured off-bottom oysters; however, the actual value may be different depending on at which point in the growing season oysters are removed from Lonnie's Pond. Additional information about seasonal variation in the nitrogen content of oysters grown to marketable size will be obtained during the second year of the Demonstration Project. It is not expected that such variations will have a substantial effect on the overall viability or costs of the program. The relationship between dry tissue weight and harvest weight will also be established in the second year in order to develop a tool for quantifying nitrogen removal over the course of the growing season and at different harvest times.

3.5 Quality Control

As stated above, samples were sent to the Boston University Stable Isotope Laboratory for nitrogen analysis. The Laboratory weighs out samples to 0.001 mg into tin capsules on a microbalance, then combusts them in an elemental analyzer and measures them using software. Check standards are inserted into the run to ensure precision and quality control. Any anomalous samples are reweighed and rerun. The precision for replicate samples is 0.5 percent for nitrogen. Boston University (BU) protocols were approved by MassDEP. Refer to the QAQC document in Appendix A for a description of the protocol.

In addition to laboratory analysis, other procedures included sampling and analyzing oysters for harvest weight and dry weight. Science Wares' Standard Operating Protocols (SOPs) for these procedures are also included in Appendix A.

3.6 Overwintering System Design and Installation

Oysters were submerged for overwintering by December 23, 2016. The overwintering system was designed to keep oysters from sinking into soft sediment, avoid ice damage, maintain enough flow for the cold weather metabolic activity of oysters, and control mortality from predation, in addition to being practical to install. The system includes a three-part PVC tube frame attached to two plastic pallets, and is illustrated in Figure 3-1. The assembly footprint is 50 in wide by 82 in long by 57 in high and requires a minimum water depth of six feet. The negative buoyancy and nine wedge-shaped feet of each assemble prevent the loaded assembly from

descending into soft bottom. Copper barriers were applied to some of the frames to discourage drills from traveling along the supports to reach the bags. This system made it possible to leave the oysters in the grow-out bags for overwintering, and is advantageous because it:

- Allows oysters to continue to filter water;
- Maintains water flow across the oysters to enable survival and prevent toxicity as oysters continue to filter and purge over the winter;
- Minimizes the handling of oysters that could damage the shells and lead to higher mortality over the winter; and
- Provides a physical barrier (6 mm bag mesh, copper wire) against mature drills and other predators.

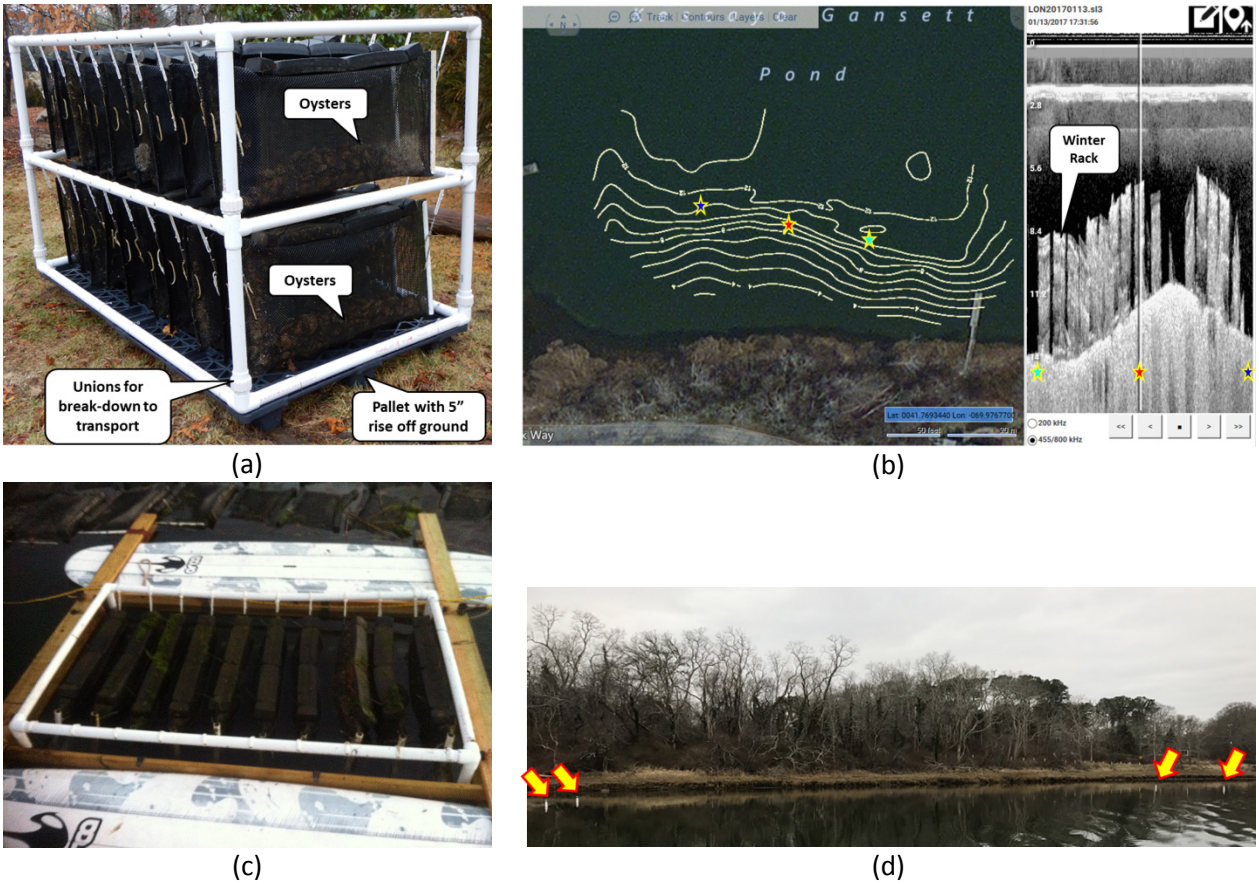


Figure 3-1. Science Wares overwintering system for 2016 Demonstration Year at Lonnie's Pond: (a) rack on dry ground showing two levels of bags oriented with one float up and oysters down (b) depth profile and sonar scan showing orientation of racks on the bottom (c) loaded rack about to be submerged (d) a view of the surface of Lonnie's Pond after all bags had been submerged, with corner markers showing the location of the overwintering racks.

A custom raft was constructed for installation of this overwintering system. Bags were installed on the racks and sunk to the bottom over the course of three days. The total biomass of oysters that were submerged was over 10,000 kg. This total weight was determined by direct measurement of oyster weights and survival. In the spring, the oysters were graded and an overwintering mortality was determined.

3.7 Winter Monitoring

Two temperature sensors were placed in different locations near the overwintering site to establish field conditions prior to overwintering. The sensors monitored water temperature at 10 minute intervals a few inches below the surface (moving up and down with the water level), and at a fixed location about a foot off the bottom near where the deepest overwintered oysters would be.

Typically oysters are kept on the surface as late into the winter season as possible, depending on environmental conditions including temperature and dissolved oxygen. Although common practice is to submerge the oysters below the surface as soon as the water temperature drops below 6°C for six days in a row, the demonstration oysters were overwintered earlier than usual due to forecasted low temperatures and risk of the water freezing at the surface. Ultimately, the water temperature at the surface did not reach -2°C, the temperature at which seawater typically freezes. The results of temperature monitoring show close tracking of the surface and bottom temperatures, highlighting two important features of Lonnie's Pond:

- A high turnover rate of water coming in from Pleasant Bay; and
- An absence of persistent stratification at the location where the oysters are being maintained.

In addition to monitoring temperature, a cluster of sensors was placed in the field of winter racks to measure temperature, water level, salinity, and dissolved oxygen at 15 minute intervals throughout the winter season. Data revealed that:

- Dissolved oxygen content does not fall below 12 mg/L, which is consistent with typical winter conditions;
- Normal cycle of tidally-influenced water levels can be affected by weather conditions, such as a northerly wind; and
- Large tidal variations (including changes of 1.65 m over a two-week period in early 2016 and typical daily oscillations of about 0.9 m and 1.2 m) indicate that there is a high rate of exchange of water with Pleasant Bay.

3.8 Resurfacing of Overwintered Oysters

The 2016 oysters were resurfaced between April 17 and April 24, 2017 after the water temperature had risen sufficiently. The oysters were brought to the surface, removed from the submerged bags, and assessed for mortality. The shells of dead oysters were separated out. The total live weight of the oysters was measured and a representative sample of individuals was weight and measured to assess growth during the winter period. These oysters were used as a part of the second year demonstration.

Table 3-4 summarizes the number of Y1 and Y2 oysters from 2016 that were processed and the mortality rate from June of 2016 through May of 2017. Year 1 oysters from the first year of the Demonstration Project (now Y2 oysters) were moved to the south side of the Demonstration Projects year two field. The Y2 oysters from 2016 (now Y3 oysters) were relayed to Falmouth, MA because they were of harvestable size but there was no location in late spring, 2017 within Orleans where they could be put out for harvest due to the time of year and lack of appropriate regulations in place at the time.

Table 3-4 - Resurfaced Oysters From 2016

Oyster Age and ID		Oysters Processed After Overwintering	Mortality Since 6/22/16	Location of Oysters in 2017
2016	2017			
Y1	Y2-L	70,769	1,320 (1.78%)	Oysters moved to south side of the Y2 field on May 4, 2017
Y2	Y3	127,346	13,772 (10.8%)	113,574 live oysters relayed to Falmouth, MA

3.9 Cost

Table 3-5 displays a cost estimate for the Year 1 of the aquaculture Demonstration Project in Lonnie's Pond in 2016.

Table 3-5 - Demonstration Project Year 1

Description	Cost
Planning and Implementation (July 2016 through October 2016)	$59,680
FY17 Planning and Implementation (November 2016 through June 2017)	
Build and Install Overwintering System	$80,000
2016 Project Report	$17,000
Assemble bags	$115,000
Install oysters (June 2017)	$135,000
Monthly Operation and Maintenance	$15,000
SMAST	$28,500
TOTAL	**$450,180**

4.0 Lonnie's Pond Oysters Demonstration Project Year 2 (2017)

4.1 Field Design and Equipment

The Demonstration Project at Lonnie's Pond was continued for a second year to further refine a long-term implementation plan that that uses shellfish to remove nitrogen and to continue to collect data needed to obtain regulatory approvals for the use of shellfish aquaculture to achieve nitrogen goals. The design of Y2 Demonstration Project is similar to the Y1 project, with two plots containing Y1 and Y2 oysters (Figure 4-1).

4.2 Shellfish Acquisition and Installation

The population of oysters that was grown as Y1 in 2016 was grown for a second year in 2017. These oysters are larger than the intermediate seed available from other suppliers. These oysters have an average dry tissue weight of about 1 gram, so the equivalent initial stocking density would be 150 oysters per bag to achieve the projected Y2 performance comparable to placing intermediate seed with a 0.5g dry tissue weight at an initial stocking density of 280 per bag.

Additional seed was ordered to continue the Demonstration Project, including:

- 480,000 2 mm oyster seed from Mook Sea Farms; and
- 58,000 2 inch (i.e. overwintered Y2 oysters) was ordered from Falmouth, MA.

Approximately 607,000 oysters, including 127,000 Y2 oysters and 480,000 Y1 oysters were deployed in two plots in Lonnie's Pond. The Y2 oysters were deployed in 510 bags with a targeted final grown-out stocking density of 250 oysters per bag in the west (W) plot (Figure 4-1).

Y1 oysters were grown from 2 mm seed in spat bags in the east (E) plot shown in Figure 4-1. The number of bags and Y1 oysters occupying each bag was adjusted over the growing season to accommodate oyster growth. It is anticipated that there will be 510 bags of Y1 oysters at the end of the growing season. The number of bags and initial stocking density for Y1 and Y2 oysters targets a final population of 250 per bag.

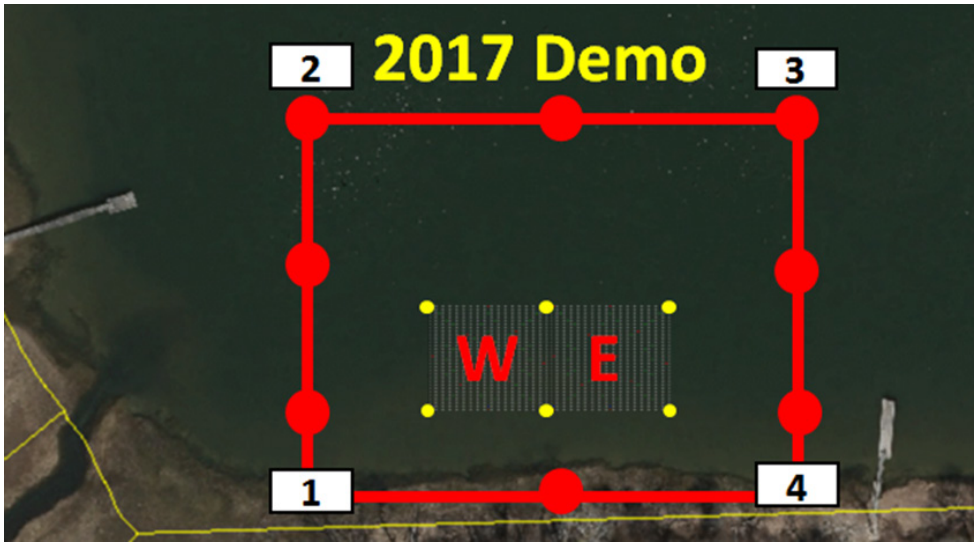


Figure 4-1 - Year 2 (2017) Demonstration Field

4.3 Maintenance and Monitoring

As in 2016, the 2017 management measures consist of flipping the bags on a weekly basis at beginning of the growing season and bi-weekly later in the season as growth begins to curtail. Gear will continue to be maintained and repaired as needed.

4.4 Disposition of Excess Oysters

All of the Y1 oysters from the 2017 Demonstration Year will be overwintered and re-deployed in spring 2018. Approximately 100,000 harvestable size oysters were removed from Lonnie's Pond in November 2017 and transported to the Town Landing on Route 28 for harvest by residents with a family harvest license. In addition, arrangements are underway to receive approximately 113,000 harvestable size quahogs from Falmouth, MA for residential harvest, in exchange for the 113,000 harvestable size oysters that were provided to Falmouth, MA in spring, 2017.

4.5 Shellfish Data Collection and Reporting

Similar to 2016, oysters were monitored for growth and mortality. Fourteen bags of Y2 oysters and 2 to 3 percent of the Y1 bags were monitored for weight and mortality on a weekly basis. During each monitoring session, 15 oysters were extracted from a different bag each time at approximately two-week intervals for size, harvest weight, and dry tissue weight analysis. Similar measurements will be made of the oysters in the Y1 field once they have a harvest weight of approximately 5 grams each. The weights and lengths were measured in the same manner as in the first year of the Demonstration Project.

At the end of the sampling period 25 oysters will be randomly selected and analyzed for nitrogen content at the Boston University laboratory. Based on the data collected in Y1 and Y2, a tool will be developed to allow the nitrogen content of live wet oysters to be estimated, which will be necessary for future quantification of nitrogen removal at full scale implementation.

4.6 Additional Activities

Additional activities in Year 2 of the Demonstration Project include:

- Work with SMAST to obtain food availability, biodeposition, and denitrification enhancement measurements from suitable locations before, during, and after the critical impairment period of July and August; and determine the feasibility of measuring the difference, if any, in the denitrification rate if maintenance is done on foot as opposed to by boat;

- Evaluate public and abutter acceptance by person interviews and/or surveys;
- Evaluate acceptance and compatibility with other local growers and commercial shellfish harvesters by personal interviews and/or surveys;
- Review the options with DMF for sale by the Town of intermediate seed;
- Identify any permitting issues for a commercial site license (grant) in Lonnie's Pond; and
- Investigate permitting for intermediate seed sale by growers

4.7 Cost

Table 4-1 displays a cost estimate for the aquaculture Demonstration Project in Lonnie's Pond for the second year of the demonstration. Y2 costs include labor for deploying, maintaining, monitoring, overwintering, and reconditioning the bags. Project management, engineering, and a final report are included. Oyster seeds were also purchased to supplement the existing supply of overwintered oysters (2016 Y1) oysters. Finally, lab costs for the nitrogen analysis are included.

Table 4-1 - Demonstration Project Cost in Year 2

Description	April - June 30, 2017	July 1 - Dec 31, 2017
Project Management	$18,000	$21,000
Engineering	$22,500	
Labor		
Overwintered Oyster Processing Labor	$14,400	
Labor for bags and fixed field alignment gear	$11,000	
2017 Oyster Deployment Labor in Lonnie's	$10,000	
Flip & Maintain Labor	$2,000	
First split Labor		$1,000
Second split Labor		$1,000
Flip & Maintain Labor		$5,000
Overwintering Labor		$5,000
Y2 Bottom Planting Labor		$2,000
Labor to recondition 500 winter bags		
Half Scale Y1X Deployment Labor		
Field sampling & sample prep	$7,680	$0
Analysis of Monitoring Data		$7,800
Permit Options Analysis		$1,000
Lab		
N analysis	$2,600	$7,800
Oyster Seed		
2 to 3mm oyster seed	$5,760	
Intermediate oyster seed	$12,760	
Materials		
Spat bags	$1,920	
Materials for two 500 bag fixed fields	$8,320	
Materials & supplies for sampling	$2,180	$6,600
Materials for 1,000 bags & lines		
Materials to recondition 500 winter bags		
Year 2 Final Report		$30,000
Contingency	$10,700	$6,200
SMAST Water Quality Sampling		$67,000
TOTALS	**$129,820**	**$161,400**
		$291,220

5.0 Lonnie's Pond Oysters Demonstration Project Year 3 (2018)

5.1 Field Design and Equipment

The layout of the 2018 Y3 of the Demonstration Project is illustrated in Figure 5-1. The northwest (NW) and southwest (SW) fields are Y2 oysters, the southeast (SE) field is comprised of Y1 oysters, and the northeast (NE) field would be comprised of a combination of Y1 and Y2 oysters.

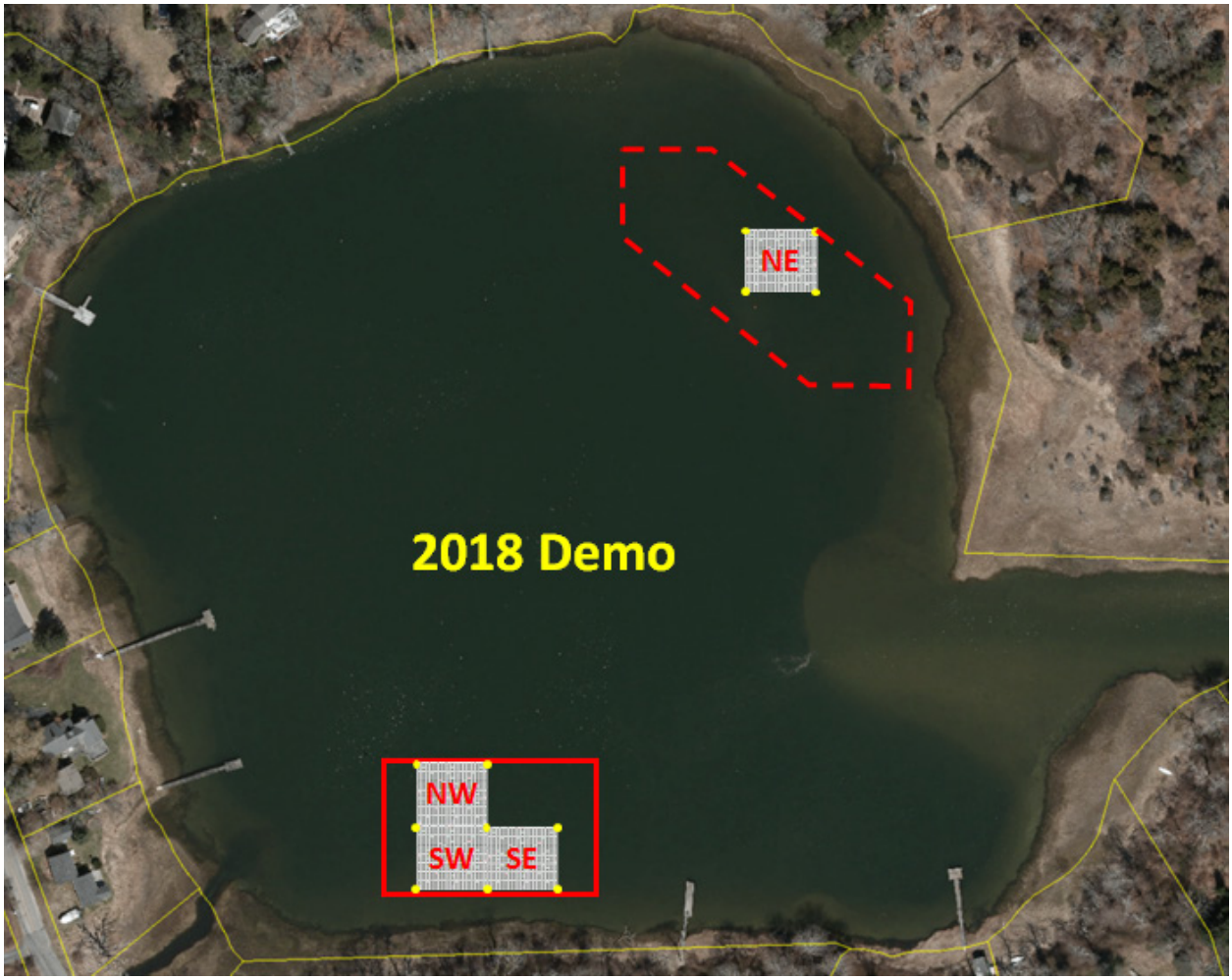


Figure 5-1 - Year 3 (2018) Demonstration Field

The design of the Y3 Demonstration Project is recommended to be approximately twice as big as the 2017 Y2, and approximately half of a full scale implementation scenario that would achieve 100% compliance with the MEP Nitrogen removal goals. The larger design is planned because it will facilitate evaluation of a deployment in which Y2 oysters occupy the majority of the deployment space to verify their nitrogen uptake in a high density layout. In addition, the expanded layout involves installing an oyster field in the northeast part of the pond, where oyster fields would be required if full scale implementation were to meet 100 percent of the MEP nitrogen removal goals. The 2018 layout will provide additional data to validate assumptions made for all scenarios currently under consideration for scale implementation depending on scenario ultimately selected (see Section 9.0).

The bags needed for the 2018 Y2 oysters would include a total of 2,040 6 mm diamond mesh bags, which will consist of the following:

- 1,020 from demo Year 2 (the 2017 growing season);
- 800 from the demo Year 1 (the 2016 growing season) which need to be reconstructed; and
- 220 new bags.

In addition, 360 spat bags will be needed for grow-out of the 2.04 million 2 to 3 mm seed until they can be kept in 6 mm diamond mesh bags:

- 80 bags from demo Y2 (the 2017 growing season) can be reused but will need new internal frames; and
- 100 new bags will need to be constructed.

5.2 Shellfish Acquisition and Installation

The Y1 and Y2 oysters for the third year of the Demonstration Project will be obtained from a combination of 2017 Y1 oysters that will be Y2 in 2018 after overwintering, as well as additional procurement of Y1 oysters in 2018 from an outside source. For the Y2 oysters needed in Lonnie's Pond in 2018, all of these are anticipated to be provided by overwintered Y1 oysters. For the 1,060,000 Y1 2018 oysters, all of these would need to be procured from a nursery in spring 2018, which necessitates submitting a request for procurement in December 2017 and submitting a deposit to secure delivery in the spring.

5.3 Management Measures

5.3.1 Equipment Monitoring and Maintenance Tasks

As in 2017, the 2018 management measures will consist of flipping the bags on a weekly basis at beginning of the growing season and bi-weekly later in the season as growth begins to curtail. As needed, gear will be repaired. Only minor repairs are anticipated to be needed, such as replacing broken zip-ties that hold the side floats to the bags, although bi-weekly inspections will occur to monitor the oyster fields and make any repairs needed. As in past years, work will be performed from kayak/skiff in order to avoid disturbance of the bottom sediments to facilitate the SMAST sampling that is ongoing.

5.3.2 Additional Permitting

Permitting requirements for 2018 are anticipated to be similar to those that were required in 2017. The Negative Determination of Applicability obtained from the Orleans Conservation Commission for the 2017 work was only valid for the 2017 year of the Demonstration Project, including the overwintering between 2017/2018. Therefore, another Request for Determination of Applicability (RDA) or a Notice of Intent (NOI) will need to be submitted to authorize deployment of the proposed oyster fields in spring 2018.

5.3.3 Shellfish Data Collection and Reporting

Shellfish data collected will be similar to 2017. Approximately bi-weekly between May 1 and December 1, 25 oysters from the 7 selected sampling bags will be removed for weight and length measurements in the field. Weights and lengths will be measured in the same manner as in past years. In addition, 25 oysters will be collected at the beginning and end of the sampling period and analyzed for nitrogen content at the Boston University laboratory.

5.3.4 Shellfish Disposition

Disposition of oysters at the end of the 2018 season will be dependent upon the status of MassDEP approval of aquaculture as part of a Watershed Permit and associated Watershed Management Plan, as discussed in greater detail in Section 9.1. Potentially, the shellfish remaining at the end of 2018 could be used in an ongoing demonstration or full-scale project, or put out for harvest if they are of harvestable size. In addition, arrangements are underway to arrange for an exchange of excess Y1 oysters with Falmouth, MA, in return for harvestable size quahogs from Falmouth, MA.

5.4 Cost

Costs for the 2018 Y3 of the Demonstration Program are envisioned to include the following:

- Labor and materials to overwinter the required number of Y1 oysters;
- Acquisition of required number of 2 to 3 mm seed;
- Labor and materials to deploy the Y1 and Y2 oysters;
- Labor to operate and maintain the four fields of oysters between May and November 2018;
- Labor to collect length, weight, and nitrogen measurements; and
- Labor to prepare the year-end report (Table 5-1).

Based on the 2017 invoice the cost for 2 to 3 mm seed would be $13 per 1,000, for a total of $26,500. A 50 percent deposit of $13,250 is required by December 31, 2017 to get early seed for 2018; a second payment on delivery of $13,250 in May 2018 will be required. The complete summary of costs for Y3 is shown in Table 5-1 below.

Table 5-1 - Demonstration Project Cost in Year 3

Description	Jan 1 - June 30, 2018	July 1 - Dec 31, 2018
Project Management	$ 44,200	$47,400
Process Engineering & Optimization	$ 12,000	$6,000
Labor		
Overwintered Oyster Processing Labor	$ 11,220	$11,220
Labor for bags and fixed field alignment gear	$ 16,900	
2017 Oyster Deployment Labor in Lonnie's	$ 11,220	
Seed Flip & Maintain Labor	$ 1,320	$1,980
Seed Splitting Labor	$ 8,360	$7,920
Seed Deployment Labor	$ 3,960	
Bag Flip & Maintain Labor	$2,250	$11,130
Field sampling & sample prep	$ 20,020	$34,320
Y2 Bottom Planting Labor		$4,490
Lab		
N analysis	$ 3,110	$9,310
Materials		
Materials & Supplies for Sampling	$ 1,000	$3,060
New floating spat bag materials	$ 3,940	
Materials for four 510 bag fixed fields	$ 9,650	
Purchase of 2 to 3 mm seed	$26,500	
Permitting	$ 5,000	
Year 3 Final Report		$30,000
TOTALS	**$180,650**	**$166,830**
		$347,480

5.5 Key Actions and Associated Dates

Key decisions for Y3 of the Demonstration Project in 2018 are summarized in Table 5-2, along with the date by which each decision is needed.

Table 5-2 - Key decisions for Year 3

Key Decision Point	Critical Date
Prepare Notice of Intent for Conservation Commission for Implementation of Year 3	January 2017
Put excess 2017 Oysters out to Harvest	November, 2017
Place Deposit on Order for 2018 Seed Shellfish for Year 3 Demonstration Project	December 31, 2017
Prepare Y1 oysters for overwintering	December 2017
Place Final Order for 2018 Year 3 Shellfish	April 1, 2018
Confirm FY 2018 Budget and Include for Town Meeting Approval	February, 2018
Receive early start seed and establish bags	May 1, 2018
Deploy Y2 field	May 1, 2018
Contact Falmouth, MA to arrange for exchange of oysters and shellfish	January 1, 2018
Evaluate status of DEP discussions and whether to continue with Demonstration Project, expand to full scale, or curtail program	Summer 2018
Identify number and location for harvestable oysters	October 2018
Inventory Overwintering and Deployment Equipment and Identify Storage/Disposition	October 2018

6.0 Oyster Viability Considerations

6.1 Ocean Acidification

Tracking the acidity (pH) of the growing area will enable a grower to be aware if concerns for ocean acidification are warranted. Primarily a cause for concern at shellfish hatcheries where young oyster larvae and juvenile seed are reared, acidity of estuarine waters is not expected to interfere with growing oysters. But tracking the pH, not only through the year, but over the past few years would give information about the pH trend so that a response can be developed.

It is likely that responses are severely limited should pH start trending down significantly. Any large-scale buffering attempts done in Lonnie's Pond would have to go through the Orleans Conservation Commission and would likely be challenged at that level. But if acidity begins to be a problem, it would not likely be in the near future and a lot may change in Lonnie's Pond and in regulations by then.

One response could be that younger, more vulnerable oysters with thin shells could be cultivated elsewhere and the older and more rugged oysters (Y2) oysters grown in Lonnie's Pond, doing the heavy lifting of the Nitrogen uptake. The overall uptake of Nitrogen in this water body would be less than is currently proposed, though, if the younger oysters weren't grown in Lonnie's Pond.

6.2 Predators

6.2.1 Crabs: Green, Blue, Calico (aka Lady), Mud, Spider, Rock, Asian Shore

Crabs can devastate an oyster crop, especially when the oysters are young. Having the oysters in floating bags off the bottom is helpful in keeping the vulnerable oysters away from the crabs' primary habitat on the bottom of the Pond. Regular maintenance of the crop to remove the crabs from the bagged oysters will serve to preserve the crop.

6.2.2 Oyster Drills

Oyster Drills may be overlooked due to being tiny and being approximately the same color as oysters in the field. Regular maintenance of an oyster crop with vigilant observations for oyster drills, oyster drill eggs and oyster drill damage can keep any loss to a minimum. Use of copper rings as a barrier on bottom structures (like the overwintering cages) can repel oyster drills from moving towards the oysters.

6.2.3 Birds: Oyster Catchers and Seagulls

Oysters can be protected from predation by these birds by being covered in cages, oyster bags and similar predation exclusion devices.

6.3 Disease

6.3.1 Juvenile Oyster Disease

This disease strikes first year oysters and is infectious. It can be minimized by making sure that the hatchery from where the seed comes utilizes good animal husbandry practices. It is expressed in the early stages of growth, from around July to September and can cause collapse of a crop in its early stage of development. Affected oyster seed exhibits cupped shells with a brown ring or deposit on the inner shell. Removing the diseased animals from the rest of the crop is advised. Moving crop to lower salinities (fresher water) can help. Obtaining seed from certified hatcheries is advised.

6.3.2 Dermo, Perkinsus marinus

Watery oyster meat is an effect of Dermo, whereby the oyster slows its growth (because of poor health) and eventually dies. Mortality is exhibited in the fall and typically affects second year oysters. Growing oysters in lower salinities helps. It's better to grow the oysters fast and sell them before diseases mature. Disease resistant oyster seed has been developed by hatcheries and has increased the survival of oysters with some prevalence of Dermo in the growing areas. Obtaining seed from certified hatcheries is advised.

6.3.3 MSX or Multinucleated Sphere Unknown, Haplosporidian Nelson

Watery oyster meat is also a hallmark of MSX. Disease resistant seed has been developed by hatcheries and has been helpful in the grow-out of oysters in the Northeast. Obtaining seed from certified hatcheries is advised.

6.4 Algal Blooms

Algal and/or seaweed mats can clog oyster growing gear, limiting the amount of oxygenated water and phytoplankton (microalgae) from feeding the oysters. If algal mats form, harvest the seaweed and dispose of it (or compost it) away from the grow-out site. Bag flipping serves to expose fouling organisms to the sun which effectively bakes them off. Regular bag flipping keeps fouling minimized on both sides of the bag.

6.5 Biofouling/ Pests

6.5.1 Sea Squirts/ tunicates/ hydroids

Fouling organisms found with oyster growing gear which may contribute to clogging the oyster growing devices and interfering with the ability of the oysters to maximize feeding. Brush off growing gear of fouling like sea squirts, tunicates and hydroids. Regular bag flipping keeps fouling at bay.

6.5.2 Mud Blisters

Mud Blisters are caused by worms in the mud that get incorporated into the oyster shell and make the oyster less marketable. Not only is it unsightly, but mud blisters may make the meat of the oyster muddy should a shucker pierce the mud blister on the inside of the oyster shell. Mud blisters are avoided by not growing oysters in the mud.

6.5.3 Boring Sponge

Affecting the integrity of the shell, not the oyster meat itself, the boring sponge penetrates an oyster shell and makes the shell too brittle to open without shattering the shell. With a brittle shell, it is not likely to open an oyster without getting shell fragments in the meat and makes it undesirable for shucking. It is evidenced by tiny holes in the shell once the sponge is rubbed or brushed off. It can be treated with air drying or brine dipping (with air drying), to kill the sponge without killing the oyster. Treating juvenile oysters this way can put the oyster at risk.

6.6 Storm Damage

Threats to a farm by storm can be devastating. With news of an impending hurricane or strong winds, extra anchors on the support structure may help "weather the storm". If a very serious hurricane is expected to hit, a decision could be made to retrieve all floating gear with the shellfish in it and store out of water for one-two day duration (a very long low tide) to preserve the crop from storm damage, keeping the oysters cool and hydrated. This, of course, would have to be done with the Shellfish Constable's knowledge and support. After the storm passes, the crop would have to be re-deployed.

Another strategy for protecting the crop from storm damage would be to employ the deep-water storage system to protect the floating gear from being thrashed around. There is concern for dissolved oxygen levels, though, especially in the summer months, when dissolved oxygen levels are typically at their lowest. Dissolved oxygen levels in the deep-water site could be tested periodically in the summer to have a course of action planned out in case of a hurricane.

The winter sinking of the crop in the deeper part of Lonnie's Pond appeared to be a successful strategy for overwintering the crop and protecting it from ice damage. It is a safe strategy that can be utilized if the deep-water space is available. From the experience last winter, the crops appeared to come through the icy part of the year in good shape and should be a good course of action should it successfully overwinter the crop again in the winter of 2017 and 2018.

6.7 Theft

Threats by theft can be very discouraging. Surveillance cameras can be set up and monitored by several outlets, especially with the Town if the aquaculture project has a municipal component to it. The Town of Barnstable has cameras set up to monitor some of the municipal shellfish growing areas. It would be advised that more than one camera be deployed to not only get the thieves in action, but also capture the numbers on license plates of the trailers and/or trucks used.

Another theft "alarm" is vigilance by neighbors living around the aquaculture site. If the neighbors are coached in what to do should they see trouble with the site, they might feel engaged to see that the project is successful. Phone numbers with 24-hour response (Police Department) could be shared as long as there are willing participants. Neighbors who serve on the watch might be proud to participate and may be able to be "paid" in oysters for their service if it was legally and procedurally found to be compatible with the project.

7.0 Water Quality Monitoring and Results

7.1 Water Quality Monitoring Methodology

SMAST staff monitored the Lonnie's Pond demonstration over the 2016 growing season. A sampling program was implemented to establish both a 2016 water quality benchmark for Lonnie's Pond, as well as to initially quantify nitrogen removal due to denitrification enhancement attributable to the oyster installation. From June 29, 2016 to October 19, 2016, eight sampling stations were monitored to further refine the long term water quality sampling database that was initiated for Lonnie's Pond as part of the MEP (Howes et al. 2006).Sampling occurred every other week during mid-ebb tide at the surface, bottom, and at mid-water column, if possible. During the demonstration period, intensive water column sampling also occurred over complete tidal cycles on August 10, 2016, August 24, 2016, September 13, 2016, and October 12, 2016. Samples were collected at nominal hourly intervals over consecutive flooding and ebbing tides.

An Acoustic Doppler Current Profiler (ADCP) was deployed to measure current direction through the oyster area relative to the sampling points in order to quantify changes in water column constituents through the oyster field. Particulate organic nitrogen (PON), total chlorophyll-*a*, bioactive N, orthophosphate, dissolved oxygen, and the complete suite of nitrogen components were assessed. The constituents of total nitrogen include (nitrate + nitrite), ammonia, dissolved organic nitrogen (DON) and PON. Samples were analyzed for: temperature, salinity, total nitrogen (TN), chlorophyll-*a* (Chl-*a*), pheophytin-*a*, orthophosphate, dissolved oxygen (DO), transparency (secchi depth), and alkalinity according to protocols outlined for the MEP.

Quality assurance samples (field duplicates) were also collected, as is protocol according to the Quality Assurance Project Plan (QAPP) under which SMAST collects MEP samples. DO and temperature profiles were performed at multiple depths and Winkler samples were collected in triplicate at water quality stations that had in-situ sensors. Continuous water quality monitoring of DO and Chl-*a* was conducted using five YSI-6600 sondes and HOBO® light sensors anchored at stations M5, M6, M7 and M8. Samples were also collected at the outflow from the cranberry bog and herring run when sufficient flow was available.

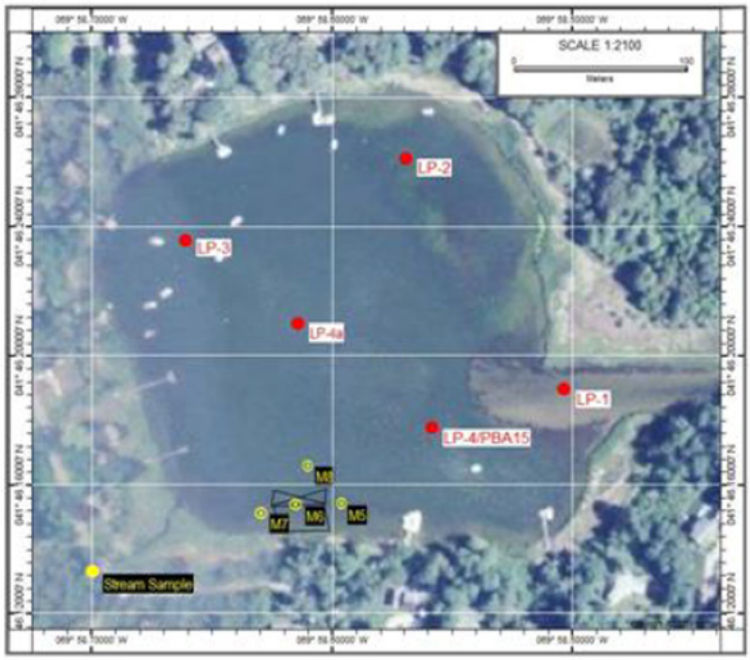


Figure 7-1 - SMAST Water Quality Monitoring Stations

7.2 Major Results of 2016 Water Quality Monitoring

A summary of key results from the SMAST Water Quality monitoring in year one follows.

- **Phytoplankton biomass was removed by the oysters as water flowed through the oyster deployment.** This is evidenced by the reduction in Chl-*a* concentrations and PON within the oyster field, relative to samples taken adjacent to the installation. These reductions in Chl-*a* and PON are statistically significant ($p<0.5$) and were seen during the tidal studies designed to capture water ebbing through the demonstration area;
- **Bioactive N levels declined by 12 to 20 percent during passage through the oyster field.** The decrease in bioactive nitrogen concentrations is likely due to the lowering of PON concentrations;
- **Observed nitrogen removals are conservative estimates** due to the oblique patterns of flow through the oyster area in the surveys, which underestimates uptake;
- **There was a clear temporal trend with higher levels of PON, Chl-a and bioactive N in mid-summer**, which is consistent with increased eutrophic conditions in estuaries in warmer summer months (poorest water quality July through mid-September);
- **Because of drought conditions, the oyster study was not influenced by surface water flows in 2016.** The nitrogen loading to Lonnie's Pond from Pilgrim Lake calculated during the low flow conditions of 2016 was significantly lower than was calculated for 2003 flows; and
- **The SMAST findings suggest that oyster growth will not be food-limited in Lonnie's Pond.** Food concentrations for summer and fall were 1,740 (±213) and 633 (±57.8) µg C/L seawater, respectively. Observations by others suggest that there is no increase in oyster feeding rates at food concentrations above 300 µg C/L (Tenore and Dunstan 1973). During the second and third years of the demonstration program, water flow to maintain adequate food concentration will be assessed throughout the field.

8.0 TMDL Compliance

Y1 of the demonstration monitoring project in Lonnie's Pond showed favorable results achieving nitrogen reduction. The results from year one of the project indicate that it is possible to use oysters to meet TMDL requirement and total nitrogen reduction targets. The oysters removed sufficient nitrogen through uptake alone. Mortality was low and the bag and line system and overwintering installation provided sufficient protection from predation and supported strong oyster growth. Y2 and Y3 of the Demonstration Project in Lonnie's Pond will provide additional data to evaluate the effectiveness of this non-traditional technology.

Overall, it appears that denitrification conservatively removes approximately 0.67 kg N for each 1 kg N removed in oyster harvest. In September/October when oysters had reached their mid-season biomass increase, an amount equivalent to almost one-third of the biodeposition rate was denitrified each day. The sediment incorporated biodeposits continue to continue to enhance denitrification after oyster harvest and will likely continue into the next spring and summer increasing the estimated N removal.

As further discussed in Section 9.0, either Y1 or Y2 oysters can be used to meet both TMDL requirements and total nitrogen load reduction targets. MassDEP is not validating results of denitrification enhancement at this time. Therefore, Full-Scale Implementation scenarios outlined in Section 9.0 focus on direct removal of nitrogen by uptake. However, is anticipated that the denitrification enhancement will be proportional to the amount of biodeposition, based on the 2016 SMAST Technical Report (Howes et. al, January 2017). If additional removal of nitrogen by denitrification is eventually demonstrated to the satisfaction of MassDEP, this removal would provide an additional margin of safety for regulatory compliance, beyond the removal predictions outlined in Section 9.0. Additional information regarding denitrification monitoring and modeling predictions is included in both the 2016 SMAST report and the Year 1 Lonnie's Pond Technical Memorandum dated October, 2017.

9.0 Full-Scale Aquaculture Scenarios

This section discusses what full-scale implementation at Lonnie's Pond would entail, based on data collected to date, TMDL scenario goal identified by MassDEP for Lonnie's Pond, estimated cost based on costs to date, and considerations regarding the feasibility of engaging commercial growers to assume responsibility for the Lonnie's Pond operation once MassDEP approves the removal data. This section also discusses anticipated permitting requirements for full-scale implementation at Lonnie's Pond as well as considerations regarding additional public engagement and future Town Staffing needs.

9.1 Scenarios and Cost

The MEP nitrogen reduction goal for Lonnie's Pond is approximately 660 pounds per year (300 kg/yr). The potential annual nitrogen per acre per year in Lonnie's was calculated based on the nitrogen content of oysters, densities, and weights measured in the Lonnie's Pond during Year 1 of the Demonstration Project. Based on these values, six different scenarios were developed identifying the number of Y1 and Y2 oysters and pond area needed to meet the full MEP removal goal as well as portions of the goal. It should be noted that the scenarios presented in Table 9-1 should be considered preliminary at this time, as they are based on one year of data collection, and will be further confirmed and refined based on data collected in Y2 and Y3 of the Demonstration project. The scenarios are summarized in illustrated in Figure 9-1 and described in Table 9-1, which summarizes oyster numbers and sizes, densities, pond area, number of bags, and other parameters associated with each potential scenario. Approximate costs for each of the scenarios are also detailed in Table 9-1. Table 9-2 provides assumptions used when developing these costs. The assumptions in Table 9-2 are subject to review and revision; therefore the costs in Table 9-1 are not necessarily final budgetary numbers, but do provide a comparative cost for each scenario.

9.2 Transition to Commercial Growers

The comparative cost numbers in Table 9-1 illustrate that a Full-Scale Implementation program at Lonnie's Pond could potentially be profitable for a commercial grower, and is likely more cost efficient for the Town than municipal operation of the aquaculture program on a long-term basis. Furthermore, results from the first two years of the Demonstration Program showed that the techniques used in Lonnie's Pond to date have resulted in high quality oysters with good market value. In 2016, approximately 80 percent of the Y1 reached harvestable size (76 mm / 3 in) in one shortened growing season (the typical season begins in May), and all of the Y2 oysters had reached petite or full market size by the end of their second growing season.

From discussions with wholesalers, it is believed that the Y1 oysters will have a significantly higher market value if they are overwintered, and it is expected that many of them would be market-ready within the first few weeks of the following season.

Operation of aquaculture at Lonnie's Pond could occur under a special grant category that would include reporting and compliance measures required by MassDEP, which are yet to be determined. A benefit of transitioning the program to a commercial grower would be that once the oysters reach harvestable size, the grower could sell the oysters for a profit, whereas the Town cannot sell shellfish under its municipal propagation permit, except to another town. Some considerations regarding the potential for transitioning the program to a commercial grower are outlined below:

- The aquaculture regulations may need to be modified to allow a new grant category for this operation, which specific reporting and compliance requirements as well as requirements for growing the oysters in floating gear at specified densities;
- The Town may want to consider issuing a Request for Proposals for the project, to allow multiple private growers as well as potentially licensed hatcheries to express their interest and approach to the project;

- It is expected that MassDEP approval of aquaculture in Lonnie's Pond as a means of nitrogen removal and TMDL compliance would be contingent upon using the same floating bag methodologies and oyster densities as have been implemented to date. If any options for alternative types of floating gear would need to be investigated with MassDEP and would need to be specified in the grant license; and
- The requirement to avoid sediment disturbance may be unrealistic, but also unnecessary if the nitrogen removed via the denitrification pathway is discounted.

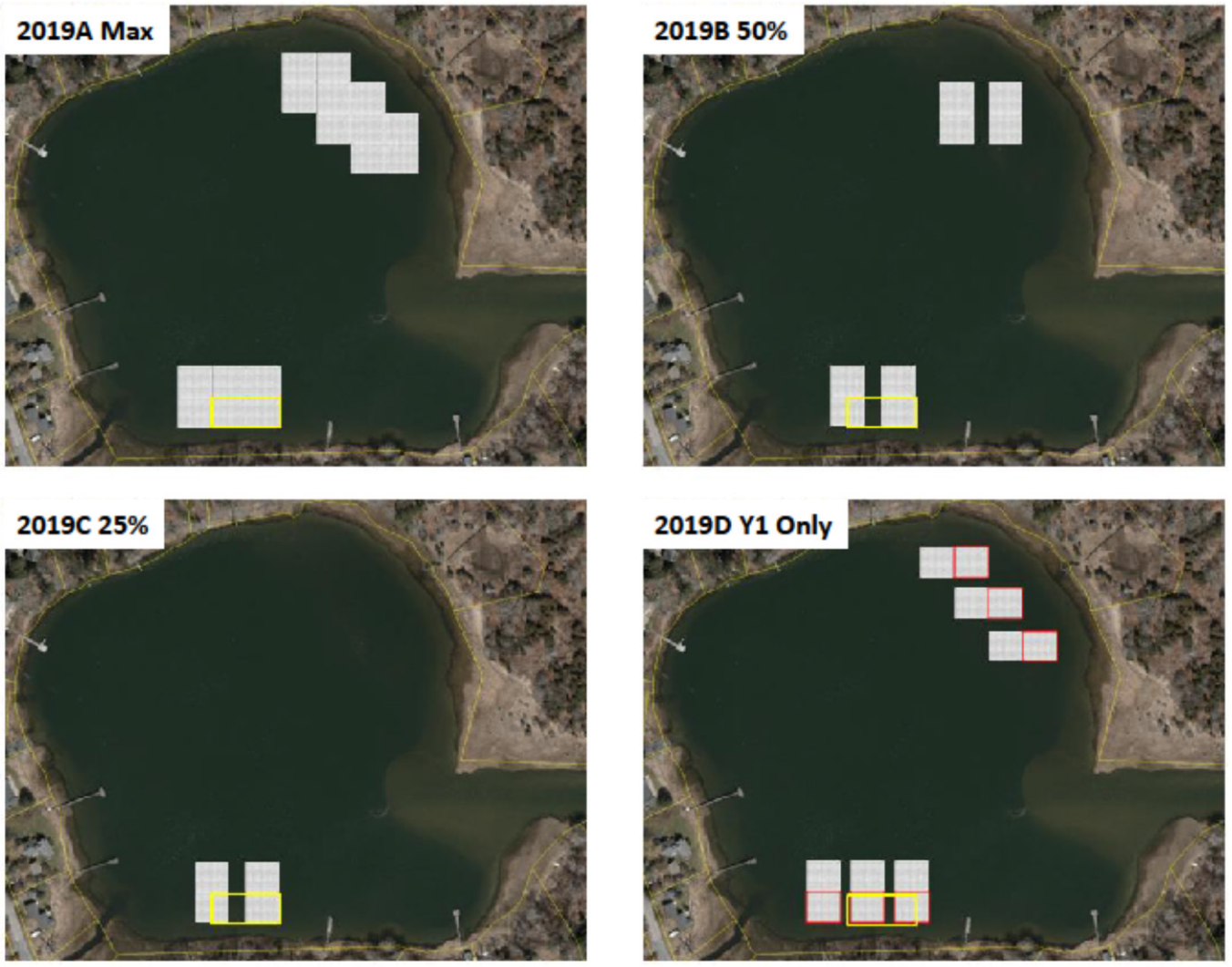


Figure 9-1 - Full Scale Implementation Scenarios

Table 9-1 - Full Scale Implementation Costs

	2019A	2019B	2019C	2019D	Town 2019B	Town 2019C
	Max Coverage	50% MEP	25% MEP	Y1 Only	50% MEP	25% MEP
Y1 Bags	1,650	843	422	6,280	843	422
Y2 Bags	6,600	3,372	1,688		3,372	1,688
Total Bags	8,250	4,215	2,110	6,280	4,215	2,110
Area Utilized	1.5	0.78	0.38	1.2	0.78	0.38
Y1 Oysters Started	1,740,000	888,000	445,000	6,610,000	888,000	445,000
Y2 Oysters Started	1,650,000	843,000	422,000	-	843,000	422,000
Live Oysters Extracted	1,530,000	784,000	392,000	6,280,000	784,000	392,000
Sale Price of Program Oysters	$ 0.35	$ 0.35	$ 0.350	$ 0.120	$ -	$ -
Total Market Value of Program Oysters	$ 535,500	$ 274,400	$ 137,200	$ 715,920	$ -	$ -
Total Capital for Floating Gear	$ 86,209	$ 25,444	$ -	$ 100,591	$ 25,444	$ -
Labor for Fabrication of Floating Gear	$ 71,625	$ 21,188	$ -	$ 47,000	$ 15,255	$ -
Over-winter Gear (Fab Labor & Materials)	$ 13,281	$ 672	$ -	$ 85,625	$ 604	$ -
Capital for Other Equipment	$ 95,375	$ 80,475	$ 62,175	$ 46,975	$ 7,800	$ 7,800
Y1 Capital Requirement	$ 266,490	$ 127,778	$ 62,175	$ 280,191	$ 49,103	$ 7,800
Amortized Financed Gear Cost	$ 64,841	$ 31,090	$ 15,128	$ 68,175	$ 9,821	$ 1,560
Seed Cost	$ 55,680	$ 28,416	$ 14,240	$ 211,520	$ 28,416	$ 14,240
Field Labor Cost	$ 278,063	$ 153,881	$ 76,488	$ 262,319	$ 110,795	$ 55,071
Business Overhead / Administration	$ 76,854	$ 49,546	$ 40,813	$ 100,863	$ 9,300	$ 9,300
Total Annual Expenses	$ 475,438	$ 262,933	$ 146,668	$ 642,876	$ 158,331	$ 80,171
Program Oversight	$ 3,360	$ 3,360	$ 3,360	$ 3,360	$ 3,360	$ 3,360
Town Net Cost	$ 3,360	$ 3,360	$ 3,360	$ 3,360	$ 158,331	$ 80,171
Grower Net Profit	$ 60,062	$ 11,467	$ (9,468)	$ 73,044		
Net Profit % of Gross Revenue	11%	4%	-6.9%	10.2%		
N Removed by Uptake, kg	290	148	74	297	148	74
N Removed in Shells (Mortality), kg	3	2	1	2	2	1
Annual N Removal, All Pathways, kg	293	150	75	298	150	75
% of MEP Annual Removal Target	99%	51%	25%	100%	51%	25%
Ongoing Labor Requirement (hrs/yr)	8,165	4,604	2,540	8,995	4,404	2,340
Labor Full Time Equivalents	4.1	2.3	1.3	4.5	2.2	1.2
Town $/kg of Target N Removed	$ 11	$ 22	$ 45	$ 11	$ 1,055	$ 1,069

Table 9-2 - Full Scale Implementation Assumptions

	2019A	2019B	2019C	2019D	Town 2019B	Town 2019C
	Max Coverage	50% MEP	25% MEP	Y1 Only	50% MEP	25% MEP
Number of new spat bags	400	116	0	2,023	116	0
Spat bag cost	$ 10,000	$ 2,900	$ -	$ 50,583	$ 2,900	$ -
Floating bags material cost	$ 76,209	$ 22,544	$ -	$ 50,008	$ 22,544	$ -
Floating bags fab labor cost	$ 71,625	$ 21,188	$ -	$ 47,000	$ 15,255	$ -
New Winter racks	43	2	0	274	2	0
Winter rack cost	$ 8,500	$ 430	$ -	$ 54,800	$ 430	$ -
Winter rack labor	$ 4,781	$ 242	$ -	$ 30,825	$ 174	$ -
Initial Deployment Labor	$ 81,094	$ 40,603	$ 19,781	$ 77,844	$ 29,234	$ 14,243
Recondition winter bags labor	$ 6,188	$ 15,806	$ 7,913	$ 23,550	$ 11,381	$ 5,697
Split Labor	$ 10,313	$ 5,269	$ 2,638	$ 39,250	$ 3,794	$ 1,899
Flip Labor	$ 30,938	$ 15,806	$ 7,913	$ 23,550	$ 11,381	$ 5,697
Remove Gear Labor	$ 51,563	$ 26,344	$ 13,188	$ 39,250	$ 18,968	$ 9,495
Y1 Winter Labor	$ 15,469	$ 7,903	$ 3,956	$ 58,875	$ 5,690	$ 2,849
Y2 to Market Labor	$ 82,500	$ 42,150	$ 21,100	$ -	$ 30,348	$ 15,192
Storage racks	107	35	0	0	35	0
Storage rack materials	$ 10,667	$ 3,493	$ -	$ -	$ 3,493	$ -
Storage rack labor	$ 6,000	$ 1,965	$ -	$ -	$ 1,415	$ -
Storage rack sq.ft.	2,667	873	0	0	873	0
Other space sq.ft.	500	500	500	500	500	500
Space rental	$ 32,667	$ 14,733	$ 6,000	$ 6,000		
Administrative hours	750	500	500	2,000	300	300
Administrative labor	$ 28,125	$ 18,750	$ 18,750	$ 75,000	$ 8,100	$ 8,100
NAP Coverage	$ 6,563	$ 6,563	$ 6,563	$ 6,563		
Disease testing				$ 4,800	$ 1,200	$ 1,200
Business insurance	$ 2,500	$ 2,500	$ 2,500	$ 2,500		
Business misc	$ 3,000	$ 3,000	$ 3,000	$ 2,000		
Equipment insurance	$ 4,000	$ 4,000	$ 4,000	$ 4,000		
Equipment delivery costs	$ 500	$ 500	$ 2,000	$ 2,000		
Carolina Skiff 19DX	$ 9,620	$ 9,620	$ 9,620	$ 9,620		
Yamaha F90LA	$ 10,405	$ 10,405	$ 10,405	$ 10,405		
Boat Trailer	$ 2,650	$ 2,650	$ 2,650	$ 2,650		
Winter raft	$ 2,800	$ 2,800		$ 2,800	$ 2,800	$ 2,800
Field maintenance craft	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000
Field float	$ 12,000	$ 12,000		$ 12,000		
Chevy 4500 Reefer	$ 49,900					
Truck with coolers		$ 35,000	$ 30,000			
Utility trailer	$ 2,500	$ 2,500	$ 2,500	$ 2,500		
Totes, tools	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000

Shell N% of DW	2.00%
Meat N% of live wt	10.50%
MEP Target kg N	297
Materials cost per bag	$ 13.30
Cost of spat bag for 2-3mm seed	$ 25.00
Years of service for Gear & Equipment	5
Commercial cost of capital, 5 yr @ 8%	21.7%
Winter bags/rack	20
Materials/rack	$ 200
Storage materials/rack	$ 100
Storage bags/rack	45
sq.ft. per storage rack	25
Winter racks available	40
Floating spat bags available after Y3	180
Bags available after Y3	2,520
Storage rental	$ 10.00
Office rental	$ 12.00
Inspections per season	6
Hours per inspection	8
Report hrs	16

	Y1	Y2
Mortality	5%	7%
Seed cost/1,000 oysters	$ 32	
Target Seed/bag	3,000	
Target Oysters/bag	1000	250
Denitrification factor (% of uptake)	68%	68%
Average Weight at Death (DW g/Oyster)	0.250	1.20
Deployment Weight (DW g/Oyster)	0.010	0.46
Ending Weight (DW g/Oyster)	0.46	1.78

	Base	Loaded
Town Labor Rate	$ 18.00	$ 27.00
Program Oversight Labor	$ 35.00	$ 52.50
Grower Labor Rate	$ 25.00	$ 37.50

9.3 Financing

Additional discussion and investigation is needed in regard to funding mechanisms for the overall wastewater management project, including the Aquaculture Non-Traditional Technology. Potential funding/financing options include: State Revolving Fund (SRF) loans, MassDEP 604b/319 grants, USDA rural development grants, 5 Star Wetland and Urban Waters Restoration grants, MA CZM Coastal Pollutant Remediation (CPR) Grant Program, North American Wetlands Conservation Act grants, and Massachusetts Environmental Trust (MET) General grants. Availability of these funding sources would be dependent on a successful application process, and can be further investigated if the Town elects to pursue these funding sources. Permitting.

9.4 Permitting

Depending on the scenario selected, permitting requirements are anticipated to include a Notice of Intent (NOI) or Request for Determination of Applicability as well as a Section 404 Permit approval from the US Army Corps of Engineers. If more than 10 percent of the pond area is utilized for aquaculture, it is likely that an NOI rather than an RDA would be required by the Conservation Commission, and that a Pre-Construction Notification (PCN) application would be required by the US Army Corps of Engineers rather than the project qualifying under the Self-Verification Process.

9.5 Communication Plan

For a full scale implementation at Lonnie's Pond, additional public outreach and engagement is recommended. This could take the form of either a public meeting at the Town Hall where the plan is presented and comments are solicited; posting the draft Lonnie's Pond management Plan on line and solicitation of written comments; or hosting a public visitation day at Lonnie's Pond; or a combination of any of the above.

9.6 Town Staffing

If the Town were to operate the Lonnie's pond full-scale aquaculture themselves, it is anticipated that additional season staff would be needed to for the installation and breakdown of the floating gear fields each year, as well as the ongoing splitting of the Y1 seed and redistribution into larger bags, as well as potentially relocating Y1 oysters into floating year or a bottom setting each winter. In addition, harvesting and associated reporting would be an additional task for town staff. It is likely that this additional field and reporting workload would require hiring one or two additional seasonal, or potentially permanent, year round staff.

10.0 Full Scale Implementation Management Plan

The next steps in the aquaculture include coordination with MassDEP to gain consensus regarding the implications of the Demonstration Project for full-scale aquaculture implementation and to determine the regulatory treatment of non-traditional technologies as a major component of the Town's efforts to meet TMDL requirements and its strategy to manage wastewater. At the conclusion of Y3 of the Demonstration Project in December, 2018, data from the three required years of deployment should be compiled and submitted to MassDEP for review, and a meeting should be held to discuss next steps required for MassDEP approval of aquaculture as a part of a long-term TMDL compliance program. Similarly, at this time, the town can review the final results of the three-year Demonstration Project to consider, select, and propose to MassDEP their selected scenario for Full-Scale implementation at Lonnie's Pond.

10.1 Watershed Permitting

MassDEP is in the process of developing guidance for a Watershed Permit that would include non-traditional technologies. This new wastewater management and impact mitigation permitting program would provide for a watershed-based approach to restore embayment water quality on Cape Cod. It is anticipated that enrollment in the program will demonstrate that the Town is taking action to address wastewater. The Pleasant Bay Alliance (PBA) has been meeting with the Cape Cod Commission and MassDEP to discuss the guidance to identify regulatory issues that would

fall under a watershed permit for the Pleasant Bay watershed, potentially including Lonnie's Pond. It is anticipated that the Watershed Permit process will likely require that the Town submit a Watershed Permit Plan that:

- Identifies proposed technologies and approaches in the proposed watershed or subwatershed;
- Describes the adaptive management strategy or process for making implementation decisions;
- Specifies a monitoring plan and describe the contingency plan;
- Identifies all permits and approvals that are required by local, regional, state, and federal entities.

Further discussion with MassDEP and the PBA is necessary once it is determined that MassDEP will accept aquaculture as part of a TMDL compliance program and the Town selects their preferred scenario for implementation.

10.2 Oyster Configuration

Oyster configuration for Full-Scale Implementation will be determined once a scenario is selected. Section 9 describes the potential scenarios under consideration. This section can be updated to identify the number of oysters, size, bag layouts, multi-year planning once a scenario is selected for implementation. For planning purposes, a safety factor of approximately 15 to 20 percent is proposed in regard to number of oysters to be installed, in case an adverse event results in oyster loss. In addition, pending the results of the denitrification studies, denitrification may provide an additional margin of safety in terms of nitrogen removal for TMDL compliance.

10.3 Required Tasks and Schedule of Activities

The schedule will be determined once a scenario is selected. Section 9 describes the potential scenarios under consideration. An initial outline of required tasks and associated schedule dates is provided below:

- Compile and provide Demonstration Project results to MassDEP – spring, 2019;
- Select preferred Full Scale Implementation Schedule – spring, 2018;
- Meet with MassDEP to discuss – spring, 2019;
- Determine number and size classes of oysters needed, as well as equipment needs – TBD; and
- Develop RFP if commercial route is chosen – TBD.

10.4 Overwintering Protocols

These are described in Section 3.1 and briefly repeated here. Typically oysters are kept on the surface as late into the winter season as possible, depending on environmental conditions including temperature and dissolve oxygen. As a guide, oysters should be submerges below the surface as soon as the water temperature drops below 6°C for six days in a row, although if water temperature and observations suggest that the water will freeze imminently, it is prudent to submerge oysters in advance of this trigger. In the spring, oysters should be raised once water temperatures reach 6°C for six days in a row.

10.5 Long-Term Costs

Long-Term cost can be determined once a scenario is selected for implementation. This section can be updated at that time.

10.6 Excess Oyster Disposal

This will be determined once a scenario is selected. Options for disposal include harvesting full size oysters or trading to Falmouth, MA for quahogs (if Town run), or sale of intermediate seed, market size oysters or both, if grower run.

10.7 Catastrophic Loss and/or Project Abandonment

If there is a catastrophic loss for one year, then either the safety factor from previous years will account for this, or nitrogen removal will need to be made up in subsequent years. Any issues will be reported to MassDEP, and it is expected that discussion with them would be needed to reach resolution. If multiple years of the project showed less than expected nitrogen removal, it would be necessary to consider replacement of the aquaculture with alternative types of treatment, such as PRBs or conventional sewering.

Appendix A

Boston University Stable Isotope Laboratory QAQC

and

Science Wares SOPs

BOSTON UNIVERSITY
STABLE ISOTOPE LABORATORY

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Quality Assurance and Quality Control

Instrumentation for stable isotope analysis has expanded to include both the original Finnigan Delta-S and now two GV Instruments IsoPrime isotope ratio mass spectrometer. With the addition of the GVI instruments and associated peripherals, we have automated stable isotope analysis of most organic (and some inorganic) samples for carbon-13 and nitrogen-15. The workhorse of continuous flow measurements of solid samples for carbon and nitrogen isotopes is done by the GVI IsoPrime and a Eurovector elemental analyzer, combined with a diluter and reference gas box.



Samples for automated isotope analysis are first weighed out into tin boats to the nearest 0.01 mg on a Mettler AE240 or a Sartorious micro electronic balance. During a sequence run by the mass spectrometer, each sample is flash combusted at 1800ºC in the Eurovector CN analyzer; the combustion products (CO_2, N_2 and H_2O) are separated chromatographically and introduced into the mass spectrometer, with water removed in a chemical trap. The gases of interest are then introduced into the mass spectrometer for isotope analysis and the rest pumped away. The sample isotope ratio is compared to a secondary gas standard, whose isotope ratio has been calibrated to international standards. For $^{13}C_{V\text{-}PDB}$ the gas was calibrated against NBS 20 (Solenhofen Limestone), NBS 21 (Spectrographic Graphite), and NBS 22 (Hydrocarbon Oil); for $^{15}N_{air}$ the gas was calibrated against atmospheric N_2 and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). All international standards were obtained from the National Bureau of Standards in Gaithersburg, MD.

International standards used for water samples include V-SMOW, GISP and SLAP, which were utilized to calibrate the secondary gas standard. In the past, water samples were prepared using the guanidine hydrochloride technique for oxygen-18 and the zinc reduction technique for deuterium (zinc obtained from John Hayes, Indiana University). With the addition of the GVI MultiFlow and ChromeHD systems, we are now able to automate both procedures. Oxygen-18 analysis is done via CO_2 equilibration and deuterium analysis is done via pyrolysis in the ChromeHD system.

When running gas samples on the Finnigan Delta-S, as a daily check on instrument performance we run a second gas (lecture N_2 or CO_2) that is isotopically distinct from our standard gas. If the isotope values are within 0.05 per mil of its long-term record, analysis proceeds; otherwise, further analysis stops until any problems are resolved. Internal precision for the instrument is $\pm$0.014 per mil. For solid continuous flow samples, a suite of in-house standards are first analyzed. If they fall within laboratory specifications, client sample analysis then proceeds.

Required external precision of a sample (i.e. replicate analysis) for either ^{15}N or ^{13}C is 0.2 per mil. Typically, our precision is better than 0.1 per mil for well-ground organic tissue samples using the trapping box.

Samples run in continuous flow mode are currently within 0.2 per mil for both nitrogen and carbon. In addition to carbon and nitrogen isotopes from the same sample, continuous flow will also report %C and %N data.

The lab runs one replicate per 10 samples, and any anomalous results are rerun. As a check on the combustion and cryogenic distillation steps, a laboratory standard is run every 15 samples. This standard is either peptone, a hydrolyzed animal protein from Sigma Chemical Company, glycine, or citrus leaves, SRM 1572. Both have been well documented by several stable isotope laboratories and their isotopic values are well known. Its value must be within 0.15 per mil of its documented value. If it does not, the samples preceding the standard are considered suspect and rerun.

The addition of the GVI Instrumentation precision of water samples (oxygen-18 and deuterium) has improved significantly and is extremely good. The lab generally runs duplicates of all samples for oxygen-18 if there is enough water. The precision is usually 0.1 permil or better. An internal lab standard is run after every 4 client samples as a check on the instrumentation. Deuterium samples are run with the ChromeHD pyrolysis system. Three injections are done with each sample, with the first injection discarded, due to memory effects in the system. The standard is Boston University deionized water, collected in batch fashion and stored. The water standard is within 0.2 per mil of its long-term value for deuterium and 0.2 per mil for oxygen-18. In addition, the metabolic samples are inputted to a spreadsheet that calculates FMR (Field Metabolic Rates). If calculated values are not within acceptable ranges, the suspect samples are rerun. The calculations are based on the equations of Lifson and McClintock (1966), as modified by Kenneth Nagy, UCLA.

For carbonate samples, NBS-20 and Carera-Z are used as two point calibration standards. Precision is currently 0.05 permil for carbon-18 and 0.06 permil for oxygen-18. CO_2 air and breath samples are calibrated using atmospheric air and a 1% CO_2/helium mix gas. The mix gas was checked against calibration gases obtained from Oztech Corporation, Texas.

Data is presented in a tabular form and can be sent by fax, mail or email. The sheet includes sample ID, mass/volume used, isotopic value and % organics (if applicable). All isotopic data are rounded to 2 decimal places.

We request that a sample list be included with all samples and that all samples be clearly identified. This allows the Laboratory Manager to look over the data and compare the isotope values against generally accepted values for that type of sample. Any samples that appear anomalous are rerun if possible to check their values; if preloaded, they are flagged as anomalous for the client.

Percent organics and nitrogen protocol

Samples are weighed out to 0.001 mg into tin capsules on a Sartorius XM1000P microbalance. They are combusted in a Fisons NA1500 elemental analyzer and measured using Eager200 software. Check standards are inserted into the run to ensure precision and quality control. Any anomalous samples are reweighed and rerun. Precision for replicate samples is 0.2 percent for carbon, and 0.5 percent for nitrogen, but will vary depending on the heterogeneity of the material.

The elemental analyzer is recalibrated each day using a size series of 5 acetanilide standards ranging from 2 to 0.2 mg. A sixth acetanilide is then measured to check for accuracy.

Samples can be either dried and ground by the client, or shipped to the laboratory in dried or wet form and ground by the lab. A mortar and pestle and liquid nitrogen are used to ensure a well-ground, homogenous mix. Samples can be stored in any container, but preferably in scintillation vials or Eppendorf tubes.

If samples are to be prepared by the client, they should be placed in 96 well trays, leaving slots 6 and 12 open for BUSIL internal standards. The amount of material will vary, but should be around 1, 2, and 5 mg for animal tissue, plant tissue, and soils, respectively. The spreadsheet found on the BUSIL website (http://www.bu.edu/sil/PDF%20files/BUSIL%20EA%20Sample%20Submission.xls) should be filled out and sent electronically to the laboratory manager prior to shipping.

The results are put into an Excel spreadsheet and sent to the client, reporting sample ID's, masses, and percent carbon and nitrogen.

Maintenance on the elemental analyzer is performed after a run of 120 samples. Excess tin and ash are removed from the combustion column. The reduction column is changed after 300 to 500 sample analyses. The combustion column is replaced after 1,500 samples.

Technical Report

DRAFT FINAL

Lonnies Pond Shellfish Demonstration Project
Year 2 Monitoring Summer/Fall 2017 Oyster Deployment

To:

Town of Orleans, MA
Water Quality and Wastewater Planning

From:

Brian Howes, Ph.D., David Schlezinger, Ph.D., Roland Samimy, Ph.D. , Micheline Labrie, Jennifer Benson, M.S., Sara Sampieri, M.S.,Amber Unruh, and Paul Mancuso

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September 2018

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Section I. Introduction

Background:

Based on the findings of the Massachusetts Estuaries Project (MEP 2002 – 2017, conducted by SMAST-CSP), it is clear that estuarine water and habitat quality in southeastern Massachusetts estuaries is impaired by nitrogen enrichment. As a result, towns across southeastern Massachusetts are now seeking innovative approaches for lowering estuarine nitrogen levels as these natural systems are integral to the character and quality of life in communities across the southeastern Massachusetts region and citizens want to achieve the MEP set nitrogen thresholds for restoration of their estuarine resources. While traditional sewage treatment is part of the solution for most communities, so too are non-traditional approaches to nitrogen management that have multiple benefits to the community. However, the nitrogen removal efficiency of these non-traditional approaches is still being quantified so that they may be formally considered and credited with nitrogen removal in town specific nitrogen remediation plans.

An *in situ* water quality management approach that is gaining momentum in many communities across southeastern MA (e.g. Westport, Falmouth, Mashpee) is the use of shellfish, particularly oysters, to increase water clarity and remove nitrogen, while also supporting recreational shellfishing and the local economy. CSP has been at the forefront of investigating the use of oyster deployments/reefs as an in-estuary means to improve nitrogen related water quality. CSP scientists have begun quantifying the mass removal of water column nitrogen and quantifying the additional removal via associated enhancement of sediment denitrification (NO3-àN2) to gauge the actual nitrogen removal efficiencies of oyster deployments. Note that oysters are being considered due to their high filtration rates, rapid growth, commercial value and ability to thrive in nutrient rich, warm, shallow waters over a range of estuarine salinities. While oysters are well suited to enhancing water quality for the listed reasons, other filter feeders can be used as well.

In this context, many Massachusetts communities have begun oyster propagation. However, almost none have quantified the integrated nitrogen removal through filtration, deposition and sediment denitrification and harvest. Similarly, water quality improvements associated with oyster deployments have not generally been accurately assessed. As a result, it is difficult to compare the cost/benefit of using shellfish compared to other nitrogen management approaches (e.g. traditional WW treatment, PRBs, floating wetlands, enhanced natural attenuation). In order for Orleans and other towns across the region to be able to implement this soft solution as part of their habitat restoration strategy, it is critical to accurately assess the role oyster filtration plays in estuarine nutrient cycling. This quantitative understanding of the net effect of oyster filtration on nutrient conditions in an estuary will facilitate incorporation of shellfish culture into management and regulatory processes.

The present investigation focuses on quantifying the nitrogen processing and removal by the oyster/sediment complex within Lonnies Pond, a terminal salt pond tributary to Upper Pleasant

Bay, Orleans, MA. The pond was selected due to its high level of nitrogen enrichment, its physical structure, its suitability for oyster culture and appropriateness for measuring nitrogen removal rates. The results are aimed at providing quantitative information to the Town of Orleans as it seeks to implement new nitrogen removal approaches and considers the use of shellfish for remediation of nitrogen related impairment of its coastal resources.

The Nitrogen Loading Problem:

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the greater Pleasant Bay system and Lonnies Pond at a smaller scale, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1996, Weiskel and Howes 1992, Smith et al. 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Pleasant Bay and Lonnies Pond more specifically, follow this general pattern, where the primary nutrient of eutrophication is nitrogen.

Nutrient related water quality decline, specifically due to excess nitrogen inputs, represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate (process) watershed nitrogen inputs without degradation. As loading increases, a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen as well as identifying both soft and hard solutions for managing nutrient loads to impaired estuarine systems. While this effort is ongoing to varying degrees of effectiveness across the United States (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area and specifically Pleasant Bay.

Project Need:

Since nitrogen removal is needed to meet estuarine specific TMDLs and restore water and habitat quality in nitrogen impaired estuarine systems, and since traditional approaches are quite costly to communities, less expensive more flexible non-traditional alternatives are needed and are now being considered on a site by site basis by Towns across the southeastern Massachusetts region. The Town of Orleans is investigating a number of these "soft" solutions, including shellfish aquaculture, specifically with oysters. In late 2015, the Town of Orleans initiated a multi-year oyster demonstration project within Lonnies Pond, a eutrophic saltwater basin tributary to Pleasant Bay, in order to test the oyster filtration approach for improving water quality. A small oyster aquaculture system was established in Lonnies Pond in summer 2016 (year 1) to determine: (1) the ability to grow oysters in this basin, (2) oyster survival, (3) the incorporation of nitrogen into oyster tissue and shell, (4) oyster filtration and biodeposition rates and, (5) the fate of nitrogen deposited by oysters to bottom sediments. The initial year 1 results of the multi-year investigation were presented to the Town of Orleans in January 2017 along with conclusions and recommendations for improving the study as the project proceeded into year 2 which captured summer 2017 conditions.

Results presented herein summarize field work completed during the summer/fall 2017 growing season and updates the 2016 data to include spring 2017 “carry over” effects. The focus is mainly on the effect of the oyster deployment on water column particulates (particulate nitrogen and chlorophyll), the amount of nitrogen deposited to the sediments by oysters and the degree to which denitrification is enhanced over background as a result of the oyster deployment. The amount that denitrification is enhanced plus the amount of nitrogen removed by oyster harvest accounts for the total nitrogen removal due to the oyster deployment. While there is a very small potential for nitrogen removal through enhanced sediment burial, the bulk of removal is through enhanced denitrification plus harvest. It is this oyster mediated N removal value that is the critical number for developing nitrogen management plans and designing larger deployments to reach specified nitrogen loading reductions required for restoration under MassDEP/USEPA TMDLs.[1]

Section II. Background Water Quality Monitoring in Lonnies Pond

Sampling Program:

A sampling program was implemented in Lonnies Pond to establish both a pond-wide water quality benchmark and to quantify nitrogen removal by the pilot oyster culture deployment undertaken during the 2016 and 2017 growing seasons. Eight (8) water quality sampling locations were monitored in 2016 (LP1-LP4; M5-M8), building upon pre-existing database of water quality from the same monitoring stations. To better evaluate water column constituent gradients within the pond and how these may be affected by the presence of oyster culture, 6 more sampling locations (LP9-LP13) were added for the 2017 season (Figure II.1). In addition, samples and flow measurements were collected at the outflow from the cranberry bog

[1] The oyster survival and growth analysis and nitrogen removed by harvest was conducted by Science Wares Inc. and is presented in a separate companion report.

upgradient of Lonnies Pond and the herring run (discharge from Pilgrim Lake) when sufficient flow was available for sampling. It should be noted that during the oyster deployment period, flow from the cranberry bogs was episodic during both summer 2016 and 2017, however, there was consistently measurable flow in the herring creek discharging into Lonnies Pond from Pilgrim Lake (summarized in Section VIII). Water sampling occurred bi-weekly during mid-ebb tide conditions and usually in the early morning. Samples were collected at the surface, bottom, and at mid-water column where sufficient depth allowed. Samples were analyzed for: temperature, salinity, total nitrogen (nitrate + nitrite, ammonia, dissolved organic nitrogen, particulate organic nitrogen), chlorophyll-a (Chl-a), pheophytin-*a*, orthophosphate, dissolved oxygen, transparency (secchi depth), and alkalinity. Samples were collected according to protocols outlined for the MEP and which are followed by all other water quality monitoring undertaken by the SMAST-Coastal Systems Program across the southeastern Massachusetts region. Weather, tide-status, and results of water quality monitoring were documented. Quality Assurance samples (field duplicates) were collected (5%-10% of total number of samples collected) with the goal of gaining acceptance of study results by MassDEP and USEPA. Dissolved oxygen and temperature profiles (surface to bottom at 0.5m-1.0m increments) were completed at each sampling location using a YSI-55 handheld DO meter and following protocols developed for the MEP. Winkler samples were collected in triplicate at the DO/CHLA moorings at the sensor depth.

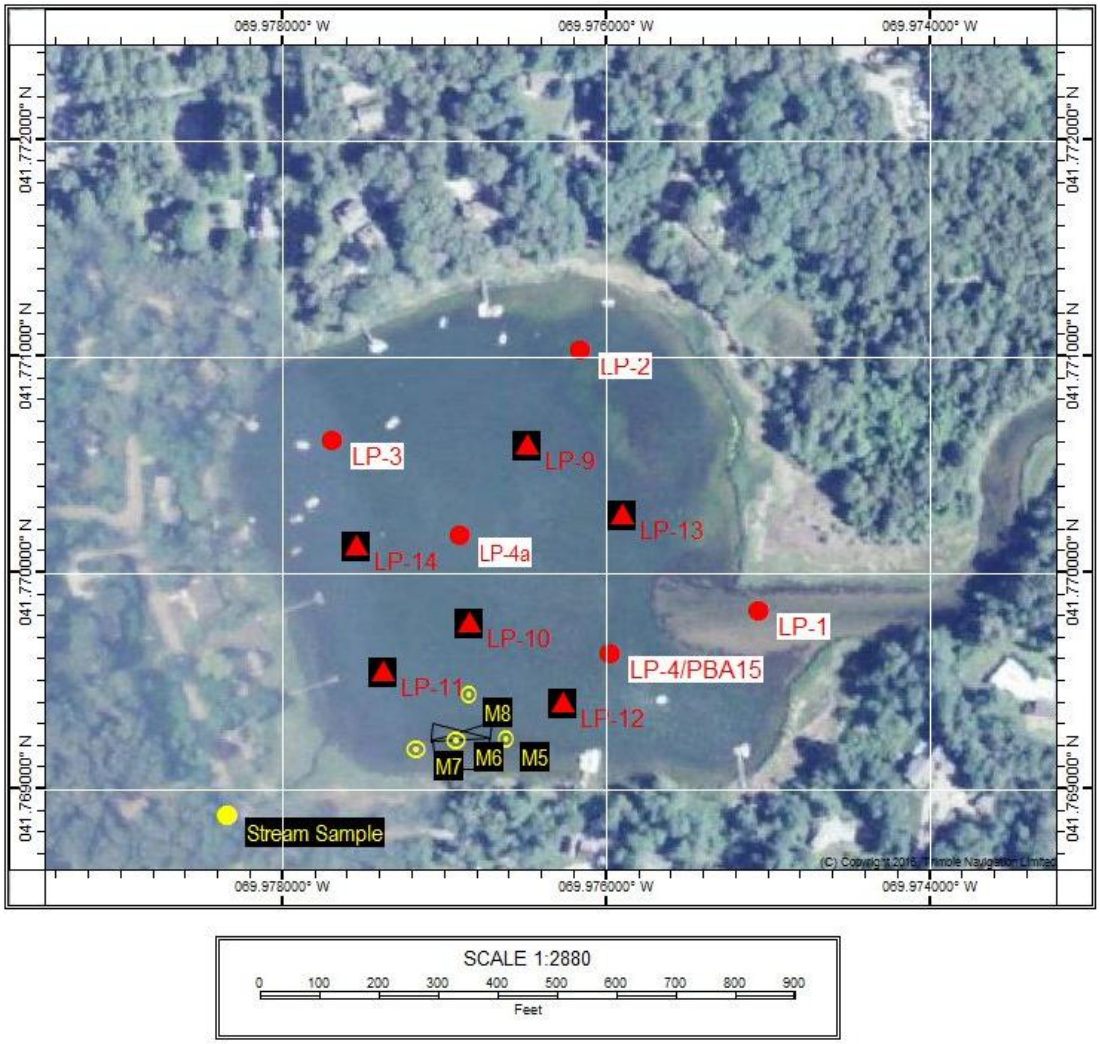


Figure II.1. Locations of water quality stations. Red dots denote stations established in 2016. Red triangles denote water quality stations added in 2017. LP4a was occupied during June 2016 until a permanent buoy was deployed by the harbormaster; hereafter LP4 was used to compliment previous water quality studies. Water quality stations LP5, LP6, LP7 and LP8 were at the mooring locations denoted on the map as M5-M8.

Brief Description of Findings and Conclusions:

The spatial distribution of major water quality constituents was variable over time. During the 2017 sampling period, there was evidence of higher concentrations of constituents along the northern edge of the pond (April samplings), however, spatial gradients (Figures II.2, II.3, II.4, II.5, top panel) were only established after deployment of the oysters (April onward). These gradients were most apparent during periods of high chlorophyll concentrations during which filtration by the oysters was enhanced. During periods of relatively low chlorophyll concentrations, gradients were small or nonexistent. This pattern differs from the 2016

sampling, during which there were drought conditions, when no evidence of point sources (e.g. stream input loads) or large scale gradients was observed (Figures II.2, II.3, II.4, II.5, bottom panel). In both 2016 (year 1) and 2017 (year 2), there was a clear pond-wide temporal trend with higher levels in mid-summer for each constituent (PON, Chlorophyll-*a*, bioactive N[2]). This temporal pattern is consistent with more eutrophic conditions in estuaries in the warmer summer months, with poorest water quality typically in July through mid-September and specifically evidenced by the large August phytoplankton bloom recorded by the time-series chlorophyll sensors (see Section IV). It should be noted that while there were blooms in both years, the chlorophyll-*a* levels in 2016 were significantly higher with a longer bloom in 2016 than 2017. It is possible that this could be related to the drought in 2016, but the specific mechanism is not well defined at this point.

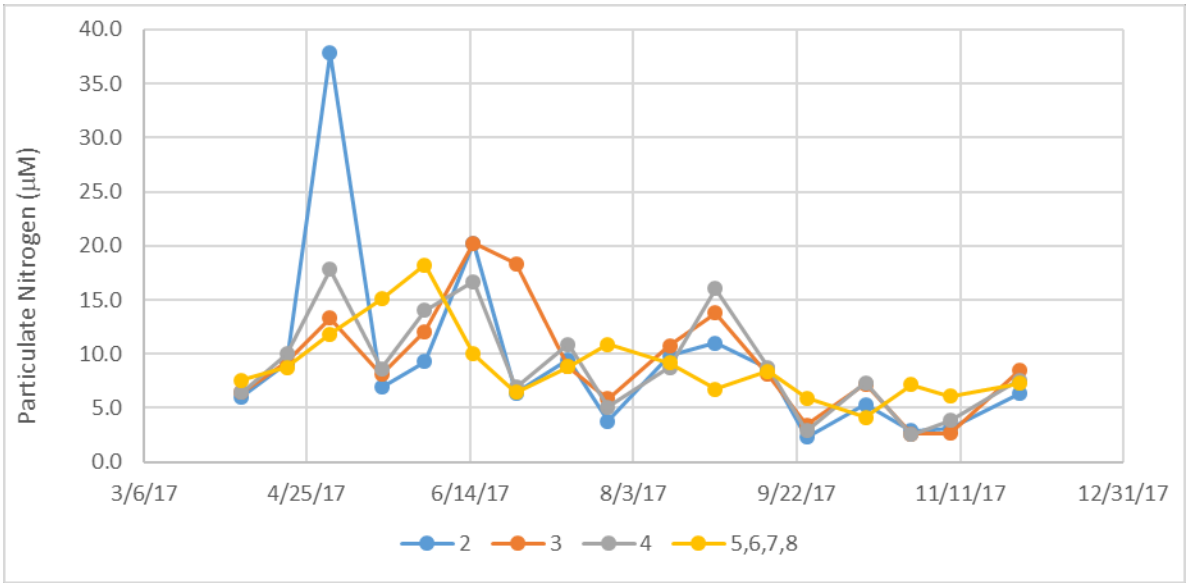
Within the generally homogeneous distribution of the major constituents across Lonnies Pond, there appeared to be lower levels of each constituent within the region of the oyster deployment. Although the magnitude of the constituents varied over time, each of the oyster influenced stations (M5-M8, Figure II.1) usually had lower concentrations than each of the far field stations (stations LP1-LP4, Figure II.1). Focusing on the period when the water quality constituent levels were consistently high (July 18-October 6), the spatial pattern is more clearly seen (Figure II.5) during both 2016 and 2017 field seasons. The distribution map of average water column constituent levels indicates lower levels of chlorophyll-*a* and PON are associated with the oyster deployment area compared to the area represented by the far field stations. Stations LP-1,2,3 and 4 showed consistently higher levels, station M8 intermediate levels and the stations directly associated with the oyster deployment showed lowest levels of each constituent. Even comparing the outboard station M8 to the nearby stations (M5, M6, M7) directly within the area of oyster influence, the influence of oyster filtration in removing particulate matter from estuarine waters was apparent (especially for station M6 in the middle of the oyster deployment area and in both 2016 and 2017). However, bioactive nitrogen for the stations within and adjacent to the oyster area was higher in 2017 due to increased dissolved inorganic nitrogen (NH_4 and NO_3). With the higher number of oysters deployed in 2017 the removal of PON by filtration and subsequent release of pseudofeces, labile fecal pellets and ingestion/digestion of filtered material likely results in increases in NH_4 and possibly nitrate (after nitrification) and lowering of water column PON and chlorophyll a.

The water quality surveys were mainly to establish temporal changes in water quality throughout the pond to establish the benchmark (setting) for the overall nitrogen cycling measurements. The surveys indicated that Lonnies Pond tends to be relatively well mixed horizontally as seen in the spatial distribution of chlorophyll-*a* and particulate nitrogen. However, the results did indicate that in the region of the oyster deployment, particulate levels, particularly chlorophyll, are reduced, consistent with the filtering effects of the oysters. This "hole" in the particulate field indicates the high volumes filtered by the oysters as water flows through the deployed bags in minutes not hours. Overall, the results show that the increased

[2] Bioactive nitrogen is ammonium+nitrate/nitrite+particulate nitrogen, the most biologically active portions of the total nitrogen (TN) pool.

oyster deployment in 2017 (year 2) generated a lowering of key eutrophication indicators associated with the oysters held within the southern region of Lonnies Pond as compared to 2016, in part due to the very high phytoplankton levels. Based upon these results, the expanded oyster deployment further improved water quality within this eutrophic estuarine basin.

A clear trend in the spatial distribution of PON and Chlorophyll-*a* was seen only after the oyster deployment (Figures II.6 and II.7), but none was observed with regards to Bioactive N (Figure II.8). The oysters appear to create a sink for PON and Chlorophyll-*a* in surface waters which extends out as far as 100m, thus the water clearing ability of oyster filtration may extend much further than the oyster impact area on the sediments. No such relationship could be seen in NH4 and NOx concentrations which are the precursors to chlorophyll and PON. It appears that the transformation of organic to inorganic forms after filtration by the oysters is lessening the drop in Bioactive N levels associated with the deployment. Interestingly, the oyster deployment area represented a local minimum for chlorophyll in 2016 and in 2017 (Figure II.5), although the average summer chlorophyll levels in 2016 were 2-3 times that of 2017. This suggests that filtration is leading to increased organic matter deposition to the sediments in the area of the oysters.



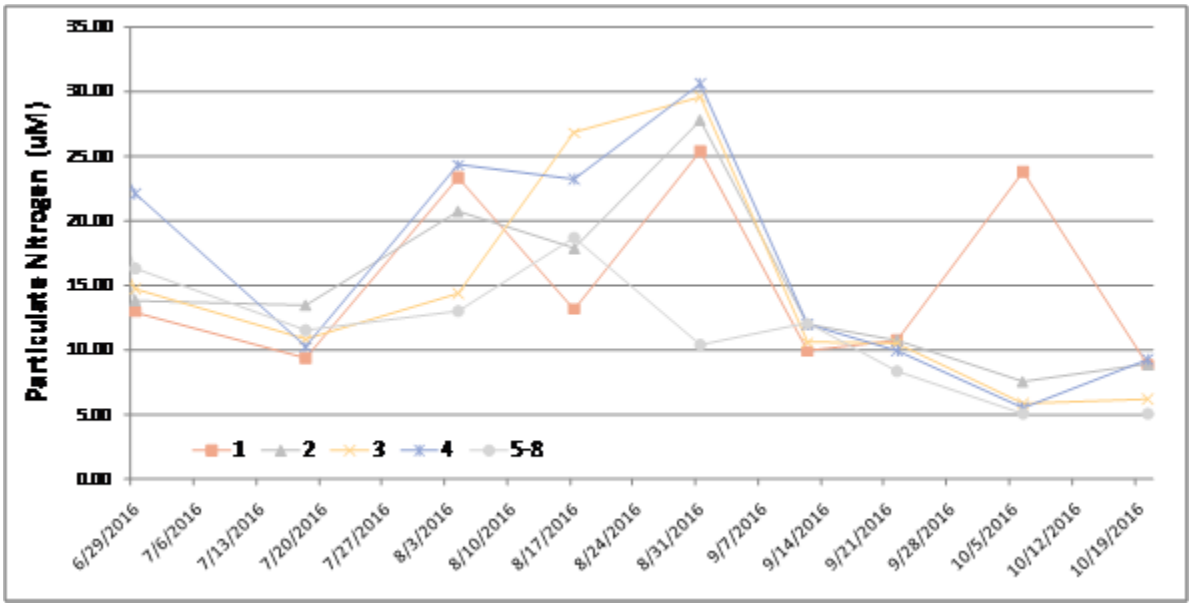
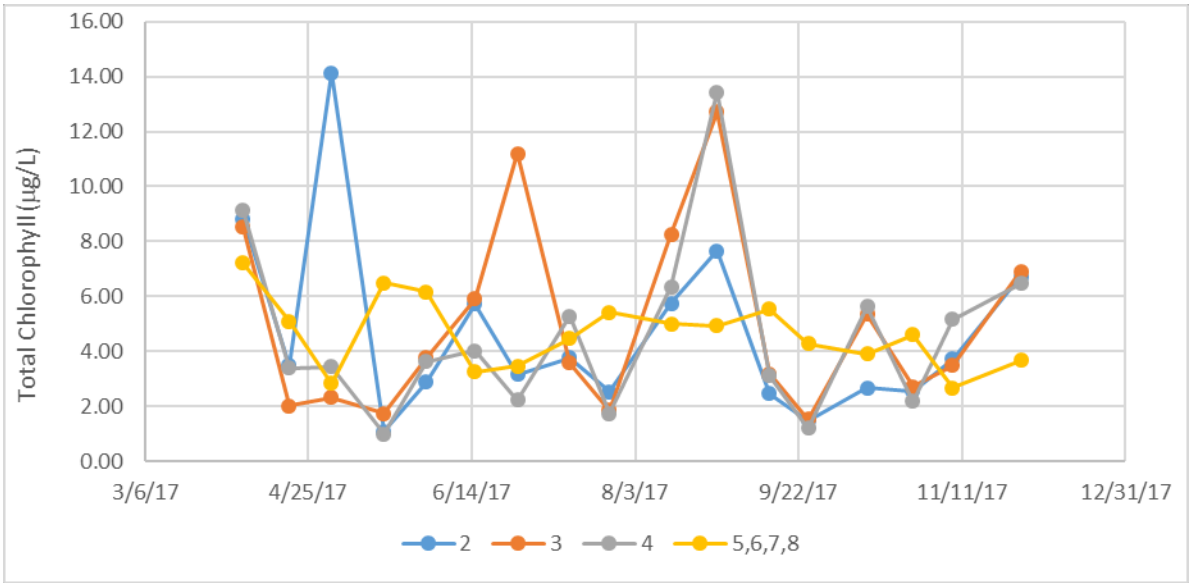


Figure II.2. Top Panel: 2017 time-series of mixed layer average particulate nitrogen at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.



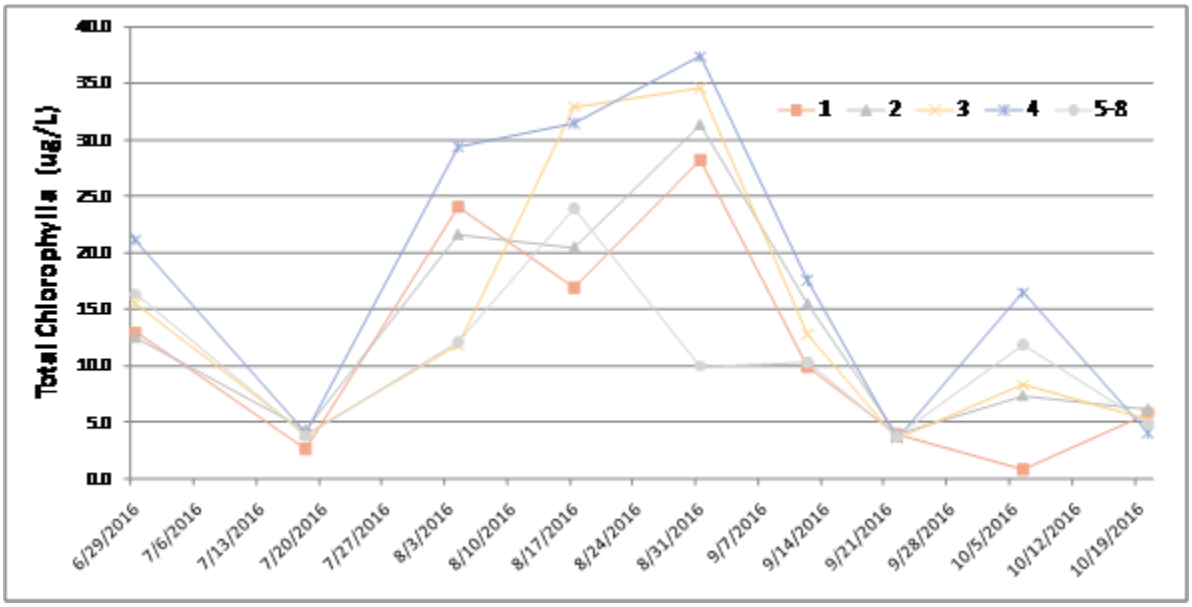
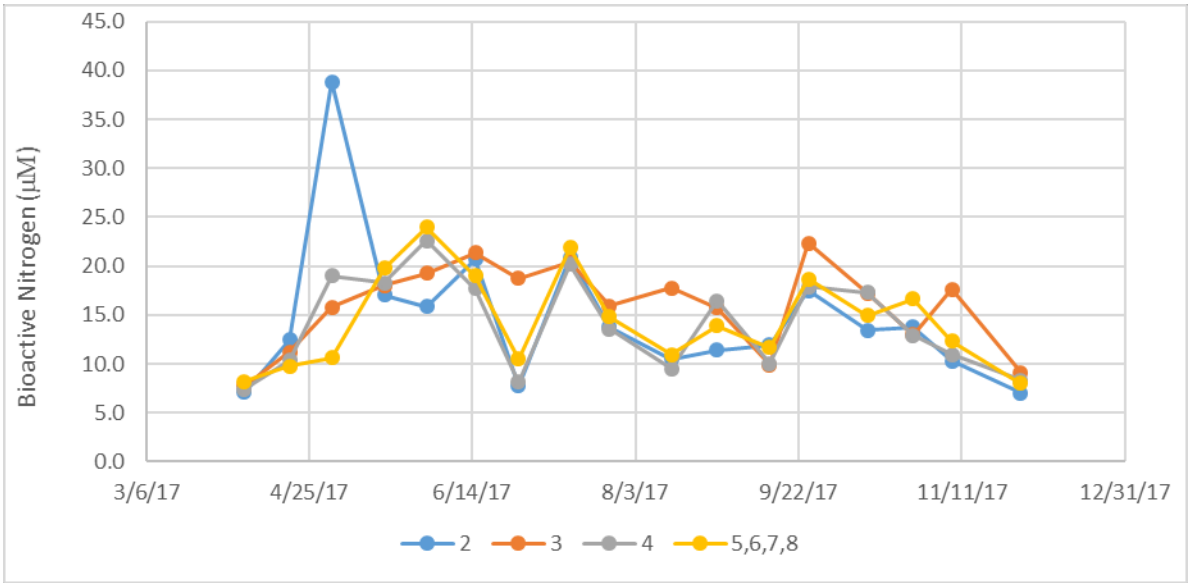


Figure II.3. Top Panel: 2017 time-series of mixed layer average total chlorophyll a at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.



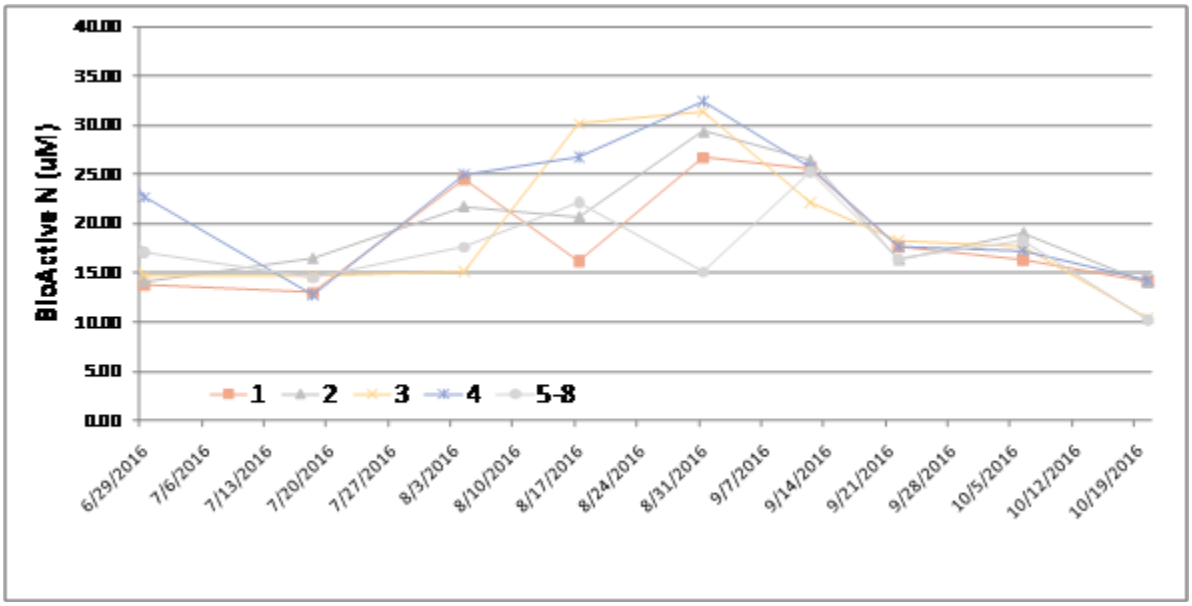


Figure II.4. Top Panel: 2017 time-series of mixed layer average bioactive nitrogen concentration at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.

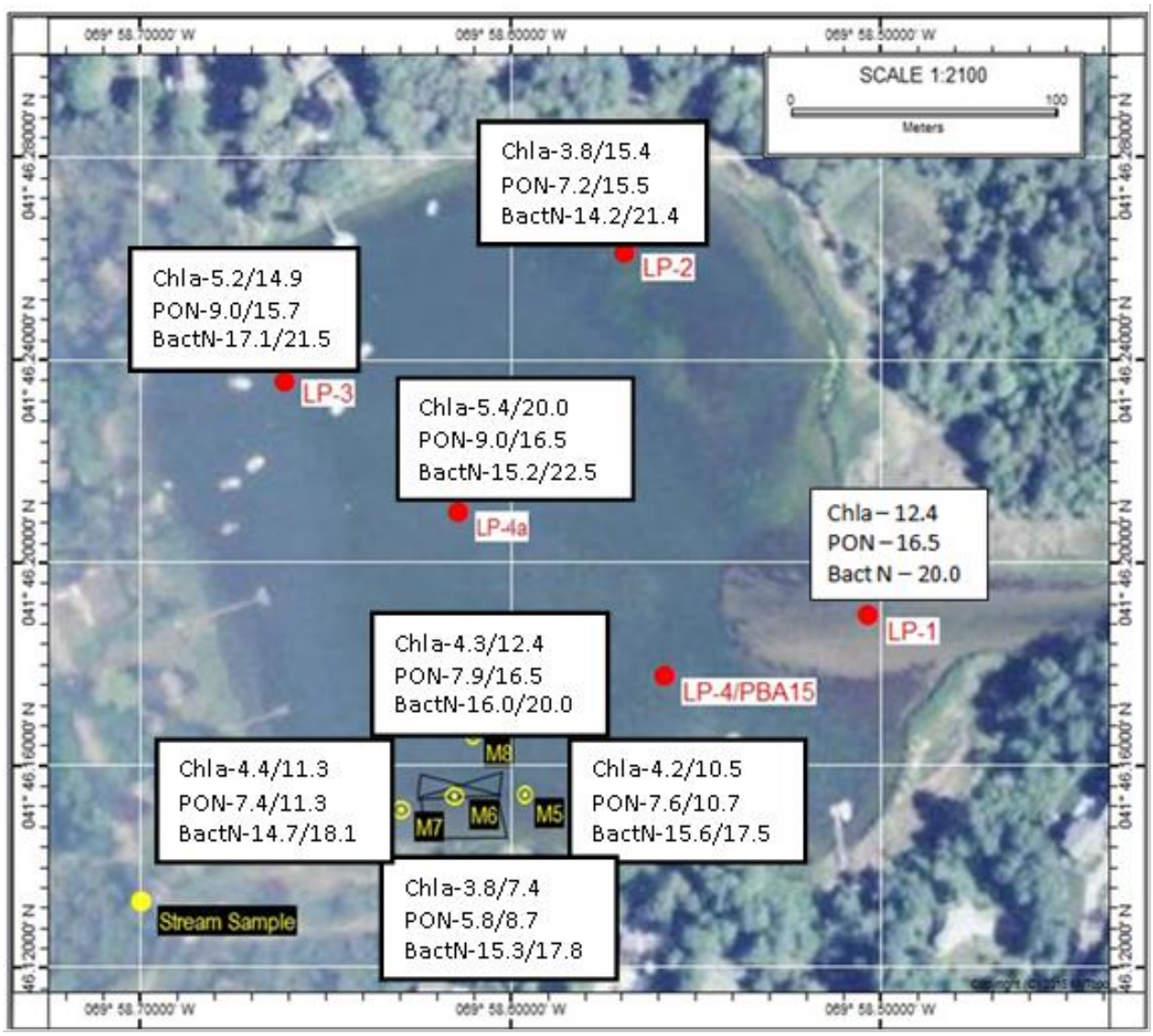


Figure II.5. Mixed layer average concentrations of total chlorophyll a (μg L^{-1}), particulate organic nitrogen (μM), and bioactive nitrogen (μM). Values represent average of samples collected from July 18 through October 6, 2016. Note the lower concentrations of each constituent in the region of the oyster deployment (stations 5,6,7,8) versus farther away (stations 1,2,3,4). 2017 values are shown first with 2016 values shown for reference (2017/2016). Values presented for station LP-1 are only from 2016.

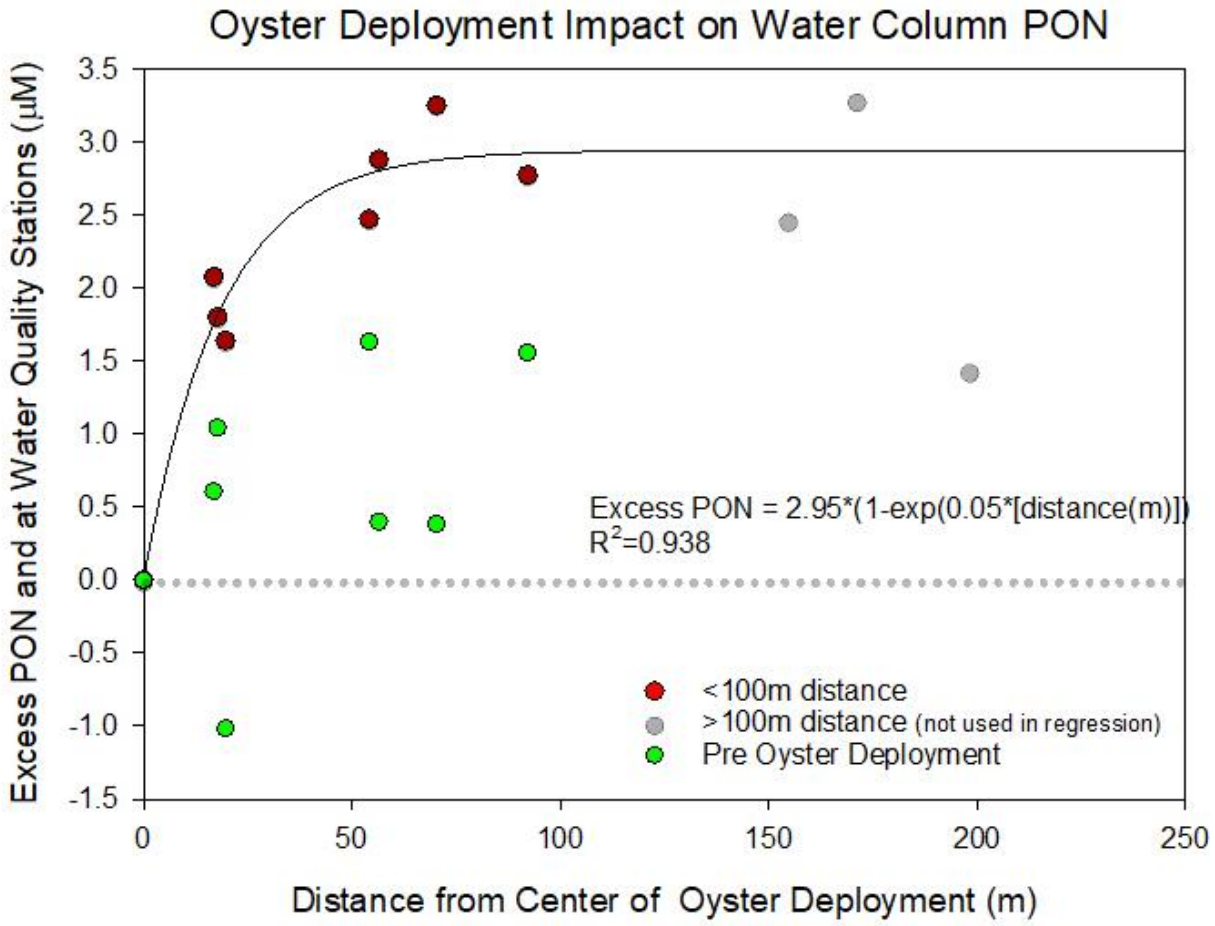


Figure II.6. Mixed layer average concentrations of particulate organic nitrogen (µM) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note the concentrations of excess PON within 100m of oyster deployment increase exponentially with distance only after oysters were deployed.

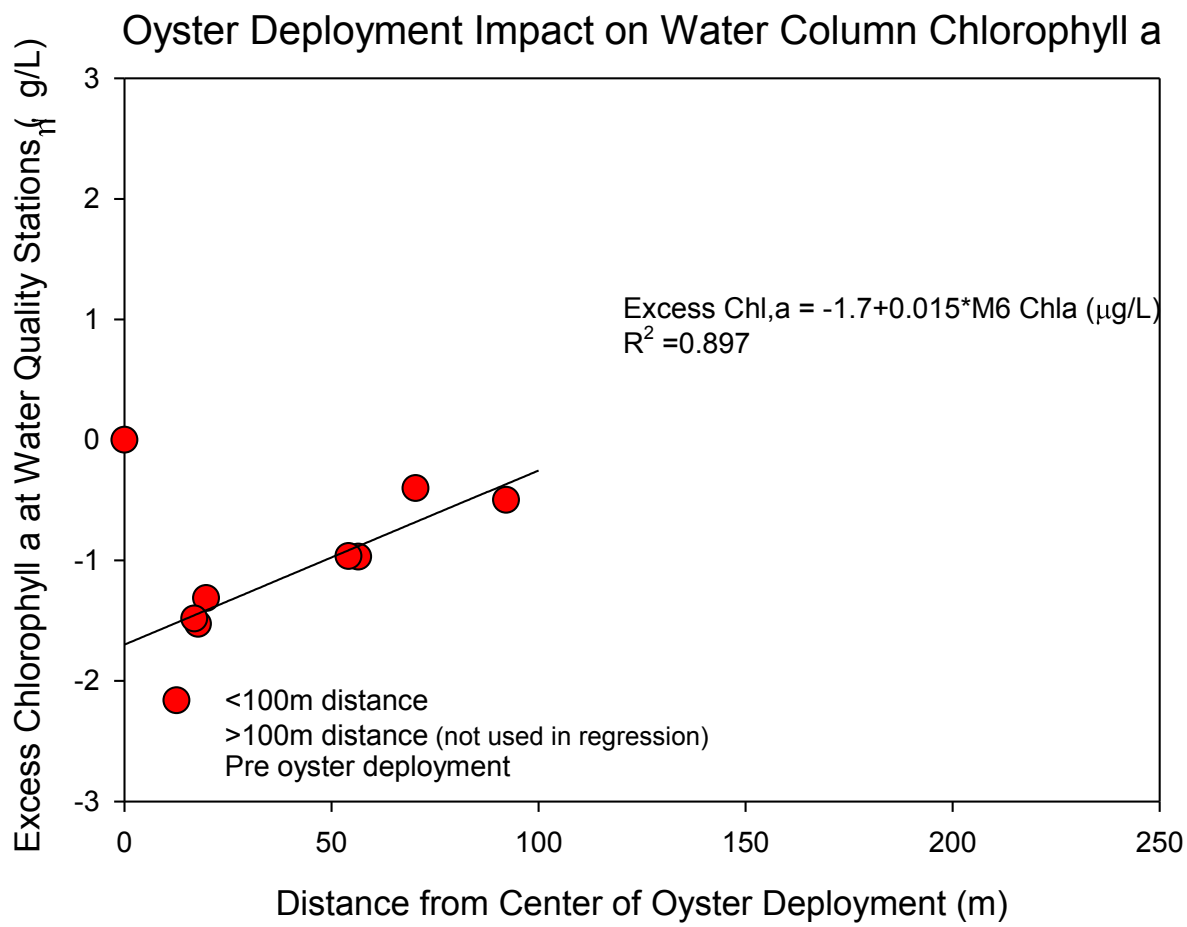


Figure II.7. Mixed layer average concentrations of chlorophyll a (μg/L) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note the concentrations of excess Chla within 100m of oyster deployment increase linearly with distance from the oyster site only after oysters were deployed and that the oysters create a local chlorophyll minimum.

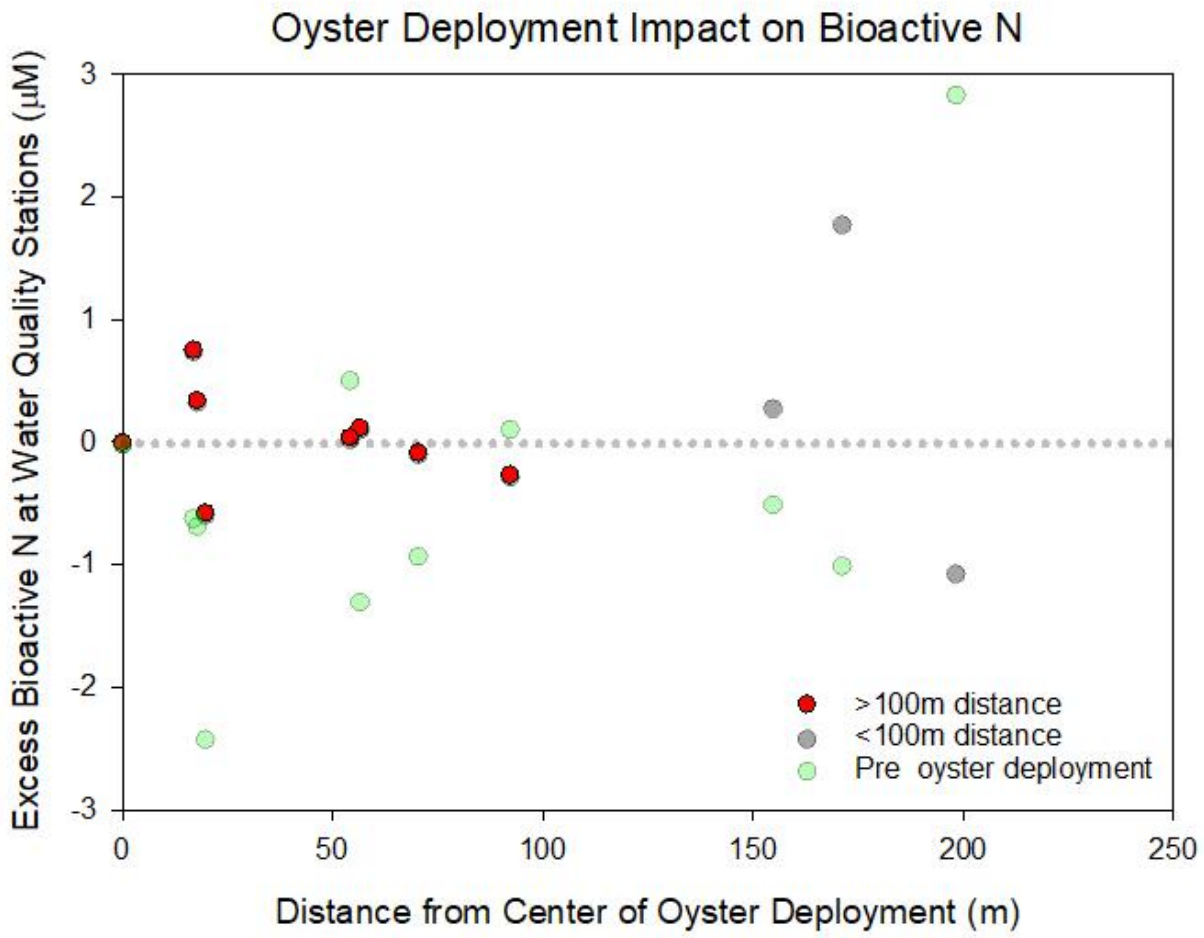


Figure II.8. Mixed layer average concentrations of bioactive N (μM) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note that unlike PON and chlorophyll there is no obvious trend with increasing distance from the oyster deployment area, possibly due to it being a composite parameter.

Recommendations based on water quality sampling results:

Sampling should commence earlier in the season to capture any gradients not due to the activities of the deployed oysters. Sampling should focus on the oyster deployment area versus stations farther away, although it may be possible to sample station LP-2 less frequently or not at all. Lastly, it is important to monitor the surface water inflows (herring creek and cranberry bog) during subsequent oyster deployments as these sources of flow and load may figure more prominently under more average or above average precipitation conditions (summer 2016 was considered a particularly dry summer).

Section III. Time Varying Water Quality Assessment Post Oyster Deployment (2016)

Approach:

Water column surveys were conducted as water flowed through the oyster deployment area during complete tidal cycles on 4 dates in Summer 2016 (August 10 and 24, September 13, and October 12). This type of time varying survey (commonly referred to as a tidal flux survey) was not undertaken during the summer 2017 oyster growing season. During the 2016 surveys, samples were collected at nominal hourly intervals over consecutive flooding and ebbing tides. The sample sites included the long-term Lonnies Pond water quality station (PB-15) as background, and 2 sites associated with the oyster deployment itself, one to the west and one to the east. Samples were collected at 0.3 m depth at about 1 m from the edge of the aquaculture footprint. Samples were assayed in a similar manner as for the background water quality surveys (see Section II). In parallel with the water column sampling, an acoustic doppler current profiler (ADCP) was deployed to measure current direction through the aquaculture area relative to the sampling points. The concept was to quantify changes in water column constituents, most importantly particulate organic nitrogen, total chlorophyll-*a* and bioactive N, although the complete suite of nitrogen components, orthophosphate and dissolved oxygen were assessed.

Results:

Although 4 sampling events were conducted during the 2016 sampling season (year 1), the first event (August 10, 2016) was halted midway through the survey due to an extreme rain event which resulted in aberrant water column conditions and un-interpretable flow through the oyster area. Fortunately, the other 3 events yielded usable/interpretable results.

For the three subsequent valid events, the flow through the aquaculture area was NE to SW (8/24 and 9/13) and W to E (10/12) with generally low velocities. Given uncertainties in the amount of contact that a parcel of water had with the aquaculture bags and resulting turbulence, it was not possible to calculate rates of particulate removal. However, it was possible to examine removals on a concentration basis from up-gradient to down-gradient. Since the samples were collected in parallel at the eastern and western sampling points, a paired analysis was possible. It should be noted that on each date, there was a constant wind direction. The constant wind effect resulted in a water flow direction that also did not change between flooding and ebbing tides even as water entered and left the basin (i.e. the circulation was mainly wind driven). Changes in the paired samples over flooding and ebbing tide showed no significant differences in any of the water column constituents in water flooding through the aquaculture system on any of the 3 dates. In contrast, for each survey, constituents showed higher values on the ebb tide in the water before it passed through the aquaculture system than after it had passed through (Table III.1). On ebbing tides over the 3 events, average reductions of 19%-37% in PON, 23%-48% in total chlorophyll-*a*, 12%-20% in bioactive nitrogen were observed. In the October survey, flows approximated the long axis of the aquaculture system and the highest particulate removals were seen (37% in PON, 48% in total chlorophyll-

a). This result likely is related to the water parcels moving along the full length of the oysters in this event, maximizing the opportunity for filtration. This helps to explain the lower observed uptake when water passes obliquely through the system. It should be noted that variation in observed uptake is due to the position of the sampling points relative to the flow direction, as measured uptake will vary with flow direction even if oysters are taking up the same mass in each survey. Nonetheless the results clearly indicate that the oysters filtered out sufficient amounts of particles to significantly lower PON and chlorophyll-*a* levels, which was also seen in the time-series measurements (Section IV). Equally important, the observed reduction in bioactive N indicates that the removal of PON resulted in a net N loss to the water column of 12%-20%, as only about half of the PON removed was returned as regenerated nitrogen from the sediments or excretion nitrogen by the oysters.

Conclusions:

The oyster deployment in Lonnies Pond removed significant amounts of PON and total chlorophyll-*a* in ebbing waters. Particulate nitrogen removal resulted in a net lowering of water column bioactive nitrogen as the amount filtered out was not returned via oyster excretion or sediment regenerated nitrogen. Bioactive N levels declined by 12%-20% during passage through the aquaculture systems. Observed removals are conservative estimates due to the oblique patterns of flow through the oyster area in the surveys, which biases the uptake estimate low in these experiments.

Year 1 Recommendations (2016):

The tidal surveys yielded useful results, but were confounded by the flow pattern at the specific location in Lonnies Pond. While the flow pattern was not ideal, the results are unequivocal and understandable, which increases their value. Future surveys should include a real-time determination of flow direction and associated adjustment of sampling points. Moving sampling points to maximize the contact of a parcel of water with the oyster system would greatly improve accuracy and should support rate estimates. However, it is clear that placement of future demonstration deployments should account for flow direction if these types of measurements are to be undertaken. None-the-less, the tidal surveys clearly indicated that partical removal is sufficiently rapid with the result that there are quantifiable changes in water quality during individual tidal cycles. This supports the contention that shellfish should be able to make a positive change in Lonnies Pond water quality during the critical management period.

Table III.1. Water column constituents up gradient and down gradient stations during tidal flow through the aquaculture system in Lonnies Pond, Summer 2016. Highlighted pairs of means have significantly different levels after passing through the oyster deployment area.

	Flow Direction	PON (uM)	PON (uM)	PON (uM)	T-pig (ug/L)	T-pig (ug/L)	T-pig (ug/L)	TN (uM)	TN (uM)	TN (uM)	BioAvailN (uM)	BioAvailN (uM)	BioAvailN (uM)
Title		East	West	PB-15	East	West	PB-15	East	West	PB-15	East	West	PB-15
	Survey 8/24/2016												
Flood	E to W	15.31	15.80	19.50	22.9	21.3	25.6	47.68	49.29	50.83	16.50	12.07	20.14
Ebb	E to W	11.05	8.94	15.10	12.6	9.8	19.1	47.22	44.16	48.19	14.89	13.05	16.12
	Survey 9/13/2016												
Flood	E to W	8.32	11.93	11.29	7.04	8.03	7.43	51.71	52.55	52.40	22.11	24.38	22.38
Ebb	E to W	13.17	8.86	19.16	9.90	7.03	14.33	50.72	46.20	47.05	22.60	18.09	24.00
	Survey 10/12/2016												
Flood	W to E	8.97	7.95	11.67	7.8	8.9	14.5	47.7	48.9	48.5	25.1	28.9	25.3
Ebb	W to E	7.03	11.21	9.19	3.0	5.8	5.3	42.2	49.4	47.2	20.2	23.0	20.8
	statistical significant p<0.05												

Highlighted pairs of means are statistically significant (paired T-test). The flow did not go down the long axis of the oyster deployment, but did pass through the bags on the ebbing tide either in a East to West (events 1 and 2)or West to East (event 3) fashion. Removal can be seen as lower values at the downgradient station.

Section IV. 2016 and 2017 Time-Series Dissolved Oxygen (DO)/Chl-a Moorings (High Frequency Sampling)

Time-series Mooring Deployment and Sampling:

SMAST scientists conducted continuous monitoring of key water column parameters, dissolved oxygen and chlorophyll-a, at 15 minute intervals to assess the impact of oyster aquaculture on the ambient water column. This high frequency autonomous monitoring was completed in parallel with the traditional water grab sampling effort. The bottom moored sondes also collected measurements of temperature and tide height/depth. The mooring program undertaken in Lonnies Pond during the 2016 and 2017 field seasons followed the same protocols and procedures developed for the Massachusetts Estuaries Project (MEP) analysis of the Pleasant Bay Estuarine System and for the Towns of Falmouth and Mashpee Oyster Demonstration Projects. The consistency of protocols allows cross comparability of data sets collected in years past and from other estuarine locations where oyster deployments have been undertaken.

A total of five YSI-6600 moored sondes were deployed at four locations in both 2016 and 2017. Moored sondes were deployed on the bottom (30 cm above the sediment surface) within the footprint of the oyster deployment area as well as to the east and west of the oyster deployment (Figure IV.1). A fourth mooring was placed to the north of the oyster deployment footprint in approximately 2.5 m of water to monitor water quality outside the influence of the oysters. Two sondes were deployed at this fourth location: 1) at the surface and 2) 30 cm above the bottom. While the moorings provided good oxygen and chlorophyll-a data during the 2016

deployment period, oxygen sensors in 2017 suffered periodic failure of their Teflon membranes. Chlorophyll-a records in 2017 and 2016 provided adequate data for comparison of the respective oyster deployment periods. It remains unclear how the sensors were damaged in situ in 2017, however, thicker membranes and better protection that does not interfere with water movement around the sensors was instituted in the 2018 field season. Bi-weekly oxygen values obtained via winkler titration were collected for sonde calibration. These data are presented as instantaneous measurements for each of the mooring locations. In addition, continuous air equilibration values were calculated from salinity and temperature data.

The moorings were maintained April – November in both 2016 and 2017 to provide information during three critical periods: 1) prior to the deployment of the oysters, 2) when the oysters were most actively filtering pond water (i.e. maximum "oyster effect") and the pond water quality is lowest, and 3) through the autumn months when oyster activity was decreased by colder water temperatures. Moorings were calibrated bi-weekly by collection of samples at the specific depth and location of each sensor. At the time of calibration, each sonde was inspected, cleaned and then downloaded. Sondes were then returned to the moorings and secured. Calibration sampling included triplicate Winkler samples for dissolved oxygen (DO) determination as well as collection of whole water for chlorophyll extraction. The sondes recorded DO, Chl-*a* (via fluorescence), salinity, and water temperature and depth at 15-minute intervals.

Time-series Sensor and Sonde Data Results and Discussion:

The dissolved oxygen (DO) records (Figures IV.1a, IV.2, IV.4, IV.6 and IV.8) all show large diurnal variation in response to water column and sediment respiration at night and photosynthesis during the daylight hours. The levels of oxygen depletion (to 2 mg/L) and large diurnal changes indicate a system that has been organically enriched due to nitrogen enrichment and impairment was seen in the summer of both 2016 to 2017. Close examination revealed lower oxygen minima in 2016 than 2017, even with consideration of the diurnal variability. In 2016 oxygen minima at most sites was ~1 mg/L or even showed periodic anoxia, where as in 2017 oxygen levels generally were above 2 mg/L or even 3 mg/L. These findings were consistent with the measured chlorophyll levels which showed a clear inter-annual difference, with 2016 supporting 2-3 times the phytoplankton biomass than observed in 2017.

A general comparison of oxygen conditions in both 2016 and 2017 was achieved by comparing the overlapping time series data and oxygen levels from the field calibration samples in both years. Calculated air equilibration values which represent the expected DO concentrations of a well-mixed water column in the absence of any biological perturbations were also assessed. The results of the comparison of the available 2016 and 2017 Winkler DO data show generally depressed oxygen concentrations at M8 (north of oysters) due to sensors being rapidly fouled and proximate to the Pond's natural pycnocline for the surface and bottom sensors, respectively. Moorings M5 and M7, located to the east and west of the oyster deployments show slight positive and negative deviations with the exception of a short period beginning June 1 and ending June 15. The extreme excursions from air equilibration were not accompanied by any dramatic change in chlorophyll concentration (e.g. a phytoplankton

bloom) and may have been the result of drift macroalgae periodically interacting with the moorings. The most complete DO record was at M6 in the middle of the oyster deployment. Diurnal excursions in DO were large (up to 10 mg/L) and oxygen minima reached 3 mg/L, however close examination of the records show these low levels were not persistent; the events did not last for more than 1 hour early in the morning.

The continuous chlorophyll records are of generally high quality and confirm conclusions from the bi-weekly sampling results. Phytoplankton concentrations in Lonnies Pond were significantly lower in 2017 than in 2016. Overall temperatures in the pond (from sonde records) were also slightly lower in 2017 than in 2016 and while there are many other environmental factors (rainfall) which can affect phytoplankton biomass, the observations are potentially due to the larger biomass of oysters acting to improve water quality in 2017 possibly coupled with a larger regional meteorological effect. It was noted that in summer 2017 there were also generally lower chlorophyll levels in Pleasant Bay than in 2016 (Orleans Water Quality Monitoring Program).

Unlike the elevated chlorophyll values seen in 2016, the highest chlorophyll concentrations in 2017 were observed within the oyster deployment area (M6). The continuous record displays consistently higher chlorophyll concentrations in the middle of the deployment area than those observed at moorings either to the east or west. This pattern suggests that filtration of plankton by oysters and resulting deposition was concentrating chlorophyll (biodeposits are high in pheophytin a) and releasing it to the water column where it settled beneath the oyster arrays. This concentration and deposition within the oyster deployment area is seen in the surficial sediments and the stimulation of sediment remineralization of organic matter within the water column and surface sediments. Interestingly, chlorophyll levels at M5 and M6 rarely exceed those observed at nearby monitoring locations suggesting that deposition is mainly within the oyster deployment area.

In some locations of oyster culture and aquaculture, concerns have been raised about potential benthic habitat decline resulting from the concentration of feces on the sediment surface which can lead to increased sediment respiration and by extension depressed dissolved oxygen concentrations within the deployment area. While dissolved oxygen concentrations were observed to be below saturation values, the lowest concentrations observed within the oyster deployment area were also observed at far field stations such as LP2 and LP3, hence attribution to oyster culture is not possible. The apparent increased phytoplankton production within the oyster deployment area warrants continued monitoring, but as long as that increased production remains restricted to the deployment area (balanced by increased oyster filtration) it could be a positive outcome as recycled N is removed by oyster assimilation.

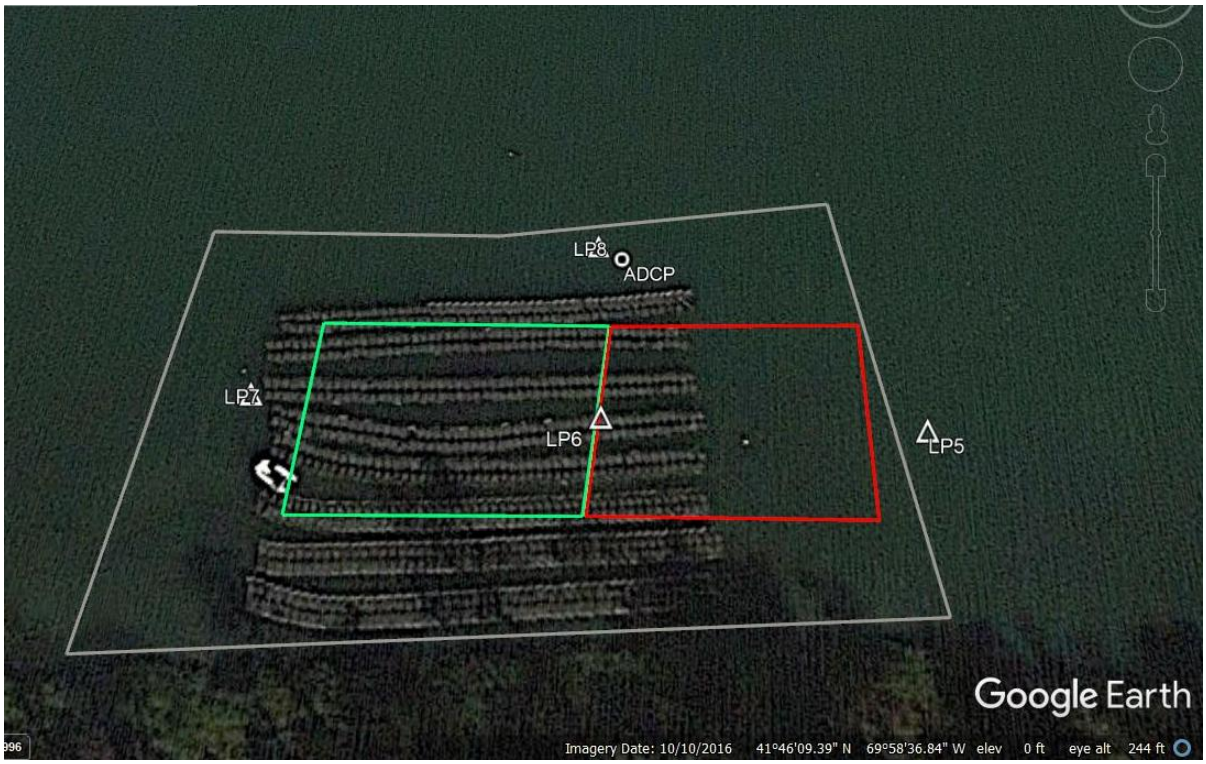


Figure IV.1. Aerial photograph showing the initial 2016 oyster deployment (floating bags) relative to mooring locations at the edges of the oyster deployment footprint (LP5 {bottom}, LP7 {bottom}, LP8 {surface+bottom}). The area defined by the green line is where the first year class oysters (2016) were redeployed in 2017 after over-wintering. The area defined by the red line is were oyster seed was deployed in 2017. The calculated 2016 impact area is denoted by the gray line.

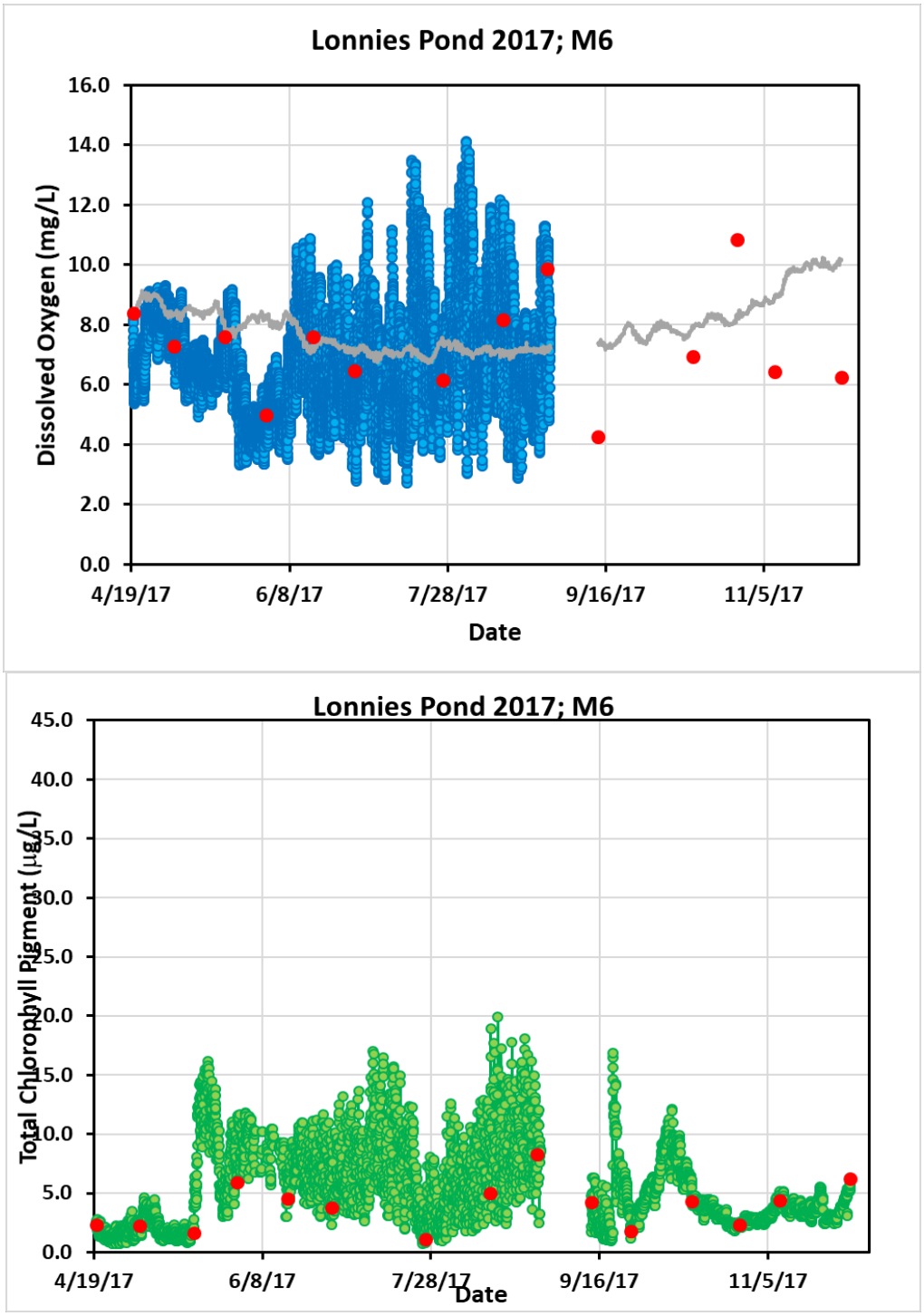
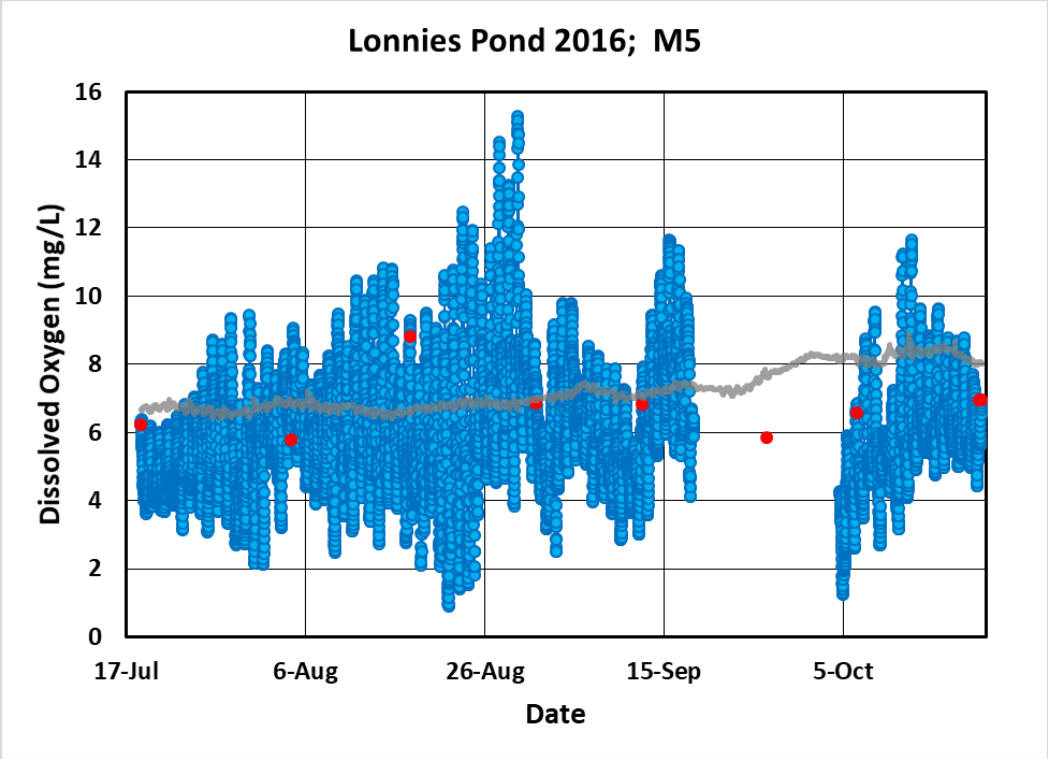


Figure **IV.1a** Time series dissolved oxygen at Lonnies Pond Mooring M6 located in the center of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top). Time series chlorophyll measurements at Lonnies Pond Mooring M6 located in the of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points.



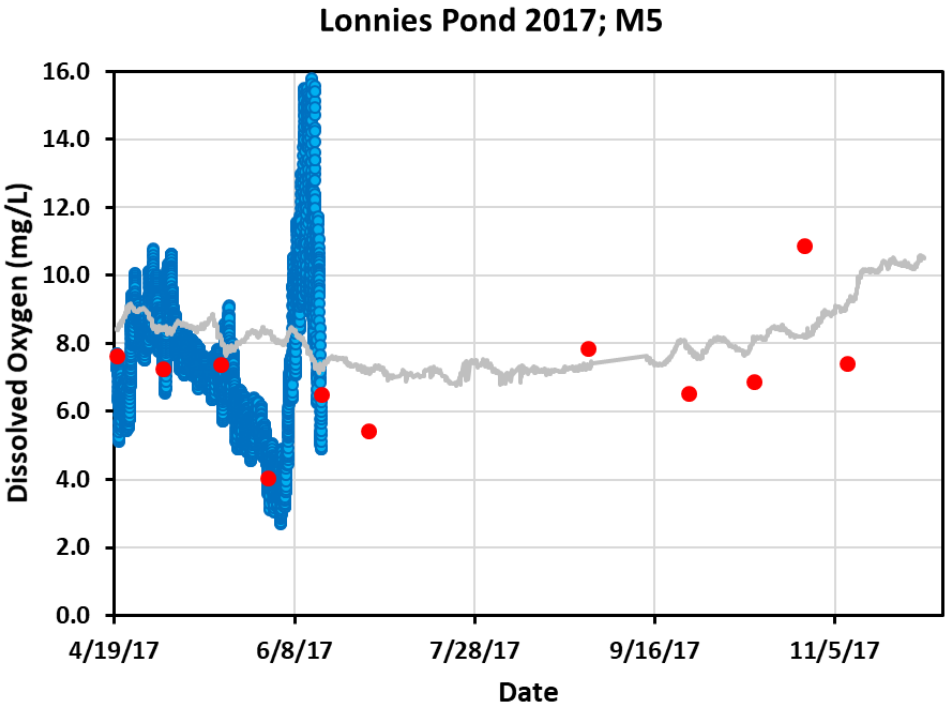


Figure IV.2. Time series dissolved oxygen at Lonnies Pond Mooring M5 located due east of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

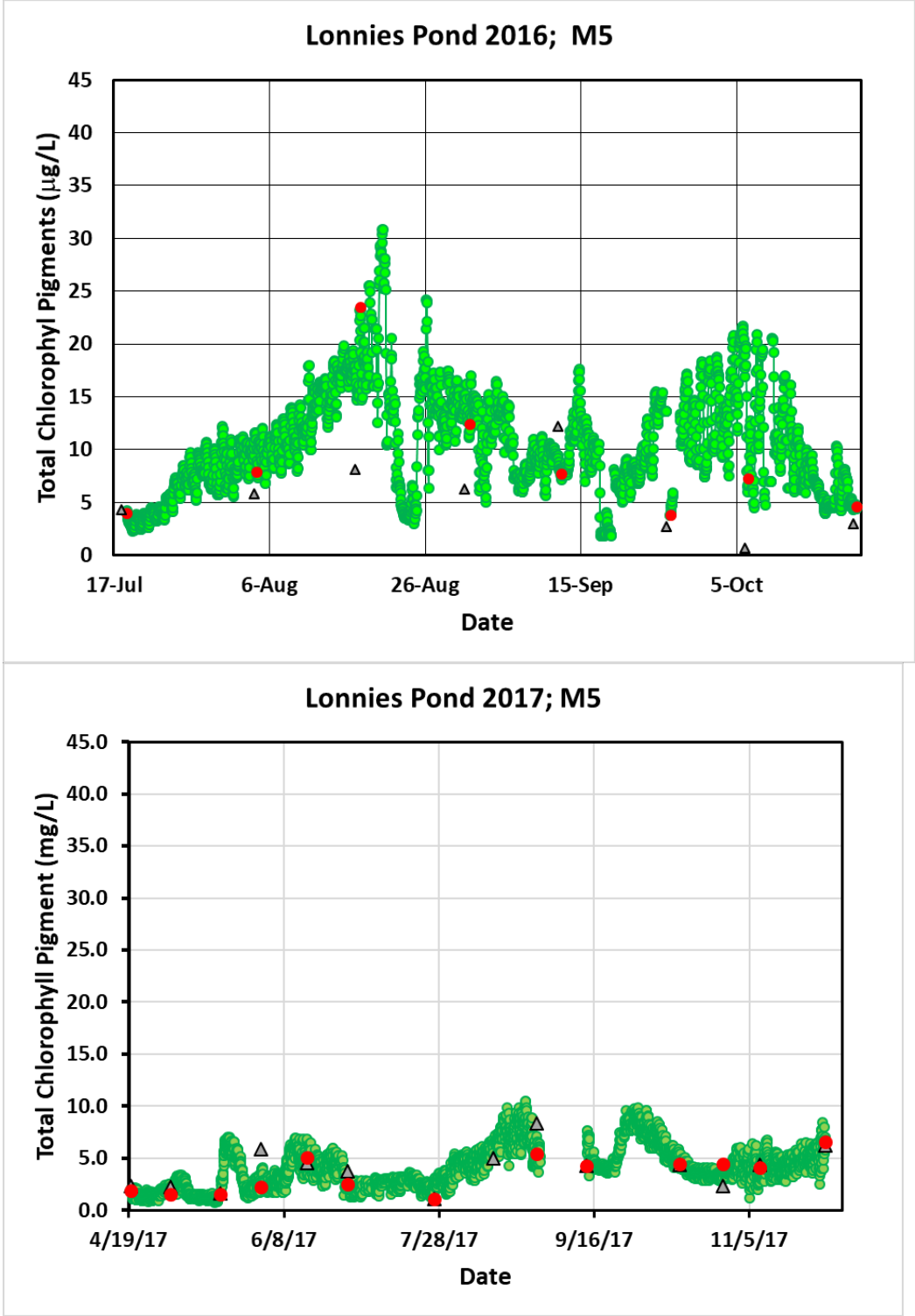


Figure IV.3. Time series chlorophyll measurements at Lonnies Pond Mooring M5 located due east of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

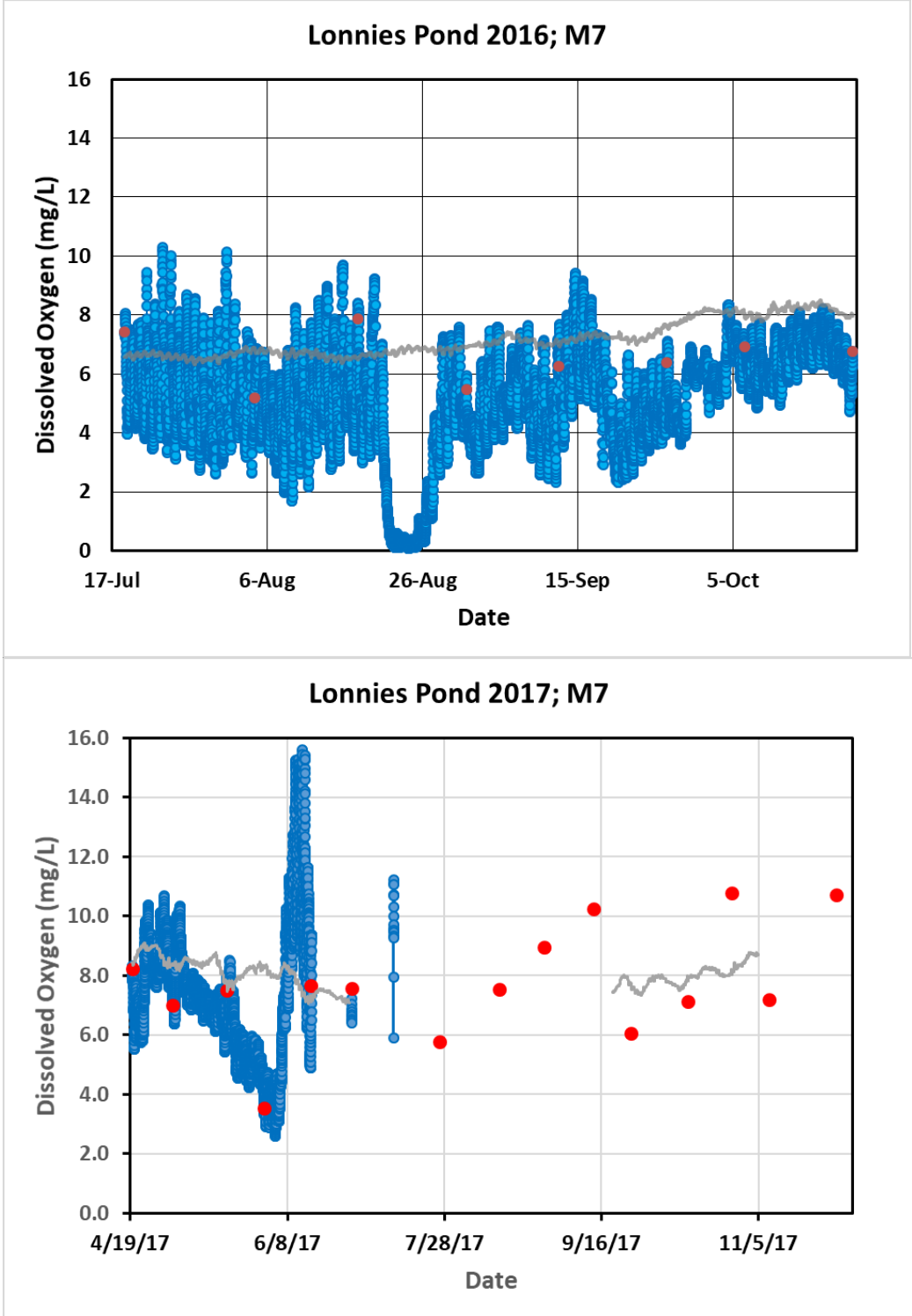


Figure IV.4. Time series dissolved oxygen at Lonnies Pond Mooring M7 located due west of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

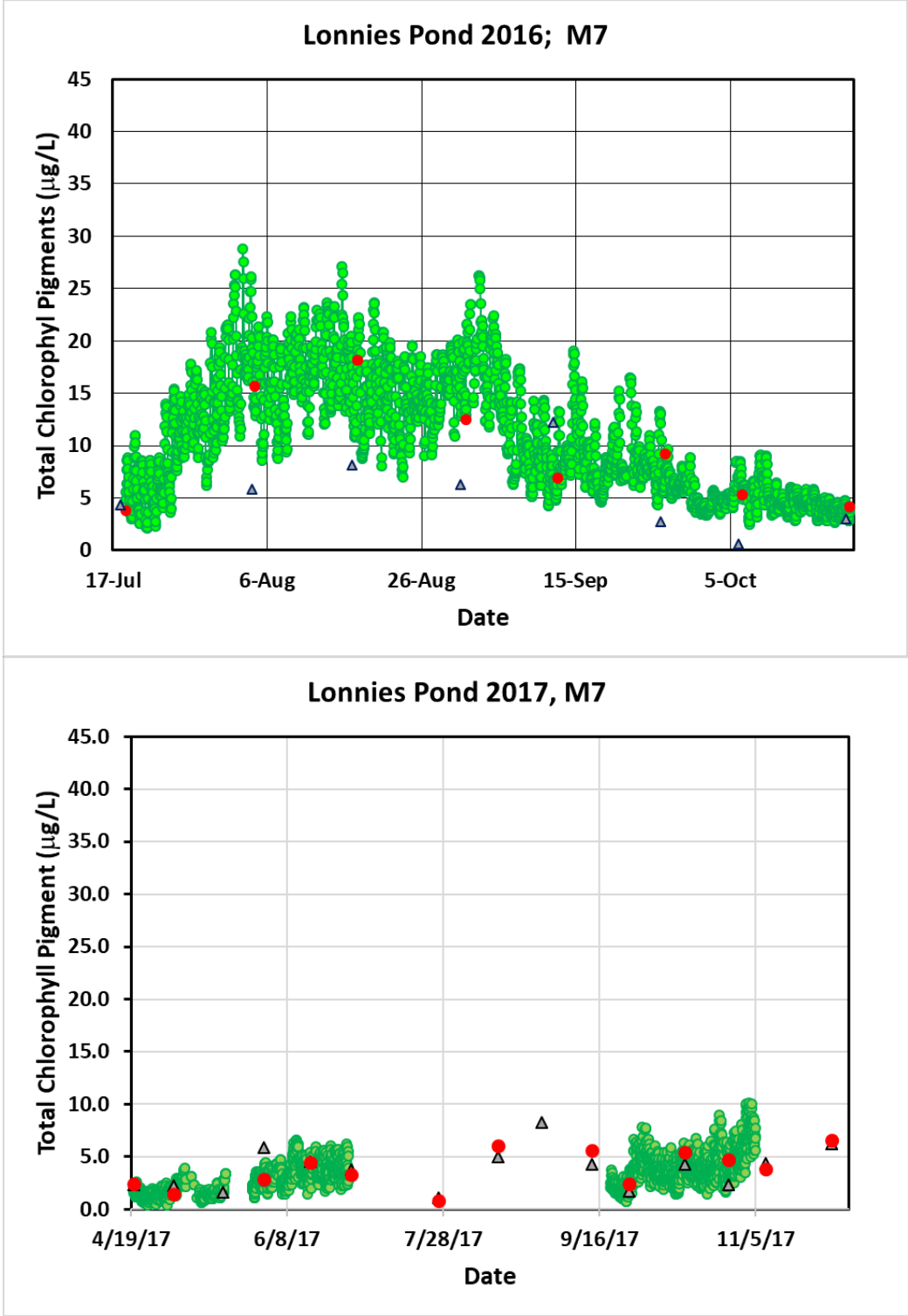


Figure IV.5. Time series chlorophyll measurements at Lonnies Pond Mooring M7 located due west of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

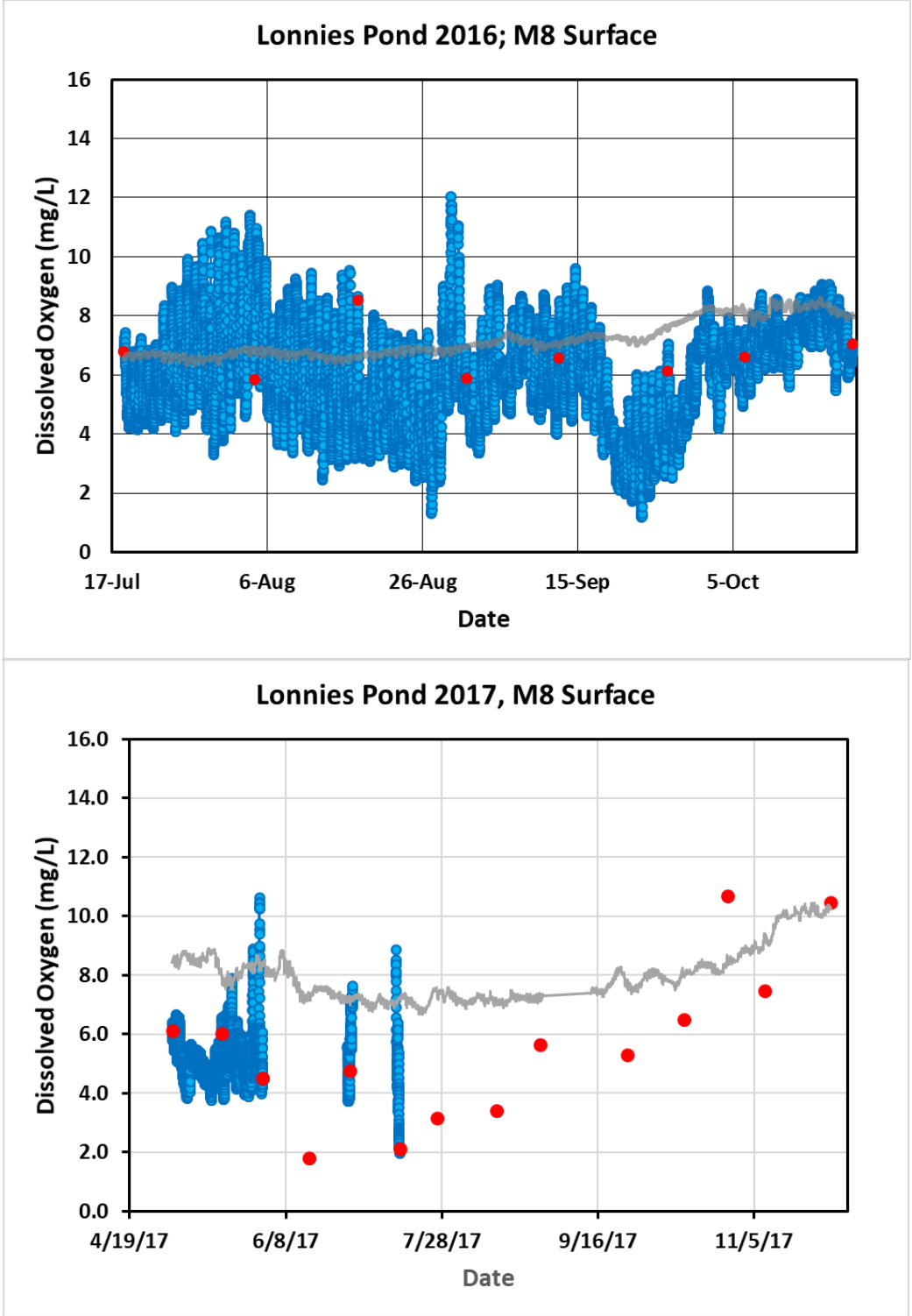


Figure IV.6. Time series dissolved oxygen at Lonnies Pond Mooring M8 (Surface) located due north of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

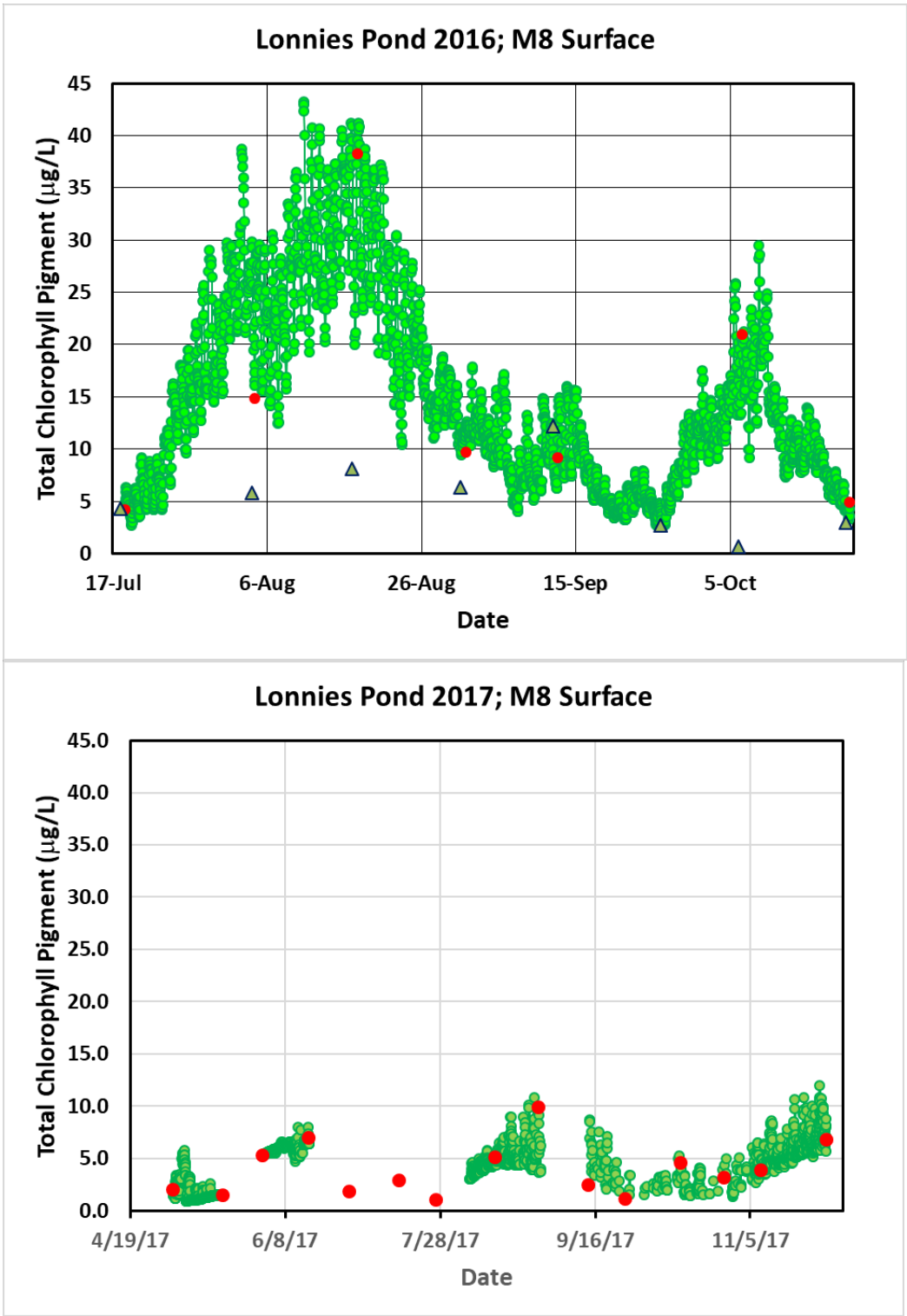


Figure IV.7. Time series chlorophyll measurements at Lonnies Pond Mooring M8 (Surface) located due north of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

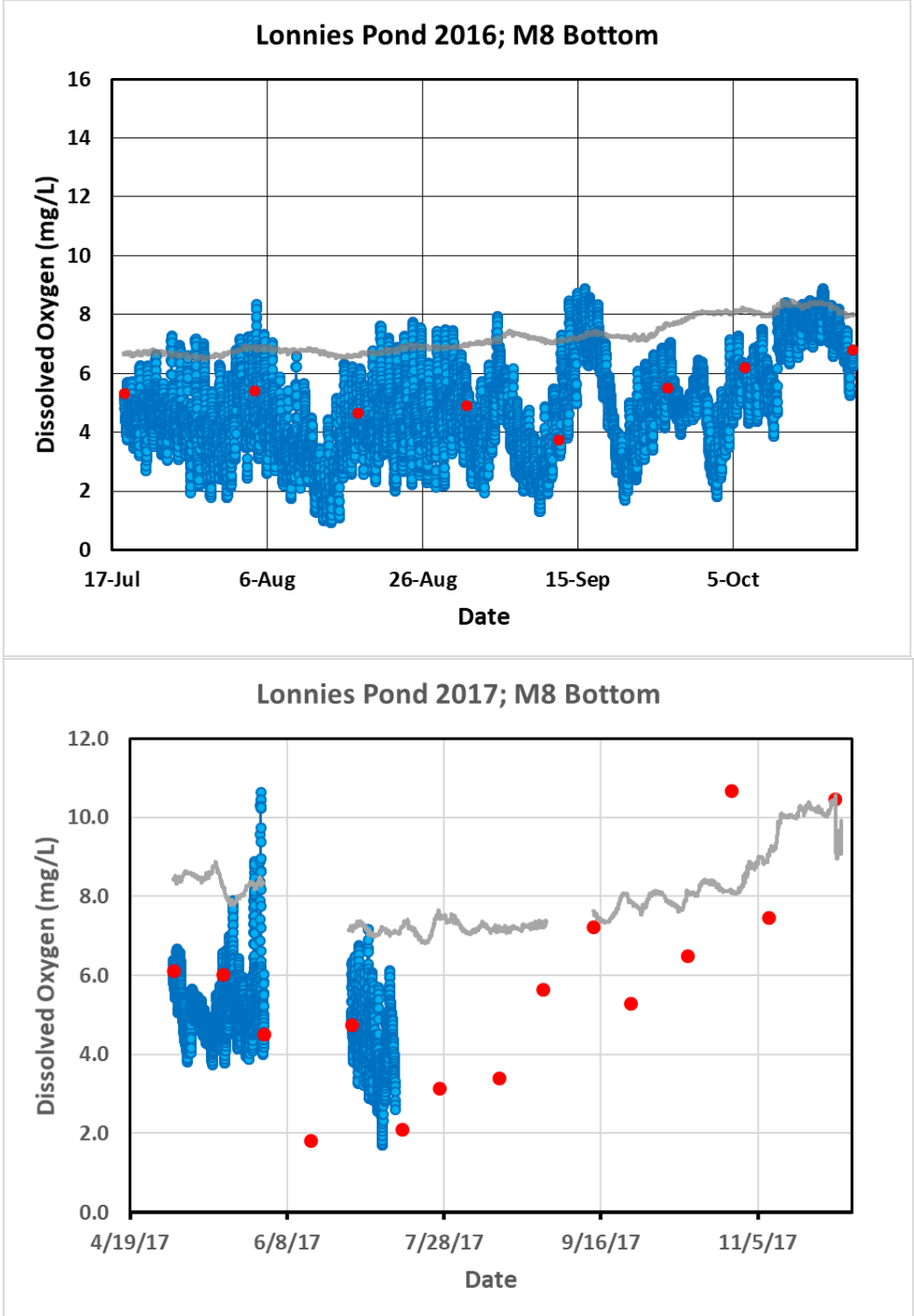


Figure IV.8. Time series dissolved oxygen at Lonnies Pond Mooring M8 (Bottom) located due north of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

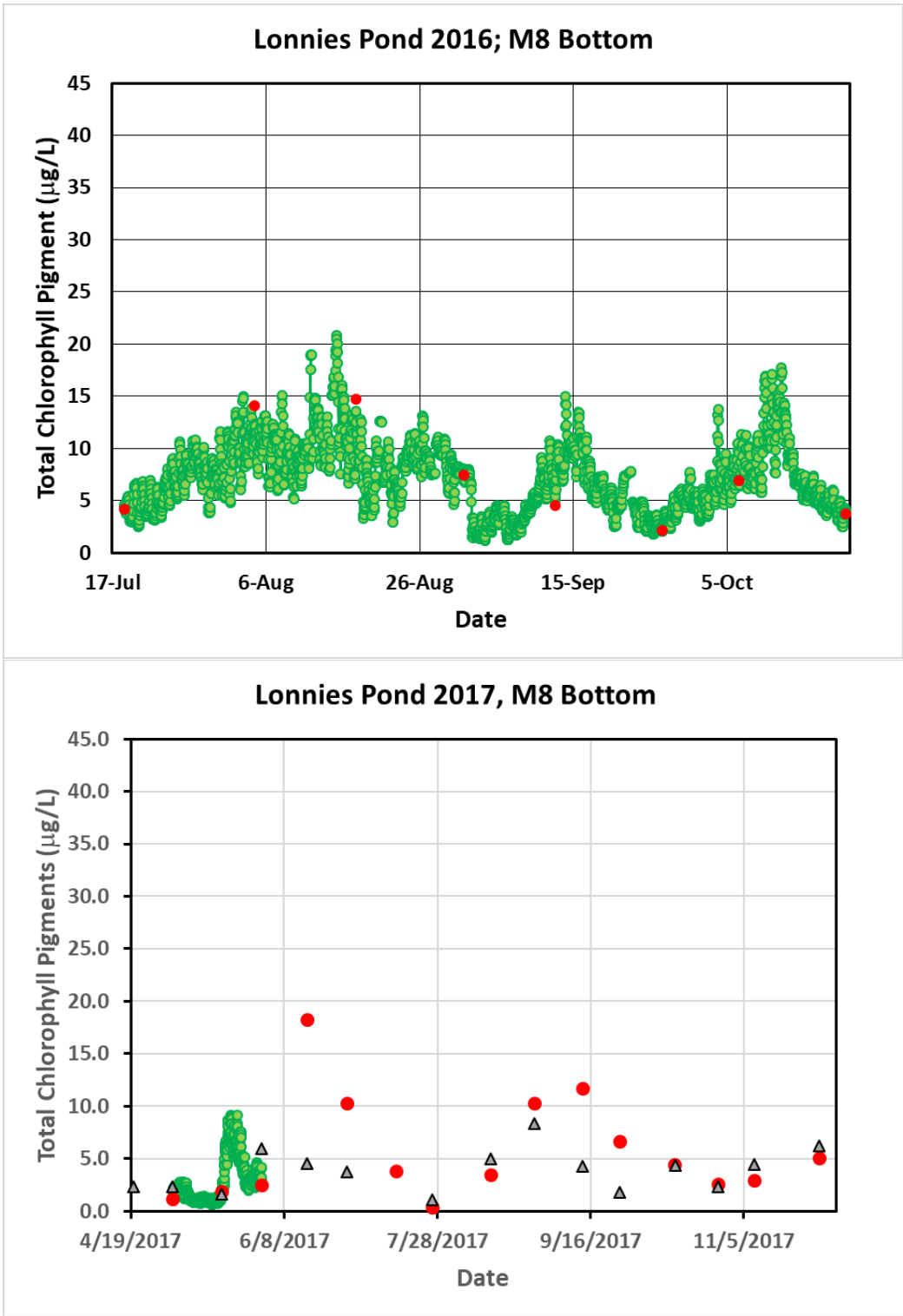


Figure IV.9. Time series chlorophyll measurements at Lonnies Pond Mooring M8 (bottom) located due east of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

Light pendants were used to measure light intensity in units of μE/m^2/s every 10 minutes and profiles were used to calculate the percent surface irradiance and the light extinction coefficient (k) within the water column associated with the oyster deployment in 2016. The light extinction coefficient, k was calculated using the Beer-Lambert Law which describes the logarithmic decay of light through a medium; the larger the light extinction coefficient, the more rapid the loss of light through the water column and represents a greater degree of turbidity. In contrast, small light extinction coefficients reflect greater light transmission through the water column and less turbidity. The mean daily light intensity was calculated using only the active photoperiod. In addition to the chlorophyll a samples collected for water quality and sonde calibration, total suspended solids (TSS), samples were collected to determine whether inorganic water column constituents could be responsible for changes in water clarity.

The average light characteristics, TSS, and chlorophyll concentrations are shown below (Table IV.1). Stations 5, 6, and 7 were within the oyster area and the bottom TSS values mirror the chlorophyll concentrations of these stations; however, the shallow water and variable shading caused by the moving bags makes light interpretation difficult. The highest light penetration and coinciding lowest light extinction coefficient was located at the site furthest away from the oysters, Lonnies 8, while also having the lowest chlorophyll concentration (Table IV.1). Note that station Lonnies 8 had additional surface samples collected. In contrast, when looking at only the data from stations in the oyster area, Lonnies 5, 6, 7, the lowest chlorophyll and lowest TSS (10.05 μg/L, 9.33 mg/L respectively) were found directly in the middle of the oysters, Lonnies 6. The chemical data represented specially as chlorophyll concentration and total suspeneded solids show these parameters are reduced within the oyster area. It appears that bag shading reduced the utility of the light records, so they were not deployed in 2017. The physical and chemical data support the data from the sondes; however, it was clear that the light data was influenced bag shading. Analysis of wind, rain, and tidal stage did not provide insight into what other factors might be influencing the light data.

Table IV.1: Results from the continuous light profiles measurements from Lonnies Pond showing the mean light intensity, penetration, and the light extinction coefficients along with the total suspended solids (TSS) and total chlorophyll pigments at each station.

Station	Depth	Light Intensity (μE/m2/s)	Mean Penetration	Light Extinction Coefficient, k	TSS (mg/L)	Total Chlorophyll Pigments (μg/L)
Lonnies5 (east)	Surface	249.74				
Lonnies5 (east)	Bottom	88.00	35.21%	1.66	10.99	11.13
Lonnies6 (oysters)	Surface	216.94				
Lonnies6 (oysters)	Bottom	44.42	20.74%	2.41	9.33	10.05
Lonnies7 (west)	Surface	156.47				

Lonnies7 (west)	Bottom	42.95	33.28%	2.39	15.64	15.54
Lonnies8 (mid)	Surface	191.06			10.39	16.62
Lonnies8 (mid)	Bottom	95.53	55.33%	0.92	16.57	9.00

Section V. Particle Capture and Biodeposit Production by Oysters

Oysters, as well as other sessile filter feeders (e.g., barnacles, sponges), increase water column clarity by filtering out particulates which are later released in biodeposition (Newell et al. 2005). The suspended particulate matter consists of photosynthesizing microscopic organisms (phytoplankton), dead particulate organic matter (detritus), and bacteria, which typically colonize the phytoplankton and detritus (Newell et al. 2002). Oysters selectively digest nitrogen-rich particles and reject the less-nutritious and inorganic particles as pseudofeces (Newell et al. 2004; Newell and Jordan 1983). Nutrients from captured foods may be assimilated into biomass (See Figure V.1) (Higgins et al. 2011). The particulates passing through the digestive system are finally deposited as feces and the rejected material deposited as pseudofeces which together are termed biodepositon.

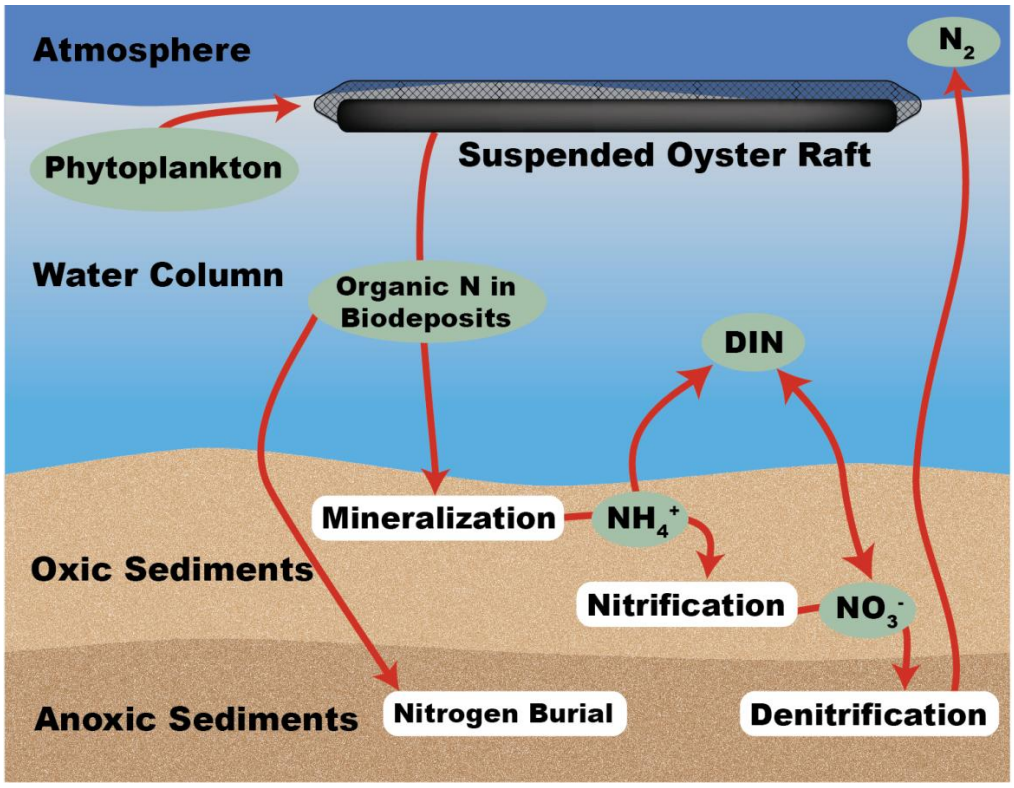


Figure V.1– Diagram of oyster's role in the marine nitrogen cycle in a shallow water estuary with oxygenated (oxic) and non-oxygenated (anoxic) sediments. White rectangles indicate microbial processes; green ovals indicate nitrogen species (Diagram adapted from Kellogg et al 2013).

Particle Capture and Biodeposition by Oysters

In situ biodeposit traps were used to determine individual oyster biodeposition rates during the 2016 and 2017 oyster growing seasons. Oysters used in the biodeposit traps were allowed to acclimate to the environment for a period of three to five days before measurement. The traps were operated for 24 hours to span a full day/night cycle and two tidal cycles. The oysters were positioned in sets of four on a rectangular PVC platform (30 cm x 20 cm; 4 mm thickness). Eight collection containers were installed beneath the platform which are capped with funnels fitted on each side of the oysters to capture and direct feces and pseudofeces into the collection containers (Figure V.2). To account for ambient particle settling into the collection containers, a control apparatus (with oyster shells) was deployed alongside the treatment group. Additionally, small mesh plastic screens were positioned over the biodeposit trap to prevent shrimp and small fish from entering and disturbing or consuming settled biodeposits. The traps were deployed once in October 2016 and on five dates during the 2017 field season. Oysters used in the biodeposit traps were second year oysters from the Lonnies Pond aquaculture oyster population.



Figure V.2. Biodeposit trap deployed in Lonnies Pond, photo by E. Karplus.

Ambient surface water temperature measurements and samples were collected upon trap deployment and removal. These surface water samples were processed for total suspended solids (TSS), particulate organic carbon and nitrogen, total chlorophyll-*a* and salinity. TSS filters were analyzed for particulate organic carbon and nitrogen using a Perkin Elmer 2400 elemental analyzer.

Biodeposit traps collect feces and pseudofeces deposited by each oyster. The collection containers were returned to the laboratory where the biodeposits were given time to settle in the pre-weighed containers, at which point the over lying water layer was siphoned away. Biodeposit samples were weighed, dried to a constant weight, and then processed for particulate organic carbon and nitrogen content. Oysters deployed in the biodeposit traps were collected to measure shell length, whole oyster weight, wet tissue / shell weight, and dry tissue / shell weight. Biodeposition rates were calculated based on the collected mass of feces and pseudofeces minus the mass of ambient particulates collected in the control traps and the deployment duration. The biodeposition rates were standardized to a 1-gram (dry tissue weight) of associated oysters based on the following allometric relationship:

$$Y_s = Y_e\,(1/W_e)^b,$$

where Y_s and Y_e are the standardized and measured biodeposition rates, respectively, W_e is the dry tissue weight of the measured oyster, and b is the allometric exponent 0.58 (Cranford et al. 2011).

By standardizing the individual biodeposition rates it was possible to use the total dry tissue biomass determined for the Lonnies Pond oyster deployment to expand the biodeposition rate to include the total oyster biomass deployed in Lonnies Pond.

The biodeposit measurements (total mass and particulate organic carbon and nitrogen collected per day) and surface water parameters (total suspended solids and particulate organic carbon and nitrogen) were used to determine the mass of particulate organic nitrogen settling from the suspended oyster bags.

Results:

Table V.1. 2017 biodeposition rates, biodeposit characteristics, and surface water column conditions associated with particle trap deployment. Deposition Rates: mean ($\pm$SE) total oyster deployment biodeposition rates and particulate organic nitrogen (PON) deposition. Biodeposit Characteristics: mean ($\pm$SE) particulate organic carbon (POC) and particulate organic nitrogen (PON) content and carbon/nitrogen mass ratio (C:N) of collected biodeposits. Surface Water Column Conditions: mean ($\pm$SE) surface water total suspended solids (TSS), particulate organic carbon (POC), particulate organic nitrogen (PON), carbon/nitrogen mass ratio (C:N), total chlorophyll-*a*, temperature, and salinity at particle trap locations.

	8/1/17	**8/17/17**	**9/14/17**	**10/5/17**	**10/30/17**
Deposition Rates					
Biodeposition (kg dry wt. day^{-1})	18.1 (2.1)	56.0 (9.8)	21.9 (3.2)	24.1 (4.6)	30.6 (1.6)
Biodeposit N deposition (kg N day^{-1})	0.7 (0.2)	2.1 (0.4)	0.8 (0.1)	0.4 (0.1)	0.5 (0.0)

Biodeposit Characteristics					
C content (%C)	21.1 (0.2)	22.8 (0.7)	21.9 (0.1)	11.8 (0.2)	9.8 (0.4)
N content (%N)	4.0 (0.1)	3.9 (< 0.1)	3.9 (0.1)	1.9 (< 0.1)	1.6 (0.3)
C:N	6.2 (< 0.1)	6.9 (< 0.1)	6.6 (< 0.1)	7.3 (< 0.1)	7.1 (0.2)
Surface Water Column Conditions					
TSS (mg dry wt./L seawater)	19.2 (4.7)	6.8 (0.9)	5.7 (0.2)	5.0 (0.5)	5.4 (0.1)
POC (uM C)	138.3 (42.2)	101.3 (9.4)	93.8 (2.1)	47.8 (1.4)	68.9 (10.5)
PON (uM N)	18.3 (5.1)	13.2 (2.1)	13.2 (1.2)	6.8 (0.2)	7.9 (0.9)
C:N	7.3 (0.3)	7.9 (0.6)	7.3 (0.8)	7.1 (0.1)	8.6 (0.4)
Total Chlorophyll-*a* (ug/L seawater)	16.7 (8.6)	15.9 (3.5)	12.9 (0.6)	7.3 (0.1)	8.9 (3.4)
Temperature (Celsius)	23.6 (0.8)	22.5 (0.8)	20.6 (0.6)	15.8 (0.3)	12.8 (0.6)
Salinity	29.5 (0.0)	29.5 (0.2)	28.2 (0.2)	29.0 (0.1)	25.7 (1.3)

Greater seston concentrations and seston organic content were observed in the surface waters during the summer biodeposit trap deployments relative to the fall trap deployments (Table V.1). Greater organic content is associated with higher oyster food quality, but oyster feeding rates appear to stabilize once food concentrations reach ca. 300 μg C/L seawater (Tenore and Dunstan 1973). Observed food concentrations were greater than 300 μg C/L seawater in 2017 with a surface water maximum of 2559 μg C/L during the 8/1/17 biodeposit trap deployment and a minimum of 538 μg C/L seawater during the 10/5/17 biodeposit trap deployment. During periods when particulate organic carbon concentrations are above 300 μg C/L in surface waters, the oysters will reject more and more captured particulate matter as pseudofeces, which is less densely "packaged" than fecal matter/pellets (Tenore and Dunstan 1973). Because the pseudofeces is less dense than fecal pellets it is more likely to be affected by turbulence and lost from the biodeposit trap. Determining *in situ* biodeposition rates means compromising between eliminating environmental factors that interrupt biodeposit collection and maintaining natural environmental conditions. For this reason, biodeposition rates are a conservative estimate of the mass of organic nitrogen transferred from the water column to the sediment through oyster filtration and deposition of feces and pseudofeces.

Table V.2. Full oyster deployment biodeposition summary for the 2017 field season. Full oyster deployment deposition rates and biodeposit carbon and nitrogen content were averaged from May 2017 to December 2017 to determine the season total dry mass of biodeposits impacting the sediments, as well as, the total dry mass of POC and PON contained within the biodeposits.

	Whole Field Season: May 2017 – December 2017
Biodeposit dry mass (kg dry wt.)	4984.8 (163.7)
Biodeposit POC (kg dry wt.)	870.6 (0.5)
Biodeposit PON (kg dry wt.)	151.2 (0.1)

In Table V.2. (above), the whole field season deposition was calculated as follows: 1) determined a dry tissue weight corrected biodeposition rate (mg dry wt. biodeposits/day) for each oyster cohort and month that the oysters were deployed, 2) multiplied the dry tissue weight corrected biodeposition rate by the number of days per month, and 3) summed the mass of biodeposits calculated for each month.

Table V.3. 2016 biodeposition rates, biodeposit characteristics, and surface water column conditions associated with particle trap deployment. Deposition Rates: mean (±SE) total oyster deployment biodeposition rates and particulate organic nitrogen (PON) deposition. Biodeposit Characteristics: mean (±SE) particulate organic carbon (POC), particulate organic nitrogen (PON), and carbon/nitrogen molar ratio (C:N) of collected biodeposits. Surface Water Column Conditions: mean (±SE) surface water total suspended solids (TSS), particulate organic carbon (POC), particulate organic nitrogen (PON), carbon/nitrogen mass ratio (C:N), total chlorophyll-*a*, temperature, and salinity at particle trap locations.

	Summer 2016*	**Fall 2016**
Deposition Rates		
Biodeposition (kg dry wt. day^{-1})	35.1 (5.7)	31.7 (6.0)
Biodeposit N deposition (kg N day^{-1})	0.6 (0.1)	0.3 (0.1)
Biodeposit characteristics		
C content (%C)	12.0 (0.3)	7.4 (0.7)
N content (%N)	1.6 (0.0)	0.9 (0.2)
C:N	7.3 (0.1)	9.8 (1.3)
Surface Water Column Conditions		
TSS (mg dry wt./L seawater)	8.9 (0.8)	7.2 (0.7)
POC (uM C)	144.6 (17.7)	52.7 (4.8)
PON (uM N)	22.9 (3.3)	6.7 (0.6)
C:N (molar ratio)	6.33 (0.12)	7.92 (0.07)
Total Chlorophyll-*a* (ug/L seawater)	23.2 (2.8)	8.0 (1.3)
Temperature (Celsius)	30.5 (0.3)	17.3 (0.7)
Salinity	24.2 (1.7)	28.7 (0.0)

* Summer 2016 data is from a 8/13/16 biodeposit trap deployment conducted in Little Pond, Falmouth, MA. Ambient water column conditions were comparable between Lonnies Pond and Little Pond in August 2016.

Discussion:

Overall, the filtration of particulates from Lonnies Pond waters and its packaging into feces and pseudofeces appears to support a large amount of biodeposition to bottom sediments. This

provides the mechanism for the observed increase in water clarity within the oyster grow-out area, the reduction in particulate concentrations in water flowing through the oyster bags, and the increases in sediment respiration associated with the oyster deployment area. While all of these features are supportive of potential enhanced nitrogen removal, none result in significant negative impacts to the associated pond water column and sediments. As seen in the water quality results the chlorophyll concentrations were elevated within the oyster deployment area, but the effects disappeared by the border of the oyster rafts. This suggests that increases in local production stimulated by the increseased biodeposition of organic material to the sediments and excretion of inorganic nitrogen were more than offset by oyster removal of plankton with the net effect of increasing the overall water quality which extended a significant distance outside of the deployment area. In addition it is notable that biodeposition rates were similar in summer and fall, even with nearly 3 fold higher chlorophyll levels in summer. This is consistent with there being more than sufficient phytoplankton in Lonnies Pond for oysters (as indicated above, ca. 300 μg C/L). However, the increased food quality in summer is seen in the much higher nitrogen levels in the biodeposits in summer compared to fall.

Section VI. Biodeposit Impact Area

Although fecal pellets fall rapidly through the water column, variables such as pellet density and current velocity can affect the dispersion of pellets before they settle to the sediment surface. During the 2016 and 2017 sediment flux measurements an Acoustic Doppler Current Profiler (ADCP, Nortek Aquapro HR) was deployed near the sediment surface facing upward at the northern edge of the oyster propagation area. Later measurements included deployments near the eastern and western edges of the deployment area. Velocity measurements were made at 10 minute intervals and conducted at the highest possible sensitivity. Velocities measured acoustically are determined by sound reflected off particles within the water column with the assumption that the particles movement is also indicative of water movement. The particles in the vicinity of the oyster rafts are comprised of a mixture of fecal pellets and phytoplankton, with the latter being numerically dominant. Therefore, measured velocities are probably biased towards under estimation since the larger sized fecal pellets would tend to settle faster and move less laterally. The underestimation would be seen in vertical velocities as well since the velocity of falling fecal pellets would be confounded by phytoplankton with a lower settling velocity. Taking these caveats into consideration, the measured velocities should be regarded as conservative.

Velocity measurements completed in 2017 were consistent and generally confirmed measurements made in 2016 with the exception that the Nortek device is more sensitive than the ADCP used in 2016 so that more accurate directionality was available in 2017 (Figure VI.1). As seen in the time series velocity plot, the high velocities were recorded during flooding tides. During other parts of the tidal cycle velocities were minimal. Over the tidal period average water column current direction roughly correlated with prevailing wind direction, North-Northwest. However, longer deployments at the start of the 2018 season at the margins of the

eastern and western borders of the array indicated that average water column current direction, which were in shallower water, were predominately oriented east to west through the oyster deployment array.

Using the previously determined mean sinking velocity of fecal pellets (8.14±5.01mm/s) and the median depth around the border of the oyster deployment area, fecal pellet settling was modeled step-wise assuming fecal pellet production was similar among all bags. (Figure VI.2). The model results largely confirm the results from 2016 concerning the extent of the impact area of surficial sediments. At 5 meters from the edge of the deployment area deposition remains at 30 % of that directly under the deployment area and declines to 10%-15% at 10 meters. With the additional data captured in 2018 the impact area would extend around the entire deployment area with the same distances and gradients.

From the above discussion of biodeposition, a deposition value of 710 mg $N/m^2/d$ was derived. Applying this calculated distribution of nitrogen derived from oyster fecal pellets to the actual footprint of the oyster deployment area, the area affected (impact area) increases from 760 m^2, actually occupied by the oyster bags, out 11.75 m from the edge to where there was no longer direct contribution of fecal pellets to the sediment surface. Including the 11.75 m extension beyond the edges of the deployment area, the total impact area was calculated to be 2735 m^2, an increase of 448 m^2over the estimated 2016 area of 2287 m^2, which was determined using less sensitive instruments (Figure VI.3). These spatial estimates for biodeposition represent direct settling to sediments, but do not include bordering areas that may be effected by particle transport along the sediment surface post-deposition. These direct deposition areas and extended areas of deposition were used to determine the enhanced particulate nitrogen loading to Lonnies Pond sediments from the deployed oyster arrays and to target areas to assess potential enhancements of sediment denitrification.

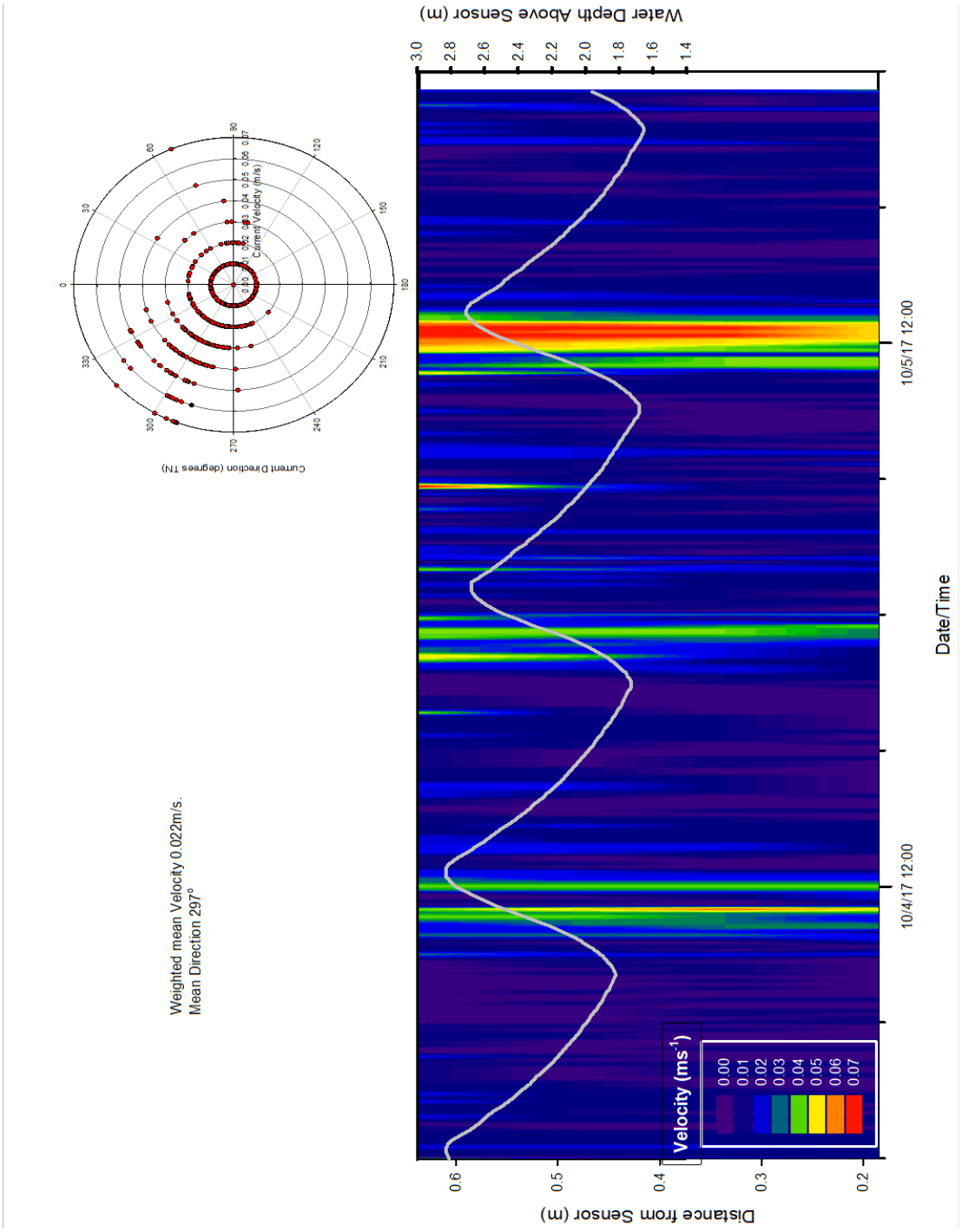


Figure VI.1. Top left: Compass rose plot of particle direction and velocity data for 23-24 August. Current direction was predominantly to the north north-west ~300 from True North . Velocities increase with distance from the center of the compass rose. Highest velocity was 0.07m/s (7cm/s). Right: Time series velocity data from the ADCP are shown at 10cm intervals above the ADCP which was moored to the bottom. Velocities at specific times and heights above the ADCP are displayed as different colors with purple indicating no water movement and red indicating the maximum observed velocity of 0.07 m/s. For reference the tidal height change in water depth is shown as a continuous white line indicating the depth of water above the ADCP.

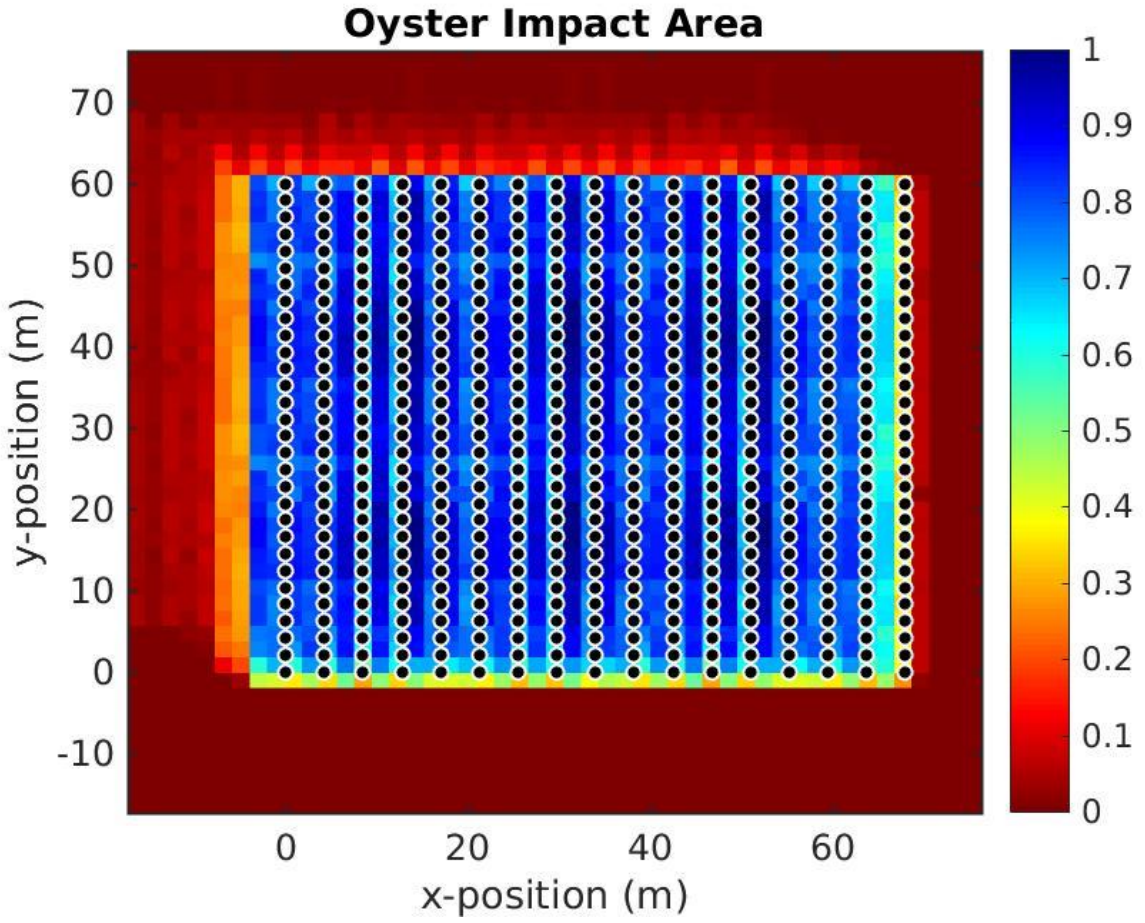


Figure VI.2. Expected deposition of fecal pellets to surficial sediments for pellets originating at the edge of the oyster array. Fecal pellet production was given as 1 and results are shown in the contours as a fraction of the pellet production. Thus, deposition areas colored dark blue received 100% of the average areal fecal pellet production and deposition; areas colored dark red received 0% of the average areal fecal pellet production and were not directly impacted by the oyster deployment. Note that the dimensions of the model grid are equal in both directions, but this has no impact on the deposition gradients at the edges of the model deployment area.

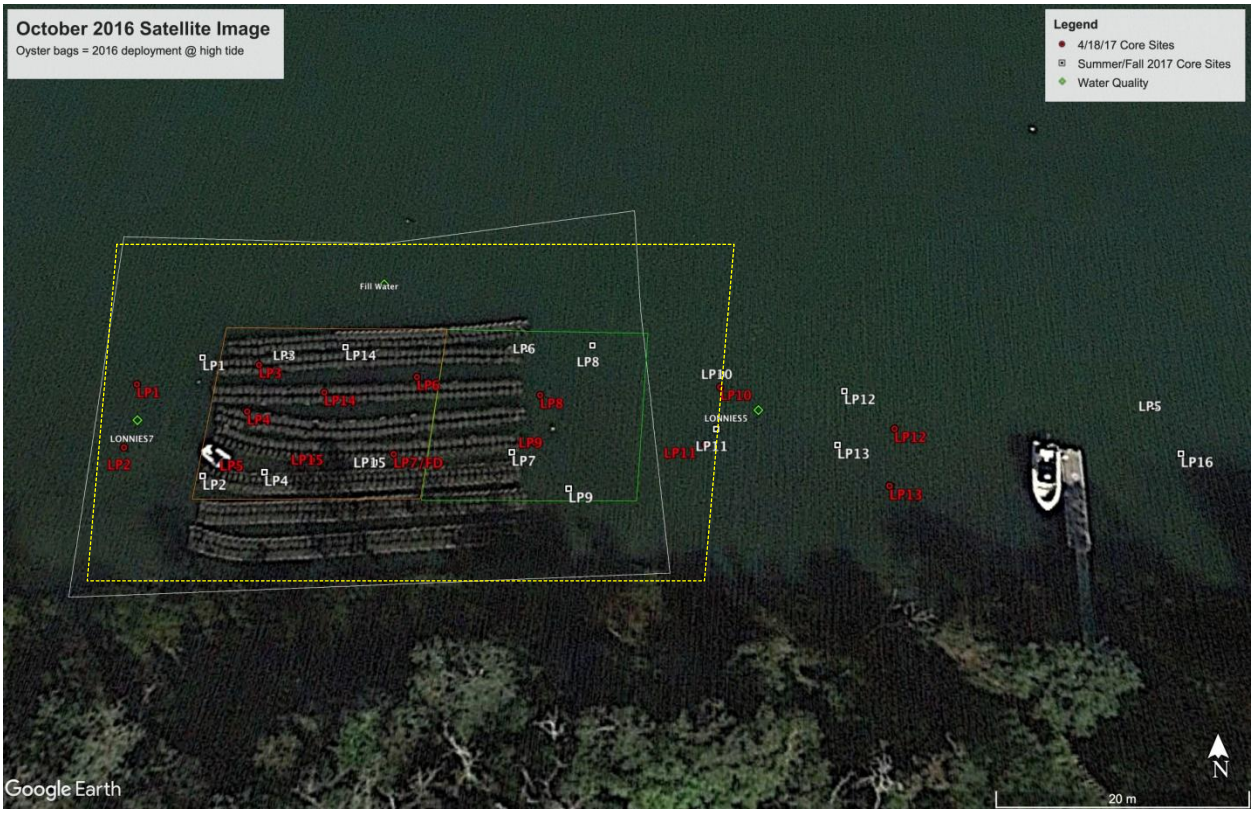


Figure VI.3. 2016 Aerial photograph showing the location of the oyster deployment area overlain with 2017 oyster deployment area (red and green polygons). Mooring and water column sampling locations (green diamonds), April (pre-oyster deployment red diamonds) and Summer/Fall (white square) flux core locations. Total area impacted by the oyster deployment as determined by fecal pellet distribution in 2016 is shown as the white bounded area while the 2017 total impact area is bounded by the yellow dashed area.).

Section VII. 2016 Nitrogen Cycling and Oyster Culture: Regeneration and Denitrification

In estuarine systems such as Lonnies Pond, nitrogen is transformed and recycled within the sediments and water column. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems under MEP investigation, recycled nitrogen can account for about half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of the effects of nitrogen loadings, the overall nitrogen balance of the system and how oyster propagation may affect nitrogen dynamics at the sediment water column interface.

The organic rich nature and relatively shallow waters of coastal systems like the Lonnies Pond

sub-basin of the Pleasant Bay Estuary and others on Cape Cod result in sediments playing a significant role in system biogeochemical cycles. Organic matter deposition to sediments, hence benthic respiration, tends to decrease with increasing depth of overlying waters due to interception by water column heterotrophic processes resulting in lower deposition of labile (decomposable) organic matter. The result is that embayment respiration rates are typically many-fold higher than in the adjacent deeper offshore waters. With potential stratification of embayment waters, sediment metabolism plays a major role in bottom water oxygen declines (an ecosystem structuring parameter). This applies particularly to Lonnies Pond which periodically goes hypoxic (i.e. low D.O) during the summer months. It should be noted that while water depth is important in altering the deposition of labile organic matter to sediments, filter feeders and especially large filter feeders like oysters can overwhelm the "depth effect" due to the large amount and size of packaged feces that they emit. In these situations, oysters are projected to increase deposition which subsequently increases sediment respiration rates.

Measurements of Benthic Nutrient Regeneration, Denitrification and Sediment Oxygen Uptake:

In order to determine the contribution of sediment regeneration to nutrient levels within the oyster aquaculture portion of the Lonnies Pond system and the effect the oysters may have on nitrogen recycling rates and oxygen levels, sediment samples were collected and incubated under *in situ* conditions on 5 dates, 4/18, 6/27, 8/11, 9/19 and 10/3. The April 18, 2017 sampling occurred prior to the oyster deployment which began on April 5 and concluded on June 22. Thus the June 27 sampling represents the first sediment sampling of 2017 with a full complement of oysters and their associated biodeposition. The August 11 and September 19, 2017 sampling dates were during the period of maximum oyster activity in the summer interval (July- September) and the October 3, 2017 sampling was during the period of maximum oyster biomass (October-December). The April 18, 2017 sampling did not include deposition from 2017, but did include the residual effect from the 2016 deployment. The 2016 oysters were held over winter and replaced in 2017, but since their late 2016 season depositions were not fully degraded in the sediments, due to the cold temperatures (December – March), they were available to stimulate nitrogen cycling in the early spring 2017. Therefore the early spring denitrification enhancement needed to be measured to determine: 1) its magnitude and 2) if there were sufficient carry over to require addition to the 2016 deployment impacts and rates.

Time series measurements of total dissolved nitrogen, nitrate+nitrite, ammonium and ortho-phosphate were made on each incubated core sample. The rate of oxygen uptake was also determined in order to: (1) evaluate sensitivity to oxygen depletion of the oyster aquaculture area of Lonnies Pond, (2) rank sediments as to organic matter deposition rates (not possible using organic content) and (3) develop a nitrogen model for how the oysters may be affecting the nitrogen cycle in the sediments associated with oysters. Assays were performed on 16 cores from sites distributed throughout the oyster aquaculture area on each date. Cores were collected directly under the oyster aquaculture rafts and at distances east and west of the aquaculture area.

The results allowed determination of the spatial pattern and rate of nutrient exchanges from the sediments to the water column and how these rates may be affected by the cultivation of oysters in Lonnies Pond. From our experience, sediment regeneration during the summer is a large and important source of nutrients supporting both phytoplankton and macroalgal blooms in embayments throughout S.E. Massachusetts and the degree to which intensive oyster aquaculture can change those rates through enhancement of denitrification needs to be determined to support innovative management of these systems.

N_2 excess was measured using membrane-inlet mass spectrometry (MIMS). N_2 produced by denitrification is precisely detected by analysis of its ratio with the inert gas Argon. Water samples were collected and stored to prevent gas exchange or bubble formation. In the laboratory, sample water was pumped at ml/min rates through a gas permeable membrane in order to extract gas into the mass spectrometer inlet. The inlet was fitted with cryogenic traps to remove water vapor and CO_2 gas. Sample gas was analyzed by the mass spectrometer for masses 28 and 40 for determining the N_2 to Ar ratio. Calibration was made by comparison with a reference gas of known composition. A quadrupole mass spectrometer (e.g. Pfeiffer 422) was used for its sensitivity and speed of analysis and the analysis of the samples conforms to the same methods as was utilized during a comprehensive survey undertaken by the CSP in 2008. Water column respiration measurements were collected east and west of the oyster area at the Lonnies 5 and Lonnies 7 water quality monitoring sites.

Results:

Benthic results are summarized in Table VII.1 below. April cores were collected approximately six weeks prior to the deployment of the oyster rafts. The second set of cores was collected in late June just after the oyster rafts were fully deployed. Both the August and September cores were collected to coincide with peak growing season and the time during which the most stressed water quality conditions were expected. Finally, October cores were collected near the end of the growing season when the full effects of oyster culture could be determined. For comparison, the 2016 values are shown appended to the 2017 data in Table VII.1. To more easily view the data through the season the averages of the cores impacted by the oysters are shown in Table VII.2. The table also includes corresponding values for oyster impact area in 2016, during August 2016, when water temperatures were greatest. For comparison the 2016 data is also presented with values adjusted conservatively by a factor of 1.9 to correct for temperature differences to allow cross comparison throughout the season and for comparison to peak 2016 values. Higher temperatures increase bacterial respiration while lower temperatures decrease respiration. The actual factor for Lonnies Pond, found empirically varies from ~2.3-1.6.

Small scale sediment heterogeneity was common in the oyster deployment area in 2016. Sediment heterogeneity was observed by divers collecting the cores in 2017, however in 2017 significantly smaller differences were observed in the sediment biogeochemistry evaluated in

duplicate cores (LP7/7Dup). Nonetheless specific patterns were immediately obvious. Average sediment oxygen uptake rates were correlated positively with changing temperatures as was NH_4 flux. Nitrate uptake, however, was predominant only during April and October, which were the coolest months and had the lowest sediment oxygen uptake. During all other sampling dates the average nitrate flux was out of the sediment. This suggests that increased ammonium production did result in increased nitrate production but that the nitrate was not fully denitrified, possibly due to a very thin surface oxidized layer, which allowed a larger proportion of the nitrate to escape to the overlying waters, thus the efficiency of nitrate uptake into denitrification may be affected by redox status of the sediment during the most stressful parts of the summer (Figure VII.1)

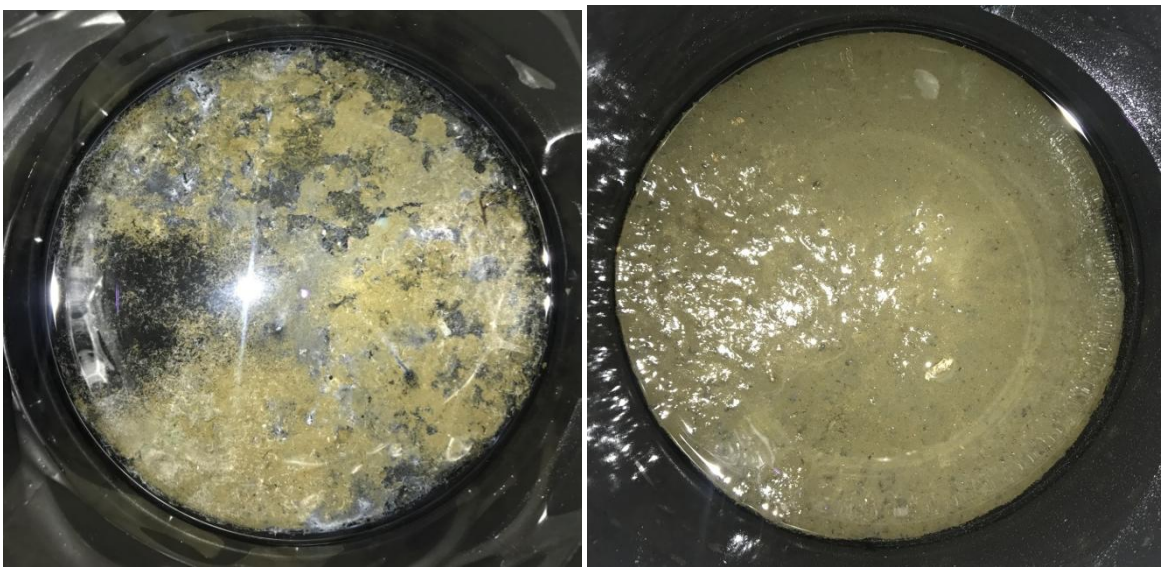


Figure VII.1 Images of sediment core surfaces from September 2017. Left: Core 3 within treatment area showed dark areas where reduced sediment was exposed to the water surface, thus preventing efficiently coupled nitrification and denitrification. Right: Core 13 outside of the treatment area showed a uniform oxidized surface.

Most importantly, the fraction of regenerated nitrogen used in denitrification was greatest in the shoulder months of summer, 74% and 29%, for April and October, respectively. While oysters had not yet been deployed in April, the residual organic matter from the previous Fall continued to be regenerated as water temperatures began warming accounting for the high rates observed. Low rates in June may represent a temporary deficit in sediment carbon between exhaustion of the previous year deposition, prior to a buildup of the current year's deposition.

Twice as many stations were sampled for benthic processes in 2017 than in 2016 to better quantify both background rates as well as treatment rates of sediment flux including denitrification. A conservative estimate of the total nitrogen removed by oyster enhanced denitrification can be made using our measurements of background denitrification with the

rates in the oyster deployment area. The background rates may be slightly high as spreading of the biodeposits by water currents was the only process examined. The 2017 background rates and rates measured under the oyster treatment are shown in Table VII.3 as well as the 2016 rates for comparison. By summing the product of the measured rates of denitrification by the intervals between the denitrification measurements and extending measurements forwards to Nov 15 when temperatures began to become too cold for significant oyster activity in both years it is possible to obtain an annual mass of nitrogen that was denitrified and compare that value to the total mass of nitrogen removed from the system by incorporation into oyster tissue. The annual enhanced denitrification resulted in a net loss of 9.7 kg N in 2017 compared to 9.54 kg N in 2016 (Table VII.4). Although the 2017 value was slightly larger than seen in 2016 both the impact area and the deployment duration were greater in 2017 than in 2016. The differences in the number of oysters, the size of the oysters, and the quantity of food (phytoplankton) available are all potential factors that can affect these results. The effect of all these factors is integrated environmentally and reflected in two primary variables: the incorporation of nitrogen into oyster tissue and the enhanced biodeposition of organic matter within the impact area. Examining these two variables (Table VII.4) we found that while enhanced denitrification was similar, the amount of nitrogen removal through assimilation in oyster tissue declined slightly from 2016 to 2017. However, denitrification, as a percent of nitrogen removal increased from 24.7% to nearly 36%. This result suggests that after a year of oyster culture the sediments were more enriched in organic matter and thus the ability to denitrify was enhanced. This result in 2017 can be partly attributed to carry over of deposition from the previous season oyster culture as seen in the high rates of denitrification in April 2017.

Table VII.1. Summary of benthic flux rates from core incubations conducted in August and October. The bottom panel shows October rates adjusted using a Q10 factor of 1.9 for direct comparison to August cores which were incubated at a temperature 10C warmer.

	4/18/2017, Temperature 12.7 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	33.05	0.03	-0.06	-0.03	2.44	2.53	97%
LP2	44.43	0.52	0.08	0.60	1.03	1.63	63%
LP3	66.73	1.23	-0.08	1.15	1.41	2.73	52%
LP4	113.37	1.38	-0.18	1.20	6.10	7.67	80%
LP5	62.83	1.75	-0.03	1.72	2.09	3.87	54%
LP6	71.46	0.20	-0.16	0.04	0.75	1.11	68%
LP7	ND	0.06	-0.03	0.03	ND	ND	ND
LP7 FD	71.13	-0.05	-0.22	-0.27	0.72	0.99	73%
LP8	37.68	0.00	-0.12	-0.12	0.89	1.01	88%
LP9	61.09	0.61	0.20	0.81	1.72	2.53	68%
LP10	22.01	-0.31	-0.09	-0.40	1.20	1.59	75%
LP11	29.66	-0.09	-0.07	-0.16	1.10	1.26	87%
LP12	36.84	-0.14	-0.11	-0.24	1.15	1.39	83%
LP13	44.92	-0.18	-0.10	-0.27	0.65	0.92	70%
LP14	55.52	-0.16	-0.09	-0.26	2.40	2.66	90%
LP15	42.90	-0.31	-0.08	-0.39	0.23	0.62	37%

	6/27/2017, Temperature 22.1 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	118.47	4.58	0.03	4.61	0.85	5.46	16%
LP2	105.29	5.02	0.14	5.16	1.93	7.09	27%
LP3	130.52	14.17	0.01	14.18	0.23	14.41	2%
LP4	134.04	12.33	0.04	12.37	1.08	13.45	8%
LP5	51.73	6.59	0.15	6.74	-2.53	9.27	-27%
LP6	239.20	5.43	0.44	5.87	1.12	6.99	16%
LP7	64.53	3.45	0.07	3.53	ND	ND	ND
LP8	60.98	3.90	0.25	4.15	-4.67	8.82	-53%
LP9	81.37	1.08	0.04	1.12	-4.05	5.17	-78%
LP10	68.06	0.26	0.05	0.30	-3.77	4.08	-93%
LP11	69.29	2.73	0.06	2.79	-2.74	5.53	-50%
LP12	169.23	7.84	0.11	7.95	-2.62	10.57	-25%
LP13	69.87	5.66	0.21	5.87	-2.71	8.59	-32%
LP14	138.06	11.18	0.40	11.58	1.08	12.66	9%
LP15	152.34	10.98	0.03	11.01	1.00	12.01	8%
LP16	101.77	6.17	0.40	6.56	0.69	7.26	10%

	8/1/2017, Temperature 23.6 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	58.14	8.69	-0.04	8.65	2.16	10.89	20%
LP2	72.81	6.41	-0.03	6.37	0.83	7.27	11%
LP3	176.21	26.93	-0.10	26.83	2.91	29.94	10%
LP4	124.63	11.47	0.15	11.63	2.58	14.20	18%
LP5	63.99	4.88	0.71	5.59	2.78	8.37	33%
LP6	101.91	7.76	2.70	10.47	4.75	15.21	31%
LP7	60.31	2.67	-0.04	2.63	ND	ND	ND
LP8	64.18	3.96	0.17	4.13	0.44	4.58	10%
LP9	112.24	7.38	0.44	7.83	1.06	8.89	12%
LP10	39.20	4.52	0.07	4.59	1.06	5.64	19%
LP11	222.07	9.72	0.26	9.98	3.40	13.38	25%
LP12	48.26	5.96	0.14	6.10	2.37	8.47	28%
LP13	92.45	0.98	0.06	1.04	3.04	4.09	74%
LP14	120.25	11.99	-0.08	11.90	0.58	12.65	5%
LP15	121.55	11.70	-0.10	11.60	2.33	14.13	17%
LP16	84.49	0.92	-0.05	0.88	2.55	3.52	72%

	9/19/2017 Dark, Temperature 23.5 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	83.42	6.89	0.07	6.97	-0.32	7.28	-4%
LP2	232.99	17.03	0.03	17.05	2.32	19.37	12%
LP3	116.82	4.91	0.05	4.96	0.37	5.33	7%
LP4	123.30	11.67	0.09	11.76	0.20	11.96	2%
LP5	53.60	5.78	0.16	5.94	0.30	6.24	5%
LP6	74.33	4.86	0.05	4.91	0.27	5.18	5%
LP7	61.67	1.81	0.05	1.86	ND	ND	ND
LP8	60.67	9.53	0.65	10.18	0.84	11.03	8%
LP9	49.81	2.52	0.13	2.65	-0.30	2.95	-10%
LP10	67.00	6.00	0.12	6.13	0.08	6.21	1%
LP11	79.18	4.76	0.31	5.06	0.39	5.45	7%
LP12	69.65	4.39	0.48	4.87	0.16	5.03	3%
LP13	82.69	5.31	0.12	5.43	4.21	9.64	44%
LP14	92.17	5.28	0.04	5.31	0.32	5.63	6%
LP15	59.95	3.55	0.06	3.61	-0.88	4.50	-20%
LP16	57.99	3.84	0.40	4.24	0.11	4.35	3%

	9/19/2017 Light, Temperature 23.5 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	78.09	0.22	-0.14	0.08	1.76	2.12	83%
LP2	154.22	7.65	-0.06	7.58	8.18	15.90	51%
LP3	109.51	15.71	-0.06	15.65	18.89	34.66	55%
LP4	102.15	9.79	0.02	9.81	12.22	22.03	55%
LP5	42.16	4.50	-0.06	4.44	5.17	9.73	53%
LP6	68.07	5.71	-0.13	5.58	5.96	11.80	51%
LP7	62.32	2.45	-0.04	2.41	ND	ND	ND
LP8	69.14	13.04	0.44	13.48	15.68	29.16	54%
LP9	62.60	0.64	-0.12	0.52	2.84	3.61	79%
LP10	78.93	4.99	0.02	5.01	5.49	10.50	52%
LP11	71.75	3.32	0.06	3.38	4.11	7.49	55%
LP12	49.93	5.33	0.09	5.42	5.97	11.38	52%
LP13	81.32	2.27	-0.11	2.16	3.25	5.63	58%
LP14	101.79	10.57	-0.21	10.36	13.86	24.65	56%
LP15	82.53	5.17	-0.07	5.11	7.06	12.30	57%
LP16	45.86	2.35	0.19	2.54	2.77	5.31	52%

	10/3/2017, Temperature 17 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	73.18	3.92	-0.12	3.79	2.02	6.07	33%
LP2	52.99	1.80	-0.27	1.53	2.95	5.01	59%
LP3	117.51	6.13	-0.37	5.75	1.71	8.21	21%
LP4	21.49	0.99	0.12	1.11	0.56	1.67	33%
LP5	39.66	0.52	-0.15	0.38	1.06	1.73	61%
LP6	42.03	2.97	-0.12	2.85	0.57	3.66	16%
LP7	36.52	3.57	0.05	3.62	ND	ND	ND
LP8	27.04	3.20	0.00	3.20	0.38	3.58	11%
LP9	37.00	0.59	-0.04	0.54	0.83	1.45	57%
LP10	19.21	0.89	0.00	0.89	0.30	1.20	25%
LP11	53.73	0.90	-0.12	0.79	1.02	2.04	50%
LP12	23.81	0.38	-0.03	0.35	0.20	0.62	33%
LP13	63.86	0.51	-0.15	0.35	1.46	2.12	69%
LP14	101.31	6.63	-0.29	6.34	2.55	9.47	27%
LP15	17.86	4.38	-0.17	4.21	0.86	5.41	16%
LP16	21.82	0.45	-0.07	0.39	0.85	1.37	62%

August 16, 2016; 28 C							
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	% Total Cycled N
LP1	115.3	1.9	-0.03	1.9	5.5	7.4	74%
LP2	139.4	14.0	0.31	14.3	3.8	18.1	21%
LP2 DUP	379.3	36.4	0.18	36.5	1.8	38.3	5%
LP3	68.4	9.5	0.01	9.5	1.3	10.8	12%
LP4	97.9	14.1	0.05	14.2	1.4	15.6	9%
LP4 DUP	150.7	18.8	0.56	19.3	4.0	23.3	17%
LP5	108.7	7.2	0.03	7.2	1.4	8.6	16%
LP6	73.8	7.1	0.08	7.2	1.0	8.2	12%
LP8	55.4	4.6	0.21	4.8	1.2	6.0	20%

October 5, 2016; 18 C							
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	% Total Cycled N
LP1	70.5	0.1	-0.38	-0.3	8.7	9.0	97%
LP2	17.1	5.9	-0.56	5.3	2.3	7.6	30%
LP2 DUP	72.3	0.3	-0.13	0.2	2.7	2.9	94%
LP3	101.8	7.1	0.22	7.3	3.9	11.1	35%
LP4	128.2	2.5	-0.16	2.4	0.7	3.0	23%
LP5	83.3	3.5	0.86	4.4	0.1	4.5	3%
LP6	59.0	-2.5	-0.31	-2.8	4.8	7.6	63%
LP7	31.9	1.3	0.05	1.4	1.5	2.8	52%
LP7 DUP	25.7	-1.1	-0.23	-1.3	2.0	3.3	60%
LP8	45.3	-2.1	-0.54	-2.7	5.1	7.8	66%

October 5, 2016; Adjusted to 28C using Q10=1.9						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)
LP1	134.0	0.1	-0.7	-0.6	16.6	17.1
LP2	32.6	11.2	-1.1	10.2	4.3	14.4
LP2 DUP	137.3	0.6	-0.3	0.3	5.1	5.4
LP3	193.4	13.4	0.4	13.8	7.3	21.1
LP4	243.7	4.8	-0.3	4.5	1.3	5.8
LP5	158.3	6.7	1.6	8.3	0.2	8.6
LP6	112.2	-4.7	-0.6	-5.3	9.0	14.4
LP7	60.6	2.5	0.1	2.6	2.8	5.4
LP7 DUP	48.9	-2.0	-0.4	-2.5	3.7	6.2
LP8	86.0	-4.0	-1.0	-5.0	9.7	14.8

Table VII.2. Summary of benthic flux rates from core incubations conducted in 2017. The bottom panel shows 2017 rates adjusted using a Q10 factor of 1.9 only to allow direct comparison to August 2016 cores which were incubated at a temperature 28C.

2017 Mean Treatment Area Sediment Flux Rates							
Date	4/18/17	6/27/17	8/1/17	9/19/17	9/19/17*	10/3/17	8/16/16
Temperature	12.7 C	22.1 C	23.6 C	23.5 C	23.5 C	17 C	28 C
Rate (mMol/m^2/d)							
SOD	62.42	93.4	82.3	92.4	82.7	46.7	100.6
NH4	0.57	6.4	6.7	7.1	6.5	2.5	9.0
NO3	-0.06	0.1	0.2	0.1	0.0	-0.1	0.1
DIN	0.51	6.5	9.2	7.2	6.5	2.4	9.0
N2-N	1.91	1.0	1.8	0.4	NA	1.2	2.4
Total N Cycled	2.67	7.5	12.0	8.4	NA	3.6	11.4
Denitrified % Total N	71%	14%	15%	5%	NA	32%	21%
*Light Treatment							

2017 Mean Treatment Area Sediment Flux Rates Q_{10}=1.9 Reference temperature 28 C							
Date	4/18/17	6/27/17	8/1/17	9/19/17	9/19/17*	10/3/17	8/16/16
Temperature	12.7 C	22.1 C	23.6 C	23.5 C	23.5 C	17 C	28 C
Rate (mMol/m^2/d)							
SOD	166.7	136.3	109.1	123.3	114.0	94.5	100.6
NH4	1.5	9.3	8.8	9.5	8.9	5.0	9.0
NO3	-0.2	0.1	0.2	0.2	0.0	-0.2	0.1
DIN	1.4	9.5	12.2	9.7	8.9	4.8	9.0
N2-N	5.1	1.5	2.4	0.6	NA	2.3	2.4
Total N Cycled	7.1	10.9	15.9	11.2	NA	7.3	11.4
Denitrified % Total N	71%	14%	15%	5%	NA	32%	21%
*Light Treatment							

Table VII.3 Mean denitrification rates for cores collected in the biodeposit impact area associated with the oyster arrays (Treated) and outside the impact area (Background). The difference in these two values should represent the contribution made by the ongoing oyster culture (Oyster Effect).

	2017 Mean Denitrification Rates (mMoles/m^2/d)				
	Treated		Background		Oyster
Date	Mean	Std. Dev.	Mean	Std. Dev.	Effect
4/18/2017	2.9	1.8	0.9	0.4	1.9
6/27/2017	1	0.5	0.3	0.4	0.7
8/1/2017	2.4	1.3	0.8	0.4	1.6
9/19/2017	0.7	0.9	0.2	0.1	0.5
10/3/2017	1.5	0.9	0.8	0.5	0.8

	2016 Mean Denitrification Rates (mMoles/m2/d)				
	Treated		Background		Oyster
Date	Mean	Std. Dev.	Mean	Std. Dev.	Effect
8/16/2016	2.1	0.6	1	0.4	1.1
10/5/2016	4.1	2.5	1.2	1	2.9
4/18/2017	2.9	1.8	0.9	0.4	1.9

Table VII.4 Annual Nitrogen Removal Budget for the oyster impact area showing including contributions from enhanced denitrification and oyster harvest.

Year	2016	2017
Deployment Duration (days)	146	195
Enhanced Annual DeN2 ($mmol/m^2$ N)	298.0	253.3
Enhanced Annual DeN2 (gm/m^2 N)	4.17	3.55
Impact area (m^2)	2287	2735
Total Annual Enhanced DeN2 (gm N)	9541	9699
Total Annual Enhanced DeN2 (kg N)	9.54	9.70
Net Annual N removed by oysters (kg N)	39.1	27.2
Enhanced DeN2 as percent of N removed by oysters	24.4%	35.7%

Recommendations:

It is clear that denitrification adds significantly to the nitrogen removed by oyster harvest. But the previously reported 2016 data allowed only a very conservative estimate due to the lack of data from the following spring. At that time, it was recommended that better estimates can be supported if:

(1) additional time points were added to the denitrification time-series, particularly early and late in the season and in the following spring and early summer. The biodeposits take time to accumulate and will persist for months to 1+ years. Therefore, the period of enhanced denitrification is almost certainly longer than a single season that the oysters are in place. This was implemented in 2017 with a multi-year deployment with measured denitrification rates as accumulated biodeposits are remineralized and some denitrified. Also, more sampling of background denitrification rates were undertaken now that the footprint of biodeposition is more accurately mapped. In the 2016 surveys, area affected by biodeposits was only generally assessed (compared to 2017). Based upon these improvements the total nitrogen removed for 2016 and 2017 has been determined below (Section IX). All future denitrification surveys should include additional background sites, some farther away than in 2016.

Section VIII. Stream flow and Nutrient Load Measurement Method: Stream Discharge from Pilgrim Lake to Lonnies Pond (2016 - 2017)

Predicting changes in coastal embayment nitrogen related water quality from nutrient load reduction strategies, enhanced flushing with low nutrient water or oyster propagation is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land (watershed). Transport of nutrients (specifically nitrogen) to Lonnies Pond from the watershed is effected namely via direct groundwater discharge or surface water inflow (and to a lesser extent direct atmospheric depositions. Rates of nitrogen loading to Lonnies Pond via groundwater were based upon the delineated watersheds and land-use coverages developed by the Massachusetts Estuaries Project (MEP). Additionally, rates of surface water inflow and associated nitrogen load to Lonnies Pond were determined using standard hydrologic techniques employed both for this study as well as the MEP nutrient threshold assessment of Pleasant Bay, which also included Lonnies Pond.

Surface water flow and N load in each study was determined at the exact same gauging location situated at the base of the herring ladder connecting Pilgrim Lake to Lonnies Pond (Figure 1a, 1b). The only difference between the stream gauging effort in 2016-2017 vs. 2002-2003 when the MEP assessment was completed is that the MEP extended the surface water N loading analysis to quantify percent nitrogen attenuation. By example, if all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters (0% attenuation). This condition exists in watersheds where nitrogen transport from source to estuarine waters is uniquely through groundwater flow in sandy outwash aquifers. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its way to the adjoining embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished (attenuated) by natural biological processes that represent removal (not just temporary storage). For the current (2016-2017) investigation of the oyster filtering effect in Lonnies Pond, the measured surface water load is the attenuated load.

Given the importance of quantifying the balance of nitrogen into and out of Lonnies Pond to determine the effect of the oyster deployment, directly measured flow and load that integrates all contributors to upper watershed attenuation was undertaken by CSP scientists in a similar manner as was undertaken under the MEP (thereby allowing for direct comparison of data sets).

Surface water flow paired with weekly to bi-weekly sampling for nitrogen concentration of the discharge from Pilgrim Lake were combined to yield a nutrient load associated with the surface water flow into Lonnies Pond that integrated all of the processes presently attenuating nitrogen in the sub-watersheds up-gradient from the gauging sites, which are the watershed to Pilgrim

Lake and a small stream-only watershed between the Lake and Lonnie's Pond. Flow, concentration and nitrogen load were determined at the stream gauging site for twelve (12) months comprising a complete hydrologic year (low flow to low flow) from October 1, 2016 to September 30, 2017. During the study period, periodic velocity profiles were completed at the stream gauge location to compare to calculated flows determined by passing the measured stage data from the gauge through the updated stage - discharge relation (rating curve) that was originally developed by the MEP. The updated rating curve reflects additional flow measurements made in 2016 and 2017. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream flow (Q).

Determination of stream flow was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma (A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Under the MEP analysis for Pleasant Bay, periodic measurements of flows over a complete hydrologic year allowed for the development of a stage-discharge relationship (rating curve) that was used to obtain daily flow volumes from the detailed record of stage measured by the continuously recording stream gauge. In order to measure stage for the present Lonnies Pond oyster study, a stream gauge was redeployed in 2016 and was maintained through 2017 in order to determine the annual flow and nutrient load to Lonnies Pond during the study period. Water level data obtained every 10-minutes from the herring creek up-gradient of the culvert passing under Herring Brook Road was averaged to obtain hourly stages. These hourly stages values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain monthly flow. In the case of tidal influence on stream stage (as is the case with the herring creek), the diurnal low tide stage value was extracted on a day by day basis in order to obtain the stage value indicative of strictly freshwater flow. The lowest low tide stage

value for a given day was then entered into the updated MEP stage – discharge relation in order to compute daily flow for the Lonnies Pond oyster study undertaken in the 2016-2017 period.

The flow record generated by passing measured stage data through the rating curve for the surface water flow into Lonnies Pond via the herring ladder was merged with the nutrient concentration data obtained through the water quality sampling program to determine nitrogen loading rates to the head of Lonnies Pond. Nitrogen discharge from the stream was calculated using the paired daily discharge and daily nitrogen concentration data to determine the mass flux of nitrogen through a gauging site. For the gauging location in this study, weekly water samples were collected (at low tide to account for tidal influence) in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient load to Lonnies Pond as appropriate. The "measured load" was representative of attenuated nitrogen entering Lonnies Pond directly from surfacewater as opposed to groundwater (recharge over area delineated by watershed).

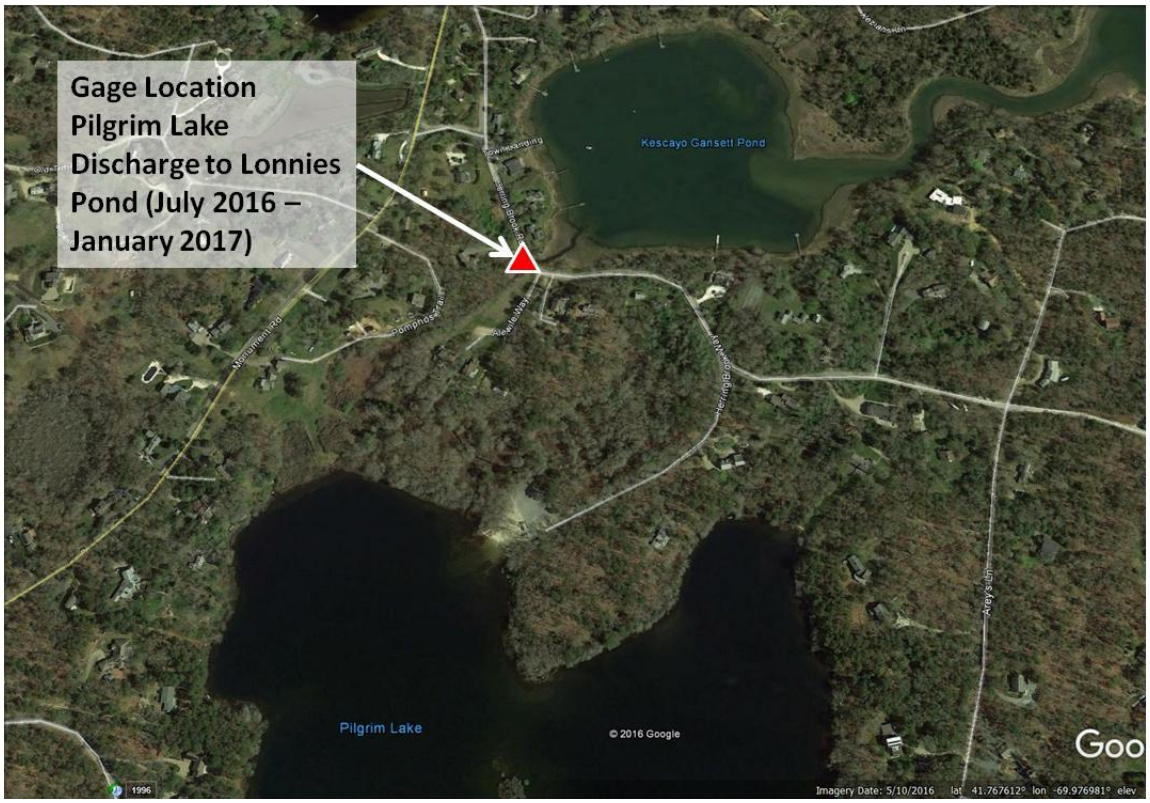


Figure VIII.1a. Location of stream gauge (red triangle) deployed at the base of the herring ladder between Pilgrim Lake and Lonnies Pond. An updated MEP rating curve initially developed in 2003 but refined with 2016-2017 flow measurements was utilized to determine daily flows and nutrient load to Lonnies Pond for the oyster study.

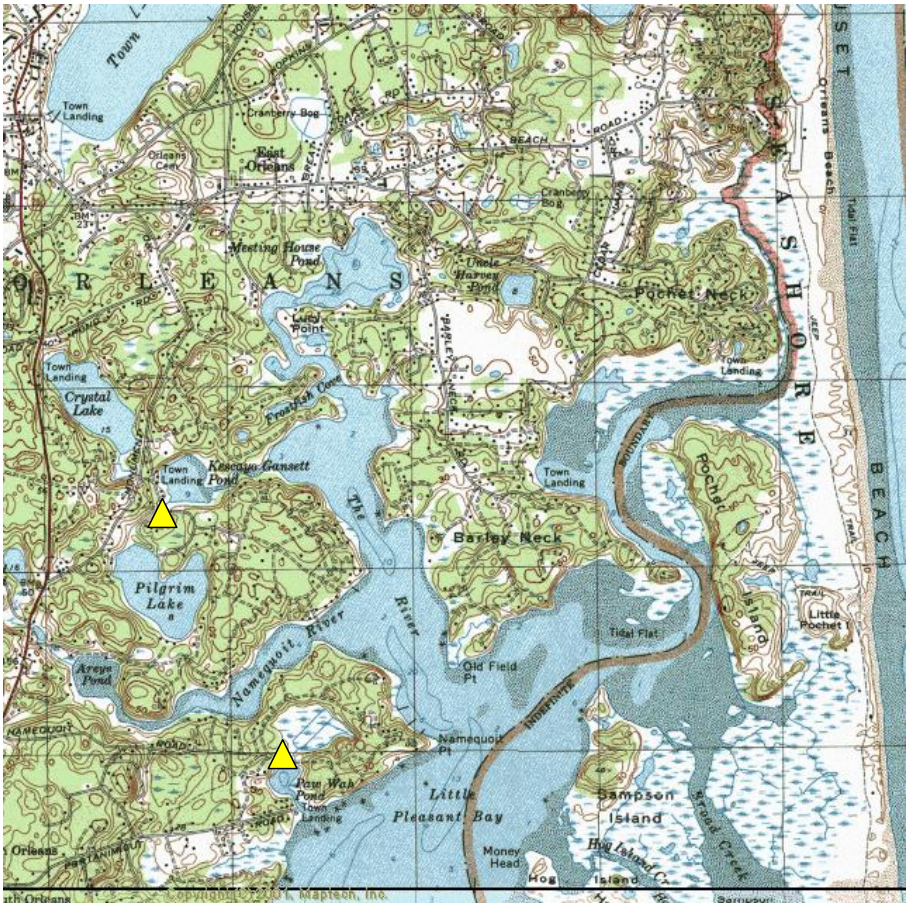


Figure VIII.1b. Location of MEP Stream gauge (yellow triangle) in the upper portions of the Pleasant Bay system embayment system. Rating curve, stage, flow, nutrient load and percent attenuation was determined for the 2002-2003 hydrologic year

Pilgrim Lake discharges freshwater and nitrogen load to the brackish waters of Lonnies Pond via a herring ladder that flows into a 1-meter diameter concrete culvert passing under Herring Brook Road. In order to quantify the flow of freshwater and the associated nitrogen load into Lonnies Pond, a stream gage was deployed immediately up-gradient of the culvert in the concrete box the herring ladder flows into on its way to Lonnies Pond.

The stream gage was deployed in late July 2016 and measured the stage of water in the box at a 10 minute frequency until October 31, 2017. As described above, the 10 minute stage data was averaged to obtain hourly stage which was then filtered to extract the lowest tide stage in a given day which would be representative of the freshwater portion of the flow (Figure 2a, b, c). The daily low tide stage was passed through the updated stage-discharge relationship originally developed by the MEP in 2002-2003 but modified to include flow measurements that were collected during the 2016-2017 Lonnies Pond study. Stage in 2016-2017 was measured at the same location as during the MEP stream analysis completed in 2002-2003. The 2016-2017

stage record was passed through the modified stage-discharge relation in order to calculate a volumetric flow in cubic meters per second (m^3/s) that was then converted to cubic meters per day (m^3/d) as depicted in Figure 3.

Total surface water inflow to Lonnies Pond (Table VIII.1) from Pilgrim Lake for the period October 1, 2016 to September 30, 2017 (a complete hydrologic year, low flow to low flow) and based on measured stage for that period and the modified MEP developed rating curve was 187,507 m^3 (average daily flow = 514 m^3). By comparison, total surface water inflow to Lonnies Pond from Pilgrim Lake during the MEP study period (October 2002-September 2003) was 355,279 m^3 (average daily flow = 973 m^3). The lower observed flows in 2016-2017 is primarily attributable to lower groundwater levels during the measurement period. During the 2002/2003 water year, January through May groundwater levels at the local long-term water level monitoring well were generally in the 75th and 90th percentile of all data and near average during the rest of the year, while groundwater levels were generally closer to the long-term averages during the 2016/2017 water year (Eichner, et al., 2018). As might be expected since precipitation and groundwater levels are related, lower precipitation rates were also noted during 2016/2017, but precipitation variations explained only 8% of the variation in streamflows, while groundwater variations explained 36% of flow variations.

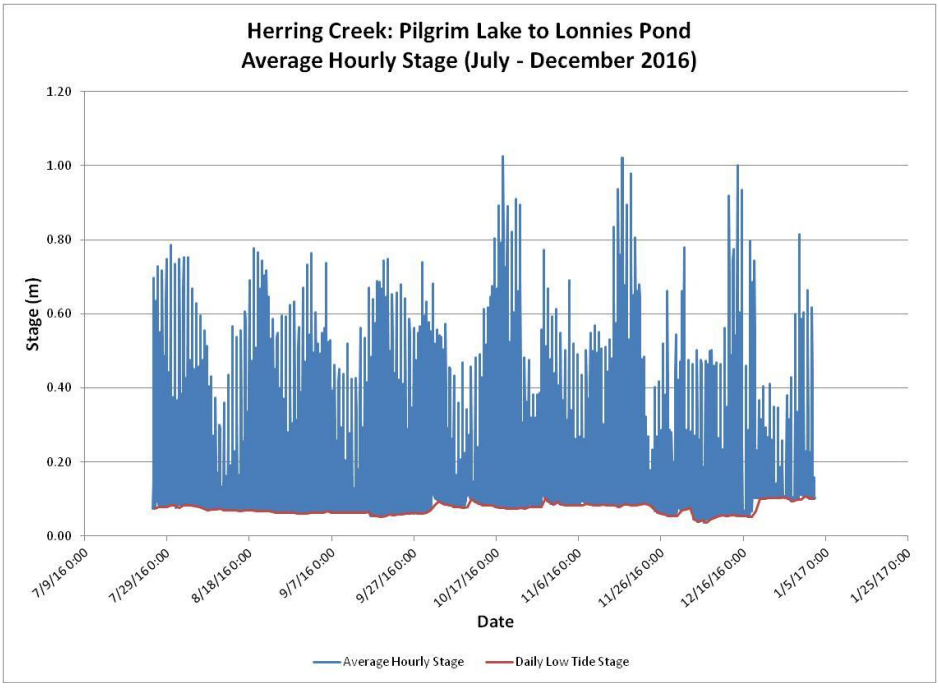


Figure VIII.2a. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, July 25, 2016 to December 31, 2016 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

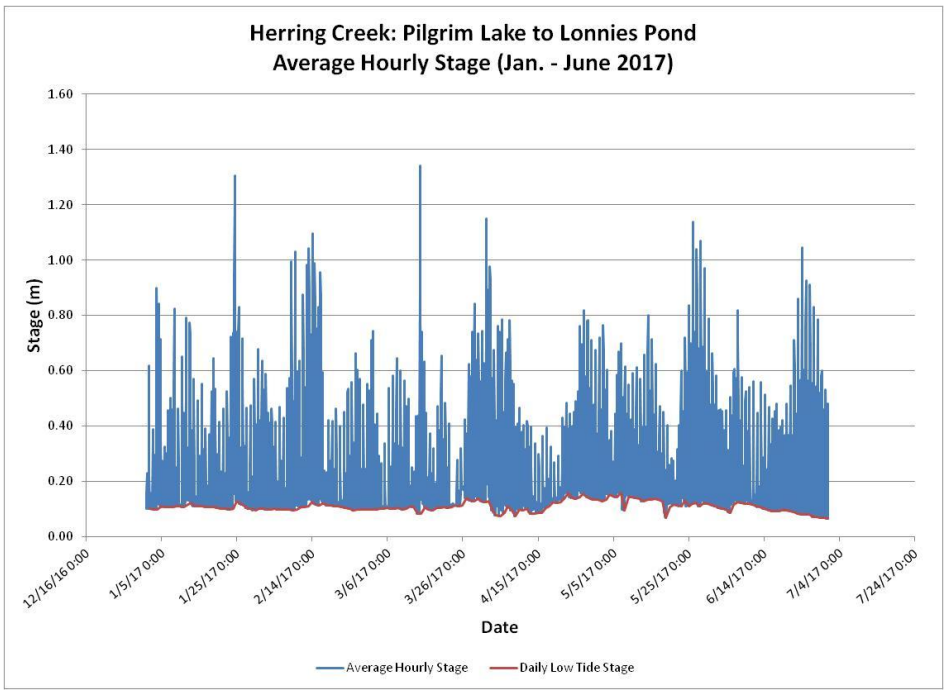


Figure VIII.2b. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, January 1, 2017 to June 30, 2017 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

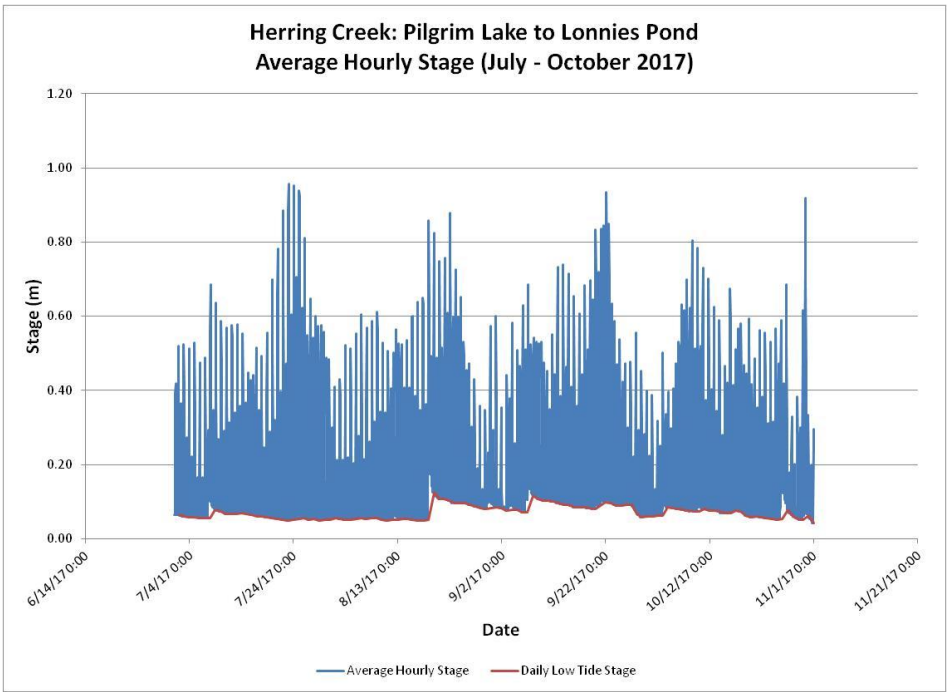


Figure VIII.2c. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, July 1, 2017 to October 31, 2017 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

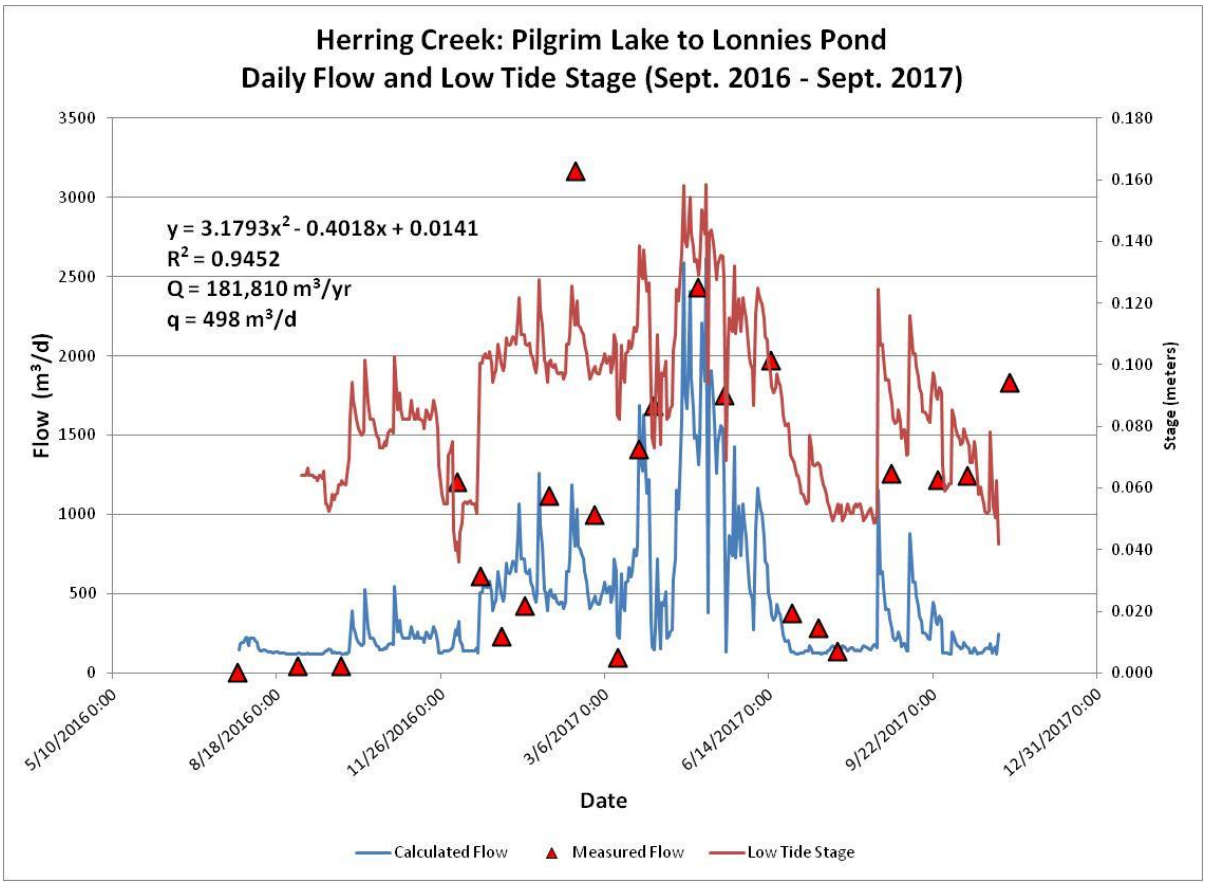


Figure VIII.3. Daily flow record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, September 1, 2016 to October 31, 2017, associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond and comparison to measured point flow measurements.

Monthly Flow Pilgrim Lake to Lonnies Pond (August - December)		
MONTH	2016-2017 FLOW (m^3/month)	2002-2003 FLOW (m^3/month)
August	4457	--
September	3791	--
October	7450	8342
November	6360	33240
December	9893	36363
January	20111	30,062
February	16981	46,759
March	21964	59,961
April	28947	41,072
May	39226	51,896
June	14210	14,367
July	4394	11,522
August	8504	9,280
September	9467	12,415
October	4920	10,754
November	--	16,887
December	--	17,520
Total (Oct.-Sept.)	**187,507**	**355,279**
NOTE:		
Annual Precip 2002-2003 = 54.39 inches		
Annual Precip 2016-2017 = 40.79 inches		
Avg. Annual Precip 1993-2015 = 46.11 inches		

Table VIII.1. Summary of monthly flow volumes discharged to Lonnies Pond. 2016-2017 significantly lower total volume for the period October to September (hydrologic year) due primarily to lower groundwater levels compared to 2002-2003.

Based on the daily flows generated during the gauge deployment period and the approximately bi-weekly sampling of the flow into Lonnies Pond, sample concentrations were interpolated and then merged with the daily flows to obtain an estimate of the nitrogen load into Lonnies Pond during the critical period of the oyster deployment. On average for the period August through October 2016, total nitrogen concentration averaged 1.11 mg/L and ranged between 0.96 and 1.30 mg/L (Figure 4, Table 2). When combined with flow during the same period, TN load averaged 5.67 kg/month TN and ranged between a high monthly average load of 7.57 kg/month and a low of 4.67 kg/month (Figure 5, Table 3). By comparison, on average for the period August through October 2017, total nitrogen concentration averaged 0.59 mg/L and ranged between 0.55 and 0.66 mg/L (Table2). When combined with flow during the same period, TN load averaged 4.15 kg/month TN and ranged between a high monthly average load of 4.83 kg/month and a low of 2.90 kg/month.

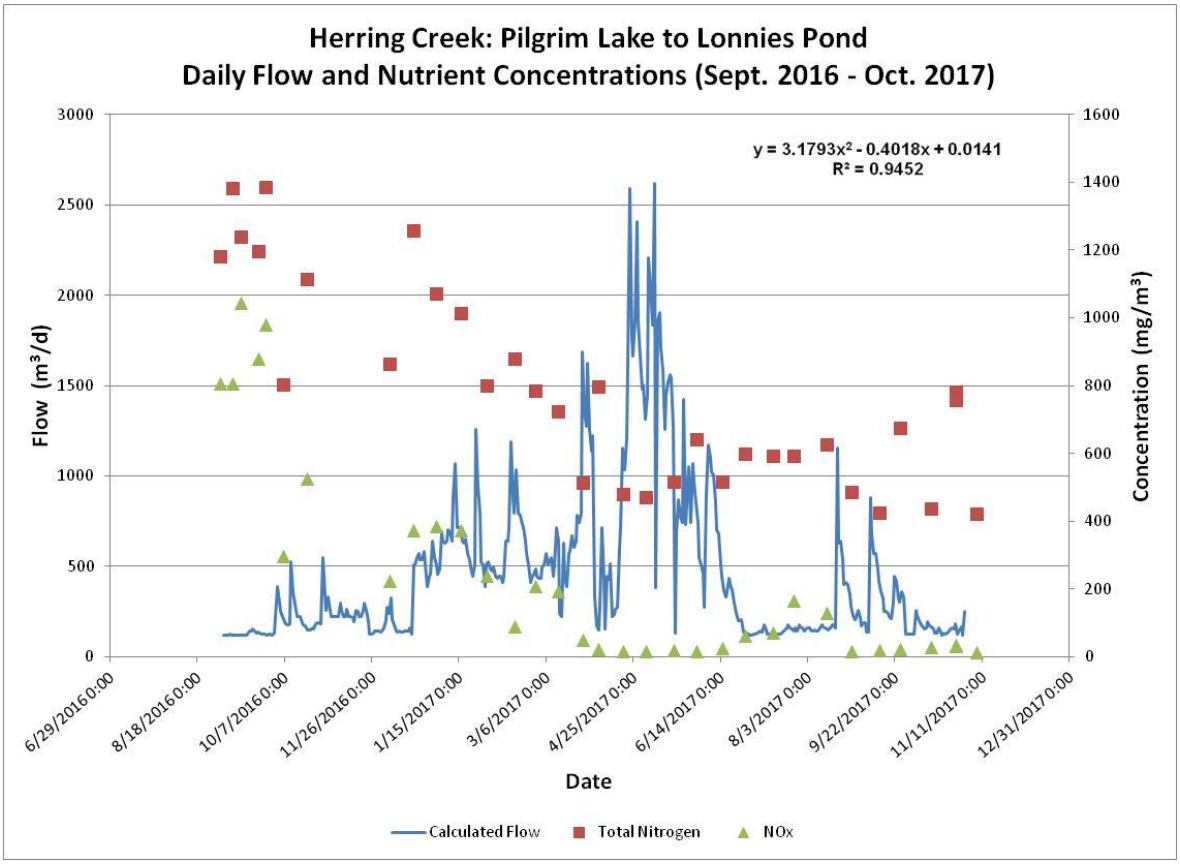


Figure VIII.4. Daily flow and stream nutrient concentration record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, September 1, 2016 to October 31, 2017 used to calculate freshwater flow and nitrogen load to Lonnies Pond.

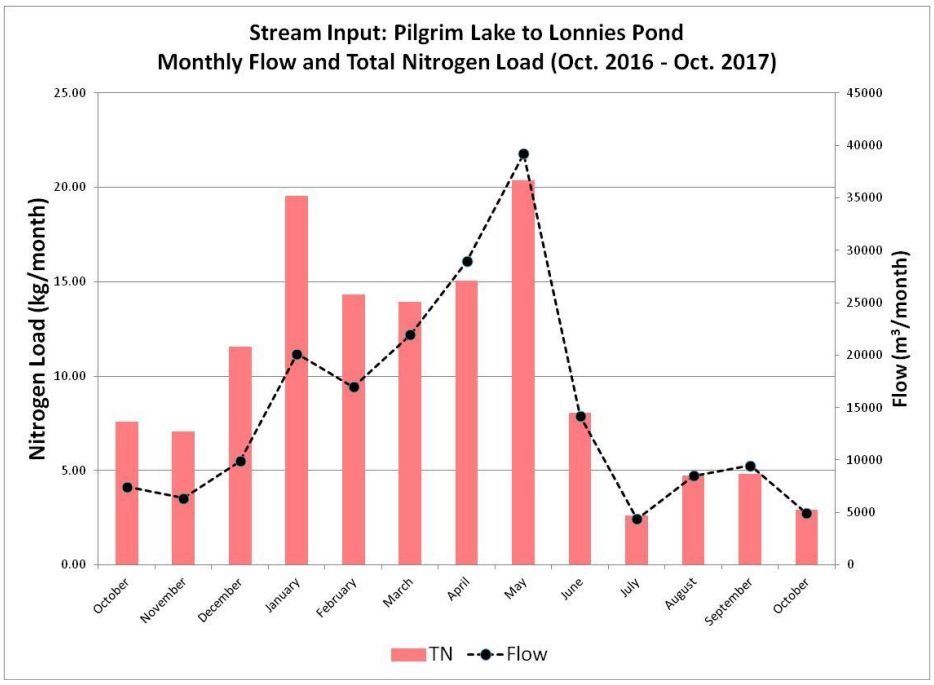


Figure VIII.5. Monthly flow and monthly stream total nitrogen load from Pilgrim Lake to Lonnies Pond.

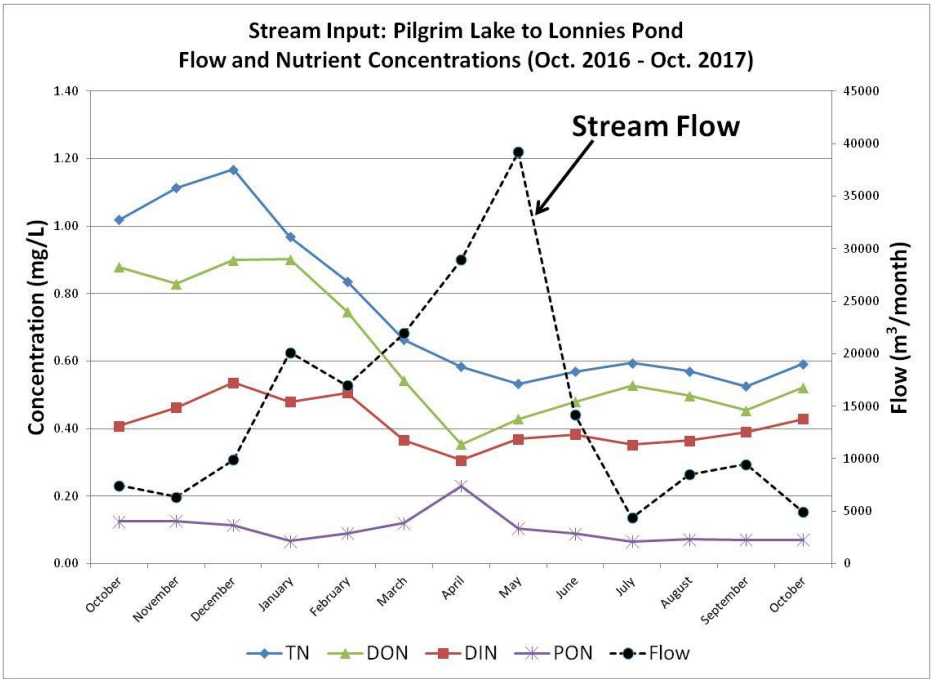


Figure VIII.6. Monthly flow and average monthly stream nitrogen constituent concentration record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, October 1, 2016 to October 31, 2017 used to calculate freshwater flow and nitrogen load to Lonnies Pond and determine seasonal differences in nutrient loading.

Considering the component nitrogen species, it appears that the total nitrogen concentration is

primarily comprised of dissolved inorganic nitrogen (DIN, 50%) and dissolved organic nitrogen (DON, 43%) with the remaining portion being comprised of particulate organic nitrogen (PON 7%). The 2003 stream nutrient concentrations determined during the MEP study were generally similar in that DIN and DON were the predominant fraction of the TN pool (30% and 58% respectively) with PON constituting the remainder of the total nitrogen (11%). DIN concentration in 2016 did appear higher than DIN levels in 2003 (50% vs. 30%), however, that may be the result of differences in annual hydrologic conditions and annually variable biogeochemical transformations in Pilgrim Lake. Lower volumetric discharge in the herring creek between Pilgrim Lake and Lonnies Pond could result in the slightly higher constituent concentrations for nitrogen (e.g. average TN 2016 {Aug.-Oct.} 1.11 mg/L, average TN 2003 {Aug.-Oct.} 0.791 mg/L). By comparison, total precipitation in the period August to October 2017 was 13.69 inches with an average TN concentration for that period of 0.59 mg/L.

NUTRIENT CONCENTRATIONS (based on samples w/o interpolation)						
Year	NH4 Avg. Monthly (mg/L)	NOX Avg. Monthly (mg/L)	DIN Avg. Monthly (mg/L)	DON Avg. Monthly (mg/L)	PON Avg. Monthly (mg/L)	TN Avg. Monthly (mg/L)
2016						
August	0.07	0.50	0.57	0.40	0.10	1.07
September	0.07	0.93	0.99	0.21	0.10	1.30
October	0.02	0.41	0.43	0.41	0.11	0.96
November *	0.01	0.35	0.46	0.83	0.13	1.11
December	0.04	0.30	0.34	0.54	0.11	1.06
* November concentrations are based on interpolation						
2017						
January	0.079	0.331	0.410	0.479	0.072	0.961
February	0.070	0.149	0.219	0.505	0.109	0.833
March	0.036	0.122	0.158	0.352	0.110	0.620
April	0.026	0.019	0.044	0.306	0.287	0.637
May	0.045	0.017	0.062	0.371	0.109	0.542
June	0.062	0.044	0.106	0.372	0.079	0.557
July	0.072	0.117	0.189	0.345	0.058	0.592
August	0.033	0.072	0.105	0.373	0.078	0.556
September	0.052	0.020	0.072	0.411	0.067	0.550
October	0.079	0.031	0.110	0.478	0.071	0.659
2003						
August	0.14	0.22	0.36	0.36	0.08	0.80
September	0.06	0.14	0.20	0.43	0.07	0.70
October	0.06	0.20	0.26	0.51	0.11	0.88
November	0.03	0.08	0.11	0.59	0.09	0.79
December	0.08	0.21	0.28	0.50	0.12	0.91
Avg. Conc. (Aug.-Oct. 2016)	**0.05**	**0.61**	**0.67**	**0.34**	**0.10**	**1.11**
Avg. Conc. (Aug.-Oct. 2017)	**0.05**	**0.04**	**0.10**	**0.42**	**0.07**	**0.59**
Avg. Conc. (Aug.-Oct. 2003)	**0.09**	**0.19**	**0.28**	**0.43**	**0.08**	**0.79**
NOTE: Oysters Removed from Lonnies Pond in December 2016.						

Table VIII.2. Nutrient concentrations by month (August - December) 2016 vs. 2003 entering Lonnies Pond from Herring Creek.

NUTRIENT LOADS						
Year	NH4 Monthly Load (kg/month)	NOX Monthly Load (kg/month)	DIN Monthly Load (kg/month)	DON Monthly Load (kg/month)	PON Monthly Load (kg/month)	TN Monthly Load (kg/month)
2016						
August	0.30	2.07	2.37	1.87	0.44	4.67
September	0.25	3.39	3.65	0.81	0.32	4.78
October	0.16	3.33	3.49	3.03	0.92	7.57
November	0.09	2.28	2.37	2.93	0.81	7.08
December	0.47	3.40	3.87	5.36	1.17	11.56
2017						
January	1.71	6.84	8.55	9.66	1.34	19.54
February	1.42	2.51	3.93	8.82	1.56	14.31
March	0.70	2.47	3.17	7.69	3.07	13.94
April	0.89	0.50	1.39	8.84	4.81	15.04
May	1.58	0.68	2.27	14.12	3.99	20.38
June	0.83	0.39	1.22	5.54	1.29	8.05
July	0.31	0.46	0.78	1.54	0.29	2.60
August	0.30	0.66	0.96	3.12	0.65	4.73
September	0.41	0.19	0.60	3.57	0.67	4.83
October	0.31	0.14	0.45	2.10	0.35	2.90
2003						
August	1.35	2.18	3.53	3.40	0.71	7.64
September	0.64	2.17	2.81	4.59	0.85	8.26
October	0.61	1.92	2.53	5.92	1.23	9.68
November	0.41	1.26	1.67	9.75	1.53	12.96
December	ND	ND	ND	ND	ND	ND
Total Load (Aug.-Oct. 2016)	0.71	8.80	9.51	5.71	1.69	17.02
Avg. Load (Aug.-Oct. 2016)	0.24	2.93	3.17	1.90	0.56	5.67
Total Load (Aug.-Oct. 2017)	1.02	0.98	2.01	8.79	1.66	12.46
Avg. Load (Aug.-Oct. 2017)	0.34	0.33	0.67	2.93	0.55	4.15
Total Load (Aug.-Oct. 2003)	2.60	6.27	8.87	13.91	2.79	25.57
Avg. Load (Aug.-Oct. 2003)	0.87	2.09	2.96	4.64	0.93	8.52
NOTE: Oysters Removed from Lonnies Pond in December.						

Table VIII.3. Nutrient loads by month (August - December) 2016 and 2017 vs. 2003 entering Lonnies Pond from Herring Creek.

Section IX. Lonnies Pond Oyster Study 2016 - 2017: Conclusions

The major results of the 2 year pilot deployment of oysters in Lonnies Pond are summarized below. While there are areas of the analysis that need refinement and additional quantification, a few things are clear from this extended deployment:

1) In both years there was a clear reduction in phytoplankton biomass by oyster filtration as water flowed through the oyster culture area. Significant reductions in total chlorophyll-*a* of >50% were commonly observed in samples adjacent versus within the deployment area.

2) Significant ($p<0.5$) reductions in total chlorophyll-*a* and particulate organic nitrogen (PON) were seen in tidal studies designed to capture water as it flowed through the culture area. Reduction in bioactive nitrogen was also seen, mainly due to the reduction in its main component, PON. Given the short time that any packet of water is in contact with the oysters, the large quantifiable reductions in all particulate groups is clear evidence of the ability of these types of oyster deployments to improve water quality even in nitrogen enriched waters

3) Biodeposition of feces and pseudofeces from the oysters was clearly evident in the region of the oyster deployment and the sediment region receiving biodeposits. The boundary of impact was refined in 2017 using a more sensitive acoustic device than in 2016. The oysters process more particulates than they incorporate by 2 fold. The deposition of organically labile particulate matter in biodeposits stimulated overall sediment respiration rates. This stimulation occurred in summer and fall with temperature moderating the absolute rate. Comparing October rates adjusted for temperature effects (Q_{10}) with August rates, overall respiration rates (carbon turnover) were similar, but with a shift towards greater uptake of NH_4 and NO_3 and greater denitrification. Rates of N biodeposition were directly measured yielding rates of 0.58 kg-N d^{-1} and 0.30 kg-N d^{-1} in August and October, respectively. The water quality surveys documented a peak in both particulate nitrogen and chlorophyll-*a* (phytoplankton biomass) in August compared to October due to a summer phytoplankton bloom (see Section II).

4) Denitrification (transformation of fixed nitrogen to nitrogen gas, N_2) was enhanced in sediments receiving oyster biodeposition. In September/October when oysters had reached their mid-season biomass, an amount equivalent to almost 1/3 of the biodeposition rate was denitrified each day. The study indicated that denitrification continues to be enhanced past the time of oyster harvest as the sediment incorporated biodeposits continue to contribute nitrogen to denitrification into the following spring when waters re-warm.

5) The second year of oyster deployment in the same area resulted in an increase in nitrogen removed through denitrification by 50% (2017[year 2] versus 2016 [year 1]) over the single season. It appears that the initial 1 year new deployment did not deliver sufficient biodeposits to the sediments to maximize the amount of nitrogen removal through denitrification. The second year also was initiated earlier than year 1 and with more oyster biomass early on, such that denitrification was higher for a longer period.

6) Should a rotational deployment be initiated, it will be important to gauge the potential reduction in denitrification if only 1 year deployments are made. At this point the optimal rotation time is unclear. In addition, it appears that the need to maximize biodeposits as early as April/May should be considered in planning where possible.

7) Re-examining the full denitrification and refined impact area and biodeposition over the 2 year deployment indicates that the initial deployment of seed only from June to December resulted in an increased nitrogen removal of 0.25 kg N per 1 kg N in harvest, but when continued into the second year the increased removal was significantly higher ~0.37 kg N per 1

kg N removed in harvest. These rates are lower than for Little Pond Falmouth, but are in the range of 0.5 kg N per 1 kg N removed in harvest found elsewhere.

8) As part of the overall effort, stream discharges to Lonnies Pond were determined in summer 2016 and summer 2017 during the oyster deployment. The flow data are consistent with 2016 being part of the drought (Aug.-Oct., 15,698 m^3) with 2017 flows being higher (Aug.-Oct., 22,891 m^3) due to higher precipitation. Precipitation in 2016 was reduced over long-term averages and more significantly flow through the main surface water discharge (Herring Run) was far below historic levels (e.g. 2003), with 2016 rates being 52% of 2003 surface water flow volumes (32,449 m^3) in the August through October period. Flow for the same period in 2017 compared to 2003 was 29% lower. At these flow levels, it did not appear that the oyster study was influenced by surface water flows in 2016 or 2017. It should be noted that at the low surface flows of 2016, average monthly nitrogen loading (Aug.-October.) to Lonnies Pond waters from Pilgrim Lake was significantly lower than 2003 loads (5.67 vs. 8.52 kg/month). It should be noted that while flows in 2016 where lower than for the same period in 2017, average monthly TN load to Lonnies Pond in 2016 (5.67) was slightly higher than for the same 2017 period (4.15) due to the very high measured TN concentrations in the stream water (1.11 mg/L and 0.59 mg/L respectively). The interannual variation in TN concentration is likely related to the turnover time of Pilgrim Lake, which is controlled by the freshwater inflow volume (lower in 2016 than 2017).

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APPENDIX B: Town of Orleans Estuary Water Quality Sampling QAPP

University of Massachusetts Dartmouth
The School for Marine Science and Technology

Quality Assurance Project Plan

Town of Orleans Estuaries Monitoring:

Namskaket, Little Namskaket, Rock Harbor, Nauset and Upper Pleasant Bay Systems

(Draft July 28, 2006)

Submitted to:

MA Department of Environmental Protection

Prepared By:

Dr. Brian Howes
Roland Samimy

Coastal Systems Laboratory
School of Marine Science and Technology (SMAST)
University of Massachusetts – Dartmouth

For:

Town of Orleans

DRAFT

Quality Assurance Project Plan

Town of Orleans
Citizens' Water Quality Monitoring Program

July 28, 2006

Dr. Brian Howes
School of Marine Science & Technology
University of Massachusetts - Dartmouth

Project Officer:

_____

George Meservey, Town of Orleans
School Road, Orleans, MA 02653; Tel: 508-240-3700, Ext 335

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A.3. Distribution List

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Department of Environmental Protection	Arthur Screpetis MassDEP CERO 627 Main Street, 2nd Floor Worcester, MA 01608 508-767-2875
Environmental Protection Agency	MaryJo Feuerbach USEPA, Region 1 1 Congress Street, Suite 1100 Boston, MA 02114-2023 617-918-1505

A.4. Project Organization and Responsibilities

The Orleans Water Quality Monitoring Program was initiated to address growing concern over the declining ecological health of coastal embayments within the Town of Orleans. Steadily increasing nutrient inputs pose a serious threat to the health of estuarine systems, not just on Cape Cod, but throughout the world. Through the present effort, the Town of Orleans has joined the growing number of southeastern Massachusetts coastal communities in an effort to provide necessary water quality data for developing long term nitrogen management plans for the protection and restoration of their coastal waters. In addition, with the establishment of the DEP/SMAST Massachusetts Estuaries Project (MEP), the Town of Orleans' Citizens' Water Quality Monitoring Program has the dual objectives of:

- Assessing the current nutrient water quality of all of Orleans' embayments
- Providing the data for validation of MEP water quality models

The present Water Quality Monitoring Program is coordinated by the Town of Orleans through its Planning Office, with technical oversight and support from the Coastal Systems Program at SMAST-UMassD. The Town of Orleans is responsible for organizing and implementing the field program. This includes the recruitment and coordination of volunteers, distribution and maintenance of field sampling equipment and transport of samples and field data to the SMAST laboratory. SMAST is responsible for training volunteers, technical guidance, development of sampling methodologies, preparation of field sampling gear (field kits, bottles, coolers etc), and database tasks. All nutrient analyses are conducted by the Coastal Systems Analytical Facility at SMAST.

Bacteria sampling focuses upon surface sampling at each of the water quality stations. Samples are collected in accordance with the *Standard Methods for the Examination of Water and Wastewater 19th Ed* (1995). Samples are transported (<6hr) to the Barnstable County Department of Health and Environment laboratory for assay. Trained volunteers are used for the field sampling and other project tasks as appropriate. An SMAST Orleans Contact, Sara Sampieri, is responsible for sample custody, tracking, and transport for the water quality samples collected during a given field season.

Alterations in program, quality assurance issues, and any other technical issues are dealt with through regular discussions between the Orleans Project Manager, George Meservey, the Coastal Systems Program Manager and Project QA Officer, Drs. Brian Howes and David White with input from various volunteer monitors and the Orleans Wastewater Planning Committee.

To date, this project has been funded solely from municipal sources and the preparation of this QAPP was undertaken both as a good practice and to facilitate incorporation of monitoring results into MEP efforts.

A.5. Project Background and Introduction

Overview:
The Orleans Water Quality Monitoring Program was established to address present nutrient related ecological quality issues within Orleans' embayments and provide necessary information with which to develop policies to protect and/or restore the habitat quality of these systems relative to nitrogen loading. The program was developed as a partnership between the Town of Orleans and the Coastal Systems Program at SMAST, working in collaboration with citizen volunteers and appropriate organizations or groups as identified by the Town.

The Orleans Water Quality Monitoring Program is managed by the Town of Orleans under the oversight of the Planning Department. The program is modeled after the Falmouth Pondwatchers (an SMAST project initiated in 1987), the Coalition for Buzzards Bay "Baywatchers" and a number of other citizen based monitoring programs all operating within the same network of programs in collaboration with the SMAST laboratory.

The Orleans Water Quality Monitoring Program primarily focuses on nutrient related issues, specifically the cultural eutrophication of the town's bays and sub-embayments. The observed effects of nitrogen enrichment include increased algal blooms and macroalgal abundance, periodic depletion of dissolved oxygen, shifts in benthic communities. The Water Quality Monitoring Program was established with the goals of assessing the nutrient related health of Orlean's coastal embayments, determining the spatial gradients of nutrients and bacterial contaminants within each basin and providing the high quality multi-year data required by the Massachusetts Estuaries Project Linked Watershed-Embayment Management Model. Providing the baseline data necessary for developing nitrogen management plans for Orleans' watersheds and coastal waters is the primary objective of this effort.

Goals:
The primary goal of the Orleans' Water Quality Monitoring Program is to provide the Town of Orleans with accurate and reliable water quality monitoring data from each of the Town's embayments: Nauset Inlet System, Upper Pleasant Bay, Rock Harbor, Little Namskaket Creek, Namskaket Marsh. The Program was established to:

- Assess current water quality
- Assess current nutrient related habitat health
- Determine the spatial distribution of nitrogen and bacteria during warmer months
- Provide data for validation of MEP water quality models
- Facilitate implementation of management recommendations.

This effort also helps to fulfill priorities of various Environmental Agencies, including EOEA's Watershed Initiative, MCZM's Coastal Monitoring effort, DEP's Massachusetts Estuaries Project, as well as to begin to address the Public's concern relating to decline of coastal resources. Regulation of nutrients is changing related to watershed-based water quality management and the public interest in clean water. Management of nutrients continues to be at the top of the US EPA's Agenda.

A.6. Project Task Description

Overview:
To assess the present nutrient related habitat quality within Orlean's embayments and to support management to protect or restore these systems with regard to nutrient overloading and bacterial contamination, a comprehensive long-term citizen based monitoring effort has been established. Because the program is a partnership between the Town of Orleans and SMAST-UMD, they will work closely together to insure all tasks are accomplished in a cohesive and coordinated fashion. The Tasks to be undertaken under the current nutrient related effort are as follows:

Task 1 – Program Setup: establish site locations, field equipment
Task 2 – Program review, procedural updates, manual updates
Task 3 -- Recruit/replace citizen volunteers
Task 4 -- Conduct formal volunteer training sessions and distribute equipment
Task 5 – QA of field program and individual retraining sessions
Task 6 – Maintain & calibrate DO equipment prior to each event (SMAST staff).
Task 7 – Summer sampling of D.O./temp/salinity/secchi depth, nutrients & bacteria
Task 8 – Laboratory assay of dissolved and particulate nutrients and fecal coliforms
Task 9 – Collect equipment and DO chemical waste
Task 10 -- Data entry and management
Task 11 -- Synthesis Report on water quality status and trends of Orleans embayments.

This Quality Assurance Project Plan covers both the field and laboratory components of the Orleans Water Quality Monitoring Program. The field program includes both the procedures for sample collection and any field sample processing. The laboratory program includes sample holding, analytical and QA/QC procedures, chain of custody procedures and data transmission.

Table 1. Schedule of Tasks for each monitoring year.

TASKS	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Program Setup, arrange for laboratory work, order equipment		———	———	———	———							
Program review & update training manual, sampling schedules			———	———	———							
Recruit Volunteers	———	———	———	———	———	———	———	———	———	———	———	———
Formal Training Sessions & Distribution of equip, manuals, protocols, etc					———							
QA of Field Program & Retraining sessions						———	———	———				
DO Equipment Main. & Calibration						———	———	———				
Field Parameter, nutrient and bacterial sampling						———	———	———				
Laboratory analysis						———	———	———	———	———	———	
Collect equip & D.O. chem. Waste									———	———		
Data entry, QAQC and graphing						———	———	———	———	———	———	———
Data analysis and reporting.	———	———	———	———								

Description:
Volunteers monitor water quality for basic parameters: dissolved oxygen, temperature, water clarity on-site, and collect water samples for a series of nutrient analyses and fecal coliform counts (**Refer to Appendix I for Field Sampling Protocols**). Water samples are collected between the hours of 6-9 AM, during mid-ebb tide. This early morning sampling is to capture the "worst-case" oxygen levels which structure the habitat. All sites from all embayments are collected on the same days, with generally 6 dates per summer season, June-August. This simultaneous sampling schedule is critical to allow site to site comparisons of data. Monitoring focuses on the warmer, more biologically active months when lowest dissolved oxygen levels can be identified and nutrient related water quality is typically at its annual minimum.

The sampling stations are placed throughout each embayment (generally along a transect) from the inner to outer portions. All attempts are made to conduct sampling "simultaneously", during mid-ebb tide in order to best characterize nutrient conditions in the embayment, not from outer offshore waters.

Water samples are collected from near 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 D.O. affects. Surface water samples are collected at a depth of 15 centimeters below the surface and bottom water samples from a depth of 50 centimeters above the bottom. These depths have been determined by SMAST as representative. Collection of a sample 15 cm below surface prevents entrainment of the overlying air into D.O. samples and of floating material into nutrient samples. Sampling 50 cm above bottom prevents stirring of the bottom sediments with subsequent contamination of the nutrient sample. Shallow stations are sampled at mid-depth. Bacterial sampling is at 15 cm depth at each station and is performed directly in the sterile sample bottle. Sampling poles and Niskin Bottles are used to collect samples for oxygen and nutrients.

The Project Manager/QA Officer assigns each sampling station to a pair of trained volunteer(s). Each station has a unique identification code, which is assigned by the QA Officer. All attempts are made to have stations at locations that are representative of embayment water quality conditions. Stations are selected to give good geographic coverage throughout the inner and outer portions of an embayment.

A.7. Data Quality Objectives

The data quality objectives have been selected to fit with the goals of the Water Quality Monitoring Program and the natural variability of the tidal estuarine environments being sampled. The methods and approaches employed by the Program are aimed at meeting the required levels of precision, accuracy, field blank cleanliness, and detection limits. The minimum performance criteria for the field physical sampling is given in Table 2, for the nutrient sampling in Table 3, and bacterial sampling in Table 4.

Table 2. Water Quality Program, field parameters measured & data objectives

Parameter	Method/ Range Units	Sensitivity	Precision	Accuracy	Calibration
Temperature	Thermometer -10°C to +100°C/Celsius	0.5°C	0.5°C	1°C	Certified Thermometer
Temperature	Thermister -10°C to +45°C/Celsius	0.1°C	0.1°C	0.2°C	Certified Thermometer
Dissolved Oxygen: YSI Meter	Polarographic Clark Electrode: 0-15 ppm	0.1 ppm	0.2 ppm	0.2 ppm	Certified Std And Air
Dissolved Oxygen Winkler Lab	Winkler Potentiometric Titration Lab	.03 ppm	.03 ppm	.05 ppm	Certified Stds and lab stds
Dissolved Oxygen/Hach OX2P (ppm)	Modified Winkler Titration Field	0.5 ppm	0.5 ppm	0.5 ppm	Parallel Assay: Lab Stds and Potentiometric Titrattion
Water Clarity	Secchi Disk disappearance/ meters	1 cm	10 cm	10 cm	NA

Note: Citizen volunteers collect water samples that are analyzed for the parameters listed in Tables 2, 3, and 4. Citizen volunteers also record observation about weather conditions during sampling.

The nutrient sampling program uses accepted methods for salt water analysis. These methods are accepted by the best marine research laboratories in the United States. Where EPA or Standard Methods techniques are available, they are employed by the SMAST Coastal Systems Analytical Facility. All methods have been inter-calibrated with a variety of methods and with various certified laboratories (freshwater only) and marine laboratories. Minimum performance criteria are listed in Table 3, although the methods used in the program generally exceed these minima. The acceptable criteria for field blank cleanliness is generally a reading less than the detection limit. In occasional instances where high sensitivity methods are employed, the field blank must be less than 10% of the sample value.

Table 3. Minimum Criteria for Nutrient Monitoring Parameters

Parameter	Matrix[a]	Estimated Total # of samples	Field Precision	Laboratory Precision	Accuracy	Detection Limit
Nitrate + Nitrite	1	300-500	<30% RPD[b]	<20% RPD	75%-125% of matrix spike	0.25 uM
Ammonium	1	300-500	<30% RPD	<20% RPD	75%-125% of matrix spike	0.25 uM
Total Phosphorus	1,2	300-500	<30% RPD	<20% RPD	75%-125% of matrix spike	0.4 uM
Orthophosphate	1	300-500	<30% RPD	<20% RPD	75%-125% of matrix spike	0.1uM
Chlorophyll *a*	1	300-500	<30% RPD	<20% RPD	75%-125% of matrix spike	0.1 ug/L
Total dissolved N	1	300-500	<30% RPD	<20% RPD	75%-125% of matrix spike	1 uM
Particulate C& N	1	300-500	<30% RPD	<20% RPD	75%-125% of matrix standard	1 uM

[a] Matrix: 1 = saltwater, 2 = freshwater
[b] RPD – Relative Percent Difference

Table 4. Water Quality Monitoring Program, Bacterial Monitoring Parameters

Parameter	Matrix[a]	Estimated Total # of samples	Field Precison	Laboratory Precision	Accuracy	Detection Limit
Fecal Coliform	1, 2	200-350	<20% RPD	<20% RPD	Certification STd	1 org./100ml** @0-100 range or 10 org/100ml @ 10-1000 range

[a] Matrix: 1 = saltwater, 2 = freshwater
** Different dilutions are used which have different detection limits.
All assays by Barnstable County Department of Health and Environment Laboratory

Precision

The precision of each chemical assay is determined by from duplicate assays of five standards. The field precision is from duplicate assay of five blind field duplicates. The precision is calculated as the relative percent difference (RDP). An additional estimate of precision is determined from the R^2 of the linear regression of each set of standards (N>5).

Accuracy

Accuracy is determined from the analysis of standards for the standard curves, analysis of the matrix spikes and use of Performance and Evaluation Samples (commercially available). Accuracy is determined as the RDP of the assay of five standards run as samples within a series of analytical runs. This is compared to the RDP of five sets of Performance and Evaluation Samples. In addition, the accuracy of the method within the sample matrix is determined from the RDP of five matrix spikes experiments (standard additions), where appropriate.

Measurement Range

The usable measurement range for each chemical assay is only within the linear range as determined from least squares linear regression of laboratory standards. Concentrations

above the linear range require standard dilutions for acceptable analysis. Since high values can be readily diluted and re-assayed the same day, the upper range of measurement is variable. Sample dilutions attempt to bring the concentration of the diluted sample into the middle of the linear range for the assay. The natural range for any analyte within the Water Quality Monitoring Program is typically less than 1000 fold.

Bacterial assays require a priori determination of dilutions. For fecal coliform analysis by membrane filtration, only 100 colonies can be counted per plate. Therefore, if more than 100 colonies per 100 mL are anticipated a dilution will be requested which shifts the measurement from 0-100 colonies/100 mL to 10-1000 colonies/100mL.

Representativeness

The goal of the Orleans Water Quality Monitoring Program is to provide data needed to evaluate overall water quality conditions and to determine changes over the long-term. Through the use of trained volunteers, we can effectively collect the substantial amount of spatial and temporal water quality data. The number and locations of sample stations is specific to each sub-embayment and depends in part upon the sub-embayment's size and shape, access, and navigational passages. The data collected by the volunteers is of sufficient quality to represent environmental conditions since (1) volunteers are trained each year and data are checked by SMAST Technical Staff upon receipt of each data sheet from each volunteer team (at the Orleans Town Annex sample delivery point), (2) volunteers collect physical data and D.O. which are performed in the field and additional D.O. "check samples" are shipped to the SMAST laboratory for titration and (3) all nutrient assays are conducted at the SMAST laboratory.

Comparability

The results are directly comparable to the results of the Falmouth Pondwatch Program, the Coalition for Buzzard's Bay Baywatcher's Program, the Martha's Vineyard Coastal Ponds Program (MV Commission), Pleasant Bay Alliance, Chatham WaterWatchers, Cotuit Waders, Mashpee's Popponesset Bay Monitoring Program, and several other programs. All of these programs use the same field sampling approaches and the Coastal Systems Analytical Facility at SMAST. The results are also comparable to many national programs, both volunteer and research, since the timing and distribution of sampling within the estuaries and the level of analysis is based upon understanding the whole system.

Completeness

Each volunteer is given a sampling schedule at the training sessions and explained that all sampling occurs on the same dates and within the 6AM-9AM window and that the data sheet needs to be checked for completeness prior to leaving a sampling station. In addition, if a team cannot perform a sampling, then a call is made to the Project Manager who will then use "back-up" volunteers for that station. The ultimate goal of the monitoring program is to make identical measurements from each station on each planned sampling date. Completeness is gauged as the number of actual measurements divided by the number of planned measurements times 100%. A "successful" sampling season would have >80% sampling of each parameter at each station. The effect of missing a sampling station can only be gauged relative to its position in the estuary and the status of the adjacent stations.

Typically, missing a single station on any given date does not limit the usefulness of a data set for an embayment.

A.8. Training

Volunteer Training- SMAST staff is responsible for the equipping and training of volunteers prior to sampling. The Project Officer works closely with the QA Officer and Analytical Facility Staff at SMAST to review and refine sampling techniques and training materials. The Project Officer initially interviews potential volunteers, explains the program's objectives, the time involved, and the role and responsibilities of volunteers. The seriousness of the enterprise and the need for completeness of sample collection are emphasized. Volunteers receive a more detailed explanation of the program and sampling methods at the formal hands-on training sessions with assistance from scientists from the Coastal Systems Group of SMAST. Specifically, volunteers are instructed on the goals of the program and the importance of taking accurate and timely measurements. They are given a demonstration of the protocol and then break into small groups to practice collecting the samples and performing the field procedures. Retraining sessions are held at the beginning of each sampling season, where the demonstration will be repeated and the volunteers methodology checked. Individual follow up field checks are conducted on new volunteers and volunteers are encouraged to team up with other trained personnel to assure consistent sampling technique. The first series of field samples each season serve as a test-run of the volunteers and the results are immediately evaluated by the SMAST staff to gauge the level of any additional individual training required. This process is continued throughout the sampling season by the SMAST Staff member (Sara Sampieri) who checks each volunteer teams data sheet and samples when they return from the field and discusses any "issues" with them. Volunteer assessment will also be checked by evaluation of data against previous sample data from earlier assessments. The Project Officer will maintain a contact database for all volunteers.

A.9. Documentation and Records

Data will be recorded on standardized data sheets on-site at the time the measurements are taken (Appendix II, III, IV). The volunteers will be asked to check that all data are accurate and legible before forwarding to the QA Officer. Data is reviewed and discussed with the each volunteer team if the information is missing, questionable or incomplete. The nutrient and bacterial sampling portion of the program requires that Chain of Custody forms (COC) be filled out as the samples are received by SMAST. COC's are checked jointly by SMAST analytical staff and monitoring personnel at the time of sample transfer. Copies of field data are maintained jointly by the Project Officer and the SMAST analytical facility. Nutrient and bacterial data is maintained as duplicate hard copies of raw data as well as computer back-up disks of entered data.

B. MEASUREMENT/DATA ACQUISITION

B.1. Sampling Process Design

Overview
Sampling focuses upon the summer months when water quality is at its annual minimum. Sampling will be conducted six times over the period of May through October to include up to 53 samples (38 marine, 3 freshwater, 5 QA samples and 7 stations with surface and bottom samples). The schedule of sampling relative to training and other activities is given in **Table 1**, above. All nutrient sampling is conducted near mid-ebb tide using system-wide volunteers. The synoptic nature of the nutrient sampling program allows us to focus the number and timing of sampling dates to achieve a sufficient level of understanding of the systems. Sampling sites are selected to give a headwaters to mouth picture of each embayment and to avoid "edge" effects. Sampling sites are generally located from navigational markers, permanent moorings or by triangulation with major shoreline markers. Volunteers are provided with this information and maps of sampling stations.

Parameters Analyzed and Data Quality Requirements and Assessments
Information pertaining to the parameters analyzed and the data quality objectives can be found in **Tables 2 through 4**. Sampling protocols and data sheets are attached in **Appendices I, II, III, IV**. **Appendix V** contains the coordinates of the water quality sampling stations. All samples will be collected by trained staff and/or trained volunteers. Citizen volunteers collect water samples that are analyzed for the parameters listed in Table 3 & 4. The numbers of samples and holding characteristics are also given in these tables. Citizen Volunteers also record observation about weather conditions during sampling.

Table 5 Water Quality Monitoring Program, Nutrient Monitoring Parameters

Parameter	Matrix[a]	Estimated Total # of samples	Sample Volume/ Container	Maximum Holding Time	Field Processing/ Preservation	Units
Nitrate + Nitrite	1	53	60 ml polyethylene acid-washed	28 days (frozen)	Field filter, store dark at -30°C	µg/l
Ammonium	1	53	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	µg/l
Orthophosphate	1	53	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	µg/l
Chlorophyll *a*	1	53	1L polyethylene acid-washed	24 hours (4C)	Store on ice in dark	µg/l
Total dissolved N	1	53	1L polyethylene acid-washed	24 hours (Frozen)	Field filter, store on ice in dark	µg/l
Particulate C& N	1	53	1L polyethylene acid-washed	28 days	Collect on Filter, Dry and Store in dessicator	µg/l

[a] Matrix: 1 = saltwater, 2 = freshwater

Table 6. Water Quality Monitoring Program, Bacterial Monitoring Parameters

Parameter	Matrix[a]	Estimated Total # of samples	Sample Volume/ Container	Maximum Holding Time	Field Processing/ Preservation	Units
Fecal Coliform	1, 2	200-350	250 ml sterilized polyethylene	6 hours	Collect, label, cooler storage in cooler blue ice	1 org./100ml
[a] Matrix: 1 = saltwater, 2 = freshwater						

Note: Bacterial parameters measured through Barnstable County Health Laboratory.

Sampling for physical parameters is not affected by weather, river flows, wind or other variables. Access to sites is part of the site selection criteria, only sites with ensured long-term access are used. However, the nutrient sampling events are postponed if there are small craft warnings or extreme rainfalls on the day of the sampling, otherwise they go forward. The Project Officer with the SMAST Laboratory makes the determination for postponement. Sampling for bacteria is targeted upon rainfall events.

B.2. Sampling Methods Requirements

The sampling approaches have to be easily mastered by volunteers with only moderate training. To ensure that the proper procedures are followed the volunteers are given detailed hands on instruction during the training sessions and are provided with extra copies of protocols for use in the field as they conduct their work. Technical support is also available to the volunteers from Coastal Systems Program staff. Volunteers are trained in the use of pole samplers for stations generally less than 2 meters and Niskin bottles for deeper samples. Field SOP's are reproduced in **Appendix I.**

B.3. Sample Handling Requirements

All samples collected for nutrient and bacterial analysis are labeled in the field with Sample ID, date (m/d/y), time of collection, depth and any other specialized information. Identical information is recorded on a data sheet/chain of custody, which also include notes as to environmental conditions, problems encountered, names of personnel, etc. Once the samples have been collected the samples are placed on ice (in a cooler). Upon completion of field processing of the samples, sample coolers are immediately transported by the volunteers to specified drop off locations for transport to the SMAST laboratory or Barnstable County Health laboratory. Upon reaching the laboratory, all samples are cross-checked to the COC's and recorded by lab personnel. Copies of the sample list, COC's and data sheets are made and kept by the laboratory and the Project Officer upon check-in.

B.4. & B.5. Analytical Methods Requirements / Quality Control Requirements

Monitoring parameters, sample volumes, containers, sample processing and storage for this project are listed in **Tables 5 and 6**. Analytical methods and associated references are listed in **Table 7**.

Analytical procedures used in this program have been tailored to the specific chemical environment of estuaries, i.e. variable salinity and analyte concentration ranges of 1000 fold. The procedures used are those commonly employed by the SMAST Coastal Systems Program for research on coastal processes. The analytical methods are being or have been used by SMAST in the measurement of water quality in a variety of monitoring programs such as the USGS Namskaket Marsh Project (required inter-calibration with USGS Central Lab), MWRA-HOM Program, Falmouth PondWatch, Buzzards Bay "Baywatchers", Pleasant Bay Alliance, USAID Water Quality Program-Jamaica, MCZM Wetlands/Stormwater Monitoring Program, Assabet River TMDL Study, RIDEM-Greenwich Bay Study, WHOI Nantucket Harbor Monitoring Program, Martha's Vineyard Coastal Pond Monitoring Program (MVC), and many others. These programs over the past 15 years have QAPP's and most of them have required acceptance by either EPA or Massachusetts DEP.

The chemical analyses used in the Orleans Water Quality Monitoring Program follow standard laboratory procedures. However, not all analytes have accepted EPA Methods for saltwater and some are not amenable to matrix spikes (eg. POC/N, Chlorophyll a). For each chemical assay, a complete standard curve is generated for each analytical run. In addition, reagent blanks and standards are prepared and analyzed with each new batch of reagent. These blanks are compared to previous data on blanks to evaluate the potential of contamination and the standard curve compared to previous records. If this initial blank and standard curve are deemed satisfactory, samples using the new reagent batch can then analyzed. Calibration blanks are prepared and analyzed simultaneously with the creation of each standard curve, which is created for independently for each sample series. If more than a 10 fold range of concentrations are encountered in the samples, then both a high and low standard curve is created. In all cases the standards are prepared new each day and are chosen to give at least 5 points over the sample concentration range. Least Squares Linear Regression is used to calculate the standard relationship and a minimum $R^2 = 0.99$ is required for acceptance. Standards well above the sample range are not used. Nitrate+Nitrite (run in duplicate) and Particulate C & N by autoanalysis have additional standards run before and after every five-six samples. Failure of these additional "check" standards (run as samples) to agree within 10% of their known value halts the assay line for complete recalibration and the re-running of the last sample set. These "check" standards are used to adjust the calculated sample values for instrument efficiency.

For nitrate+nitrite, dissolved ammonium, total dissolved nitrogen and ortho-phosphate, are all assayed in duplicate at a frequency of more than 15% of the samples and with a <5% tolerance between duplicates required for acceptance. After completion of analyses, remaining sample is frozen, for possible reanalysis if required (and appropriate). For the particulate analyses (Chlorophyll a, pheophytin a, PON, POC), only field duplicates and laboratory standards can be assayed as the analysis consumes the entire sample.

Spiked samples are periodically analyzed as analytical checks in dissolved ammonium, nitrate+nitrite, total dissolved nitrogen and ortho-phosphate assays. Spiked samples are not widely run, as the standards are made up in the same matrix as the samples. Greater numbers of spiked samples are sometimes run as "unknowns" similar to field duplicates. Recovery of spikes must be within 15%-20% of expected to meet QA, see **Table 7**. Spikes for PON/POC samples are not available. Therefore, POC/PON at known concentrations is added directly to filters and is done during machine calibration as an internal QA check after every fifth field sample assayed. Performance and Evaluation Samples for the nutrient assays are run during the course of this monitoring program to evaluate the accuracy of the SMAST laboratory. Performance and Evaluation Samples are submitted to the laboratory by the State as a QA procedure for the Massachusetts Estuaries Project.

Table 7. Analytical Procedures/Quality Control Samples

Parameter	Method	Detection Limits	Frequency	QC Samples	Acceptable %Recovery
Temperature	Thermometer -15 °C to 100°C	0.5 C	Monthly May – October	NA	
Salinity	Specific Conductance	0.5 ppt	Monthly May – October	Field Dups ± 1ppt	
Dissolved Oxygen	Modified Winkler Titration/Oxygen Meter	0.5 ppm	Monthly May – October	Field Dups ± 0.5 ppm	
Water Clarity	Secchi disk	5 cm	Monthly May – October	Field Dups ± 10 cm	
Nitrate + Nitrite-	LACHAT Autoanalyzer[a] (Cd Reduction)	0.1 µM	Monthly May – October	Lab/Field Dups ± 10%	85%-115% of spike
Ammonium-	Indophenol[b]	0.1 µM	Monthly May – October	Lab/Field Dups ± 10%	85%-115% of spike
Orthophosphate-	Molybdenum Blue[c]	0.05 µM	Monthly May – October	Lab/Field Dups ± 10%	85%-115% of spike
Chlorophyll a	Acetone extraction[e]	0.1 µg/l	Monthly May – October	Lab/Field Dups ± 20%	NA
Total Dissolved Nitrogen	Persulfate digestion[d]	0.5 µM	Monthly May – October	Lab/Field Dups ± 20%	80%-120% of spike
Particulate Nitrogen & Carbon -	Elemental analysis[f], 440.0	0.5 µM	Monthly May – October	Lab/Field Dups ± 20%	95%-115% of check std

a Standard Methods 19th Edition, Method 4500-NO3-F using Lachat Autoanalysis procedures based upon: Wood, E., F. Armstrong and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11:87-96.

b Standard Methods 19th Edition, Method 4500-NH3-F and Schneider, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10:31-36.

c Standard Methods 19th Edition, Method 4500-P-E Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.

d Standard Methods 19th Edition, Method 4500-Norg-D D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.

e Parsons, T.R., Y. Maita and C. Lalli. 1989. Manual of Chemical and Biological Methods for seawater analysis. Pergamon Press, 173 pp.

f Perkin-Elmer Model 2400 CHN Analyzer Technical Manual.

B.6. & B.7. Calibration Procedures and Preventive Maintenance for Field Equipment

The equipment in the basic parameter kits are calibrated on a yearly basis to assure data accuracy. New thermometers are tested in air, room temperature bath and ice bath against a certified mercury thermometer. Volunteers using oxygen titration kits and/or field meters will process an oxygen sample from a room stabilized bath or in a group sample training session. Existing equipment is field checked for accuracy. Results are compared to the acceptable accuracy range. For existing equipment, refer to **Appendix VII** for Calibration procedures. Any new or additional sampling equipment (DO meters, refractometers, etc) are maintained and calibrated under the manufactures specifications and requirements with assistance from the SMAST Laboratory.

SMAST staff will perform a routine inspection and maintenance of field sampling equipment prior to distribution to volunteers, as well as at the conclusion of the sampling season. Throughout the season spare parts and replacement equipment is available to keep field operations running smoothly in the event of equipment failure. All equipment is cleaned and put away in good working order at the completion of the sampling season. Dissolved oxygen test kit reagents are stored in a cool dry location with new oxygen reagents being ordered and used each year. At the completion of the season, left over and returned reagents are delivered to SMAST Lab for proper disposal.

B.8. Acceptance Requirements

The level of repeatability of the data collected by the Water Quality Monitoring Program and the chemical assays conducted by the SMAST Coastal Systems Analytical Laboratory are presented in **Table 8**. The levels presented are those to be used in the actual screening of Program data. In some cases they are more rigorous than the minimum requirements put forth in **Tables 2,3,4**.

Table 8. Acceptance criteria for QC samples

Parameter	Acceptable % difference	Acceptable absolute difference
Temperature	[a]	1.0C
Salinity	[a]	1 ppt
Dissolved Oxygen	[a]	1 ppm
Water Clarity	[a]	0.2 m
Nitrate + Nitrite coastal WQ	10 %	0.5 µM
Ammonium coastal WQ	10%	0.5 µM
Orthophosphate coastal WQ	10%	0.5 µM
Chlorophyll *a*	20%	0.5 µM
Total dissolved N	20%	0.5 µM
Particulate N & C coastal WQ	20%	2 & 10 µM

[a] Acceptable percent difference not applicable, absolute acceptable error takes precedence.

B.9. Data Acquisition Requirements

For the water quality monitoring program, U.S.G.S. topographic maps are used to identify site locations. Printed scanned copies with marked site ID's are provided to each volunteer. Rainfall Data is obtained at the end of each sampling season. Rainfall data (date and amount) is from the Town of Falmouth Waste Water Treatment Facility (WWTF), OTIS Air Force Base, Wareham Cranberry Station, City of New Bedford WWTF, and by a volunteer at the Westport River Watershed Alliance office. Rainfall data is checked against water monitoring data following specific rainfall events for its effects on individual water quality parameters and if biasing to the data is shown.

B.10. Data Management

Data from field observations is recorded on standardized data sheets (**Appendix II-IV**) on-site at the time the measurements are taken. The volunteers are asked to check that all data is accurate and legible. As the data is received by the Project Officer and the SMAST laboratory, it is reviewed and the volunteers are contacted to clarify any numbers, issues or if any information is missing. The Project Officer and the SMAST laboratory both maintain copies of field parameter data and the SMAST laboratory maintains duplicate hard copies of raw analytical data as well as computer back-up disks of entered data.

The nutrient sampling field observations are recorded on data sheets/chain of custody on-site at the time the samples are collected. The volunteers are asked to check that all data is accurate and legible before relinquishing the data sheets with the sample coolers. The nutrient analysis data is provided to the Project Officer in a predefined spreadsheet format. Data entry is checked by two laboratory personnel and the QA/QC checks by the Project QA Officer.

Data will be reviewed by the Project QA Officer before being entered by laboratory staff into a computer spreadsheet. Upon being entered the data sheets will be checked against the spreadsheet on a regular basis and against a final print out. If an unusual recording is noted, data will be re-checked, samples re-run if appropriate and if necessary the volunteer will be called to discuss the data. Volunteers are also instructed to take replicate samples if an unusual reading is recorded in the field.

Upon completion of data entry and data checks, the following will be calculated for each parameter: averages, minimum value, maximum value, standard deviation, and any other required calculation. Statistical methods will be used to determine significant trends.

C. ASSESSMENT AND OVERSIGHT

C.1. Assessment and Response Actions

Review of the Orleans Water Quality Program field activities and data documentation is the responsibility of the Program Officer. All field and laboratory activities will be reviewed with scientific advisors from the Coastal Systems Group from SMAST. After data has been QC checked, the data will be evaluated relative to the whole of the database and a second QC check performed. Because this is a collaborative effort, the Program Officer and scientists from SMAST will meet frequently to review and discuss the activities, performance and objectives of the Water Quality Monitoring Program.

C.2. Reports

Annual data reports on the results of the monitoring program will be provided to the Project Officer by the SMAST laboratory. Additional synthesis reports will be provided upon agreement between the Project Officer and SMAST. It is anticipated given long-term nature of the Orleans Water Quality Monitoring Program that subsequent long-term synthesis reports will be developed based on the annual data. Specific reports linked to ongoing or proposed alteration or management actions will be prepared as required in collaboration between the Orleans Water Quality Monitoring Program and SMAST scientists and would be available to municipalities, citizens or agencies as part of the decision making process.

Sub-watershed based fecal coliform data collected through this program will be used for evaluations of embayments and their watersheds from a bacterial perspective for non-point source prevention and remediation activities, such as installing future stormwater remediation projects. Results will be used to flag potential hot spots in need of further investigation and or remediation.

D. DATA VALIDATION AND USABILITY

D.1 Data Review, Validation / Usage

As part of the data review and validation all field and lab data will be reviewed and discussed by the Program Officer and Science advisors from SMAST to determine if the data meets the QAPP objectives and decisions will be made to accept or reject the data. Errors in data entry will be corrected, and any outliers will be flagged for further review or discarded. Upon completion of data entry and data checks, the data will be summarized with the intent to develop findings, conclusions and recommendations. The findings shall include a measure of water quality using the Buzzards Bay Project Health Index. Other water quality indices may be used to augment the BBP Index as needed. This Health Index is a mechanism in which embayments will be compared and is also useful in tailoring the data and summarized results to a broad range of data users. These users range from public to resource managers, and regulators in federal and state agencies. The Bay Health Index measures the relative summertime health of each of the Bay's major harbors and coves. It does not include bacteria monitoring and is not an index of swimability or shellfish bed status but does make general conclusion on the summertime water quality in particular areas, embayments or sampling locations.

The data will be used by the Town of Orleans to develop management plans for its watersheds and coastal waters. The data will also be used by the Coastal Systems Group at SMAST to include Orleans as part of the Massachusetts Estuaries Project, a multi-disciplinary inter-agency program to develop data based nitrogen management and TMDLs for 89 of the States estuarine ecosystems. The Estuaries Project involves the collection of long-term water quality monitoring data integrated with watershed hydrology and land use, and carries these efforts through to the implementation of resulting data for development nitrogen management approaches for restoration of each individual estuary.

D.2 Data Review, Validation

Data entry is checked by two laboratory personnel with QA/QC checks by the Project QA Officer. This nutrient spreadsheet is then checked by the Project QA Officer and eventually imported into the master database for this project and the whole of the data rechecked.

Data will be reviewed by SMAST Coastal Systems Program Analytical Facility staff before being entered into a computer spreadsheet. Upon being entered the data sheets will be checked against the spreadsheet on a regular basis and against a final print out. If an unusual recording is noted, the sample will be re-run (as appropriate) and if necessary the volunteer will be called to discuss the data. Volunteers are also instructed to take replicate samples if an unusual reading is recorded in the field.

Upon completion of data entry and data checks, the following will be calculated for each parameter: averages, minimum value, maximum value, standard deviation, and any other required calculation. The averages for lowest 20 percent oxygen saturation, secchi disk,

chlorophyll, organic and inorganic nitrogen will be scored and combined to form the Water Quality Bay Health Index by which embayments will be compared.

D.3. Reconciliation with Data Quality Objectives

If data requirements and quality indicators are not being met in accordance to the projects specification and objectives, equipment and techniques will be reassessed and improved, sampling volunteers will be retrained and related specifications may be revised for the next sampling season.

The Project Officer and Scientific advisors from SMAST will meet periodically to review and discuss the activities, performance and objectives of the Water Quality Monitoring Program. The data on the health of each embayment will be shared as warranted with the volunteers, community leaders, environmental managers, scientific and education community, Commonwealth of Massachusetts and Federal officials, and the general public for management actions. In doing so, any limitations due to equipment failure, sampling performance, or techniques will be explained in final reports and other summary reports as needed.

APPENDIX I: Orleans Field Sampling Protocol

EMBAYMENT SAMPLING WITH OXYGEN METER

1. Preliminary Check List The Night Before Sampling
Ensure all equipment is present (see check list)
Label bottles with station ID, date (Mo/Day/Yr), depth
Put freezer pack in freezer

2. Morning of Sampling
Take freezer pack out of freezer and put into cooler
Put roll of paper towels into kit
Fill wash bottle with distilled water
Turn on oxygen meter
Remove oxygen probe from meter and replace after a few seconds.

3. At Sampling Station
Drop anchor
Record Station Observation Data:
Names of Field Team
Site location
Date of sampling
Time of day
Wind direction and force from Beaufort scale
Weather conditions, precipitation, other

4. Record Secchi depth and total station depth:
Lower Secchi disk into water until it just disappears from view and read depth at water line.
Lower below view, raise until just visible and read depth at water line.
Average two depths (should be close) and record.
Lower disk slowly until it reaches bottom, record total depth.

5. Record Temperature and Oxygen Using Oxygen Meter Calibration

Ensure that the oxygen meter has been on for 20 minutes and that readings are stable over ~30 seconds.
Press the **UP** and **DOWN ARROW** keys simultaneously.
Meter display should read 0, press **ENTER.**
Press **ENTER** a second time.
Press **ENTER** a third time.

6. Taking oxygen readings with oxygen meter:
Record dissolved oxygen (mg/L) and Temperature (^{o}C) before making any measurements.
Remove probe from calibration chamber and lower to the first depth.
Bob the probe up and down until the dissolved oxygen values no longer increase.

When values are stable (~2 minutes), record DO (mg/L) and Temperature (^{o}C) and repeat for the next depth.
After last depth has been recorded, rinse the probe with wash bottle and return probe to calibration chamber
Repeat **6.** at the next station. DO NOT RECALIBRATE.
If dissolved oxygen readings are less than 5 mg/L you must take a winkler bottle.

Collecting oxygen sample for Winkler titration
Sample collection using sampling pole:
Put stoppers in bottles and hook bottom hoses to wires at bottle mouths.
Lower pole to the proper depth (S = 15 cm ; B = 30 cm above sediment; M = ½ of the total water depth.
Pull stopper out using RED cord. When the bubbles stop, bring bottle aboard for processing.
Lower tube from oxygen bottle to the bottom of Winkler bottle.
When collection bottle is ¾ drained, remove rubber tubing and carefully drop in the glass stopper.
IF THERE ARE BUBBLES THE SAMPLE MUST BE RETAKEN.
Leaving the water on the lip of the bottle, remove glass stopper and add reagents 1 and 2 to bottle.
Replace stopper without trapping bubbles and shake while holding the stopper. Repeat after 2 minutes.
Wait until visible floc settles to bottom half of bottle.
Open reagent 3, remove glass stopper, pour into bottle, replace stopper, shake until all the particulates dissolve.
Place tap water over glass stopper. Place safety cap over stopper. Place bottle in cooler.

Oxygen Sample collection using Niskin Bottle
Blue air vents should be in the closed position (perpendicular to the drain plug).
Pull open the top Niskin end cap with nylon string and attached ball
Holding onto the top end cap, pull open the bottom end cap and thread the loop through the loop of the top end cap. Press down on the metal piston (has line traveling through it) and place the loop inside the metal pin. This will hold the Niskin caps open. Lower Niskin to appropriate depth.
Trigger the Niskin by releasing the weight and allowing it to slide down the line, you should feel the caps close.
Raise the Niskin into the boat, open the vent on the top of the niskin and collect an oxygen sample using the sampling process above

Collect nutrient samples
Sample collection using sampling pole
Attach a dark 1L bottle (chlorophyll) and a light 1L bottle (nutrients) to the sampling pole.
Lower pole to appropriate depth. Pull out stoppers. When the bubbles stop, bring pole aboard for processing.
Remove bottles from pole. Cap dark bottle, put on ice.
Put thermometer into light bottle, record temperature on data sheet. Cap and set aside.
Place filter on clear plastic filter holder; align steps in holder top and bottom and secure with screw cap.
Shake 1L light bottle, rinse and fill 60cc syringe with water from bottle
Attach filter holder to syringe. Push through and discard first 20cc of water.

Push next 20cc of water into the small white plastic bottle (60ml) provided, shake and discard water.
Push remaining water into 60ml bottle. Refill syringe and push enough water into bottle until it is 99% full (over shoulder) and cap. Check that the bottle is labeled and put on ice.
Cap 1L bottle and put on ice.
Check off space data sheet for appropriate sample.

Collecting nutrient samples with Niskin
Use above procedure for collecting water samples for oxygen determination
Rinse 1L bottles. Using the hose, transfer a small amount (50ml) of water to the clear and dark bottles. Cap, shake, pour out.
Fill the 1L dark bottle, cap, put on ice. Fill 1L light bottle, cap.
Proceed according to the above procedure

Coliform Sampling
Label sterile sample bottle with site ID, date and time.
Plunge bottle into water up to the wrist (4-5 inches) facing into the current.
Pour off ~1/2" of water to leave an air, then cap the sample tightly.
Return to the shore and immediately place the sample bottle in the cooler on ice.

ORLEANS STREAM SAMPLING PROTOCOL

1. Preliminary Check List The Night Before Sampling
Ensure all equipment is present (see check list)
Label bottles with station ID, date (Mo/Day/Yr), depth
Put freezer pack in freezer

2. Morning of Sampling
Take freezer pack out of freezer and put into cooler
Put roll of paper towels into kit
Fill wash bottle with distilled water

3. At Sampling Station
Drop anchor
Record Station Observation Data:
Names of Field Team
Site location
Date of sampling
Time of day
Wind direction and force from Beaufort scale
Weather conditions, precipitation, other

4. Record Secchi depth and total station depth:
Lower Secchi disk into water until it just disappears from view and read depth at water line.
Lower below view, raise until just visible and read depth at water line.
Average two depths (should be close) and record.
Lower disk slowly until it reaches bottom, record total depth.

5. Collect nutrient samples
Sample collection using sampling pole
Attach a dark 1L bottle (chlorophyll) and a light 1L bottle (nutrients) to the sampling pole.
Lower pole to appropriate depth. Pull out stoppers. When the bubbles stop, bring pole aboard for processing.
Remove bottles from pole. Cap dark bottle, put on ice.
Put thermometer into light bottle, record temperature on data sheet. Cap and set aside.
Place filter on clear plastic filter holder; align steps in holder top and bottom and secure with screw cap.
Shake 1L light bottle, rinse and fill 60cc syringe with water from bottle
Attach filter holder to syringe. Push through and discard first 20cc of water.
Push next 20cc of water into the small white plastic bottle (60ml) provided, shake and discard water.
Push remaining water into 60ml bottle. Refill syringe and push enough water into bottle until it is 99% full (over shoulder) and cap. Check that the bottle is labeled and put on ice.
Cap 1L bottle and put on ice.
Check off space data sheet for appropriate sample.

6. Coliform Sampling

Label sterile sample bottle with site ID, date and time.
Plunge bottle into water up to the wrist (4-5 inches) facing into the current.
Pour off ~1/2" of water to leave an air, then cap the sample tightly.
Return to the shore and immediately place the sample bottle in the cooler on ice.

ORLEANS EMBAYMENT SAMPLING WITH WINKLER

1. Preliminary Check List The Night Before Sampling
Ensure all equipment is present (see check list)
Label bottles with station ID, date (Mo/Day/Yr), depth
Put freezer pack in freezer

2. Morning of Sampling
Take freezer pack out of freezer and put into cooler
Put roll of paper towels into kit
Fill wash bottle with distilled water

3. At Sampling Station
Drop anchor
Record Station Observation Data:
Names of Field Team
Site location
Date of sampling
Time of day
Wind direction and force from Beaufort scale
Weather conditions, precipitation, other

4. Record Secchi depth and total station depth:
Lower Secchi disk into water until it just disappears from view and read depth at water line.
Lower below view, raise until just visible and read depth at water line.
Average two depths (should be close) and record.
Lower disk slowly until it reaches bottom, record total depth.

5. Collecting oxygen sample for Winkler titration
Sample collection using sampling pole:
Put stoppers in bottles and hook bottom hoses to wires at bottle mouths.
Lower pole to the proper depth (S = 15 cm ; B = 30 cm above sediment; M = ½ of the total water depth.
Pull stopper out using RED cord. When the bubbles stop, bring bottle aboard for processing.
Lower tube from oxygen bottle to the bottom of Winkler bottle.
When collection bottle is ¾ drained, remove rubber tubing and carefully drop in the glass stopper.
IF THERE ARE BUBBLES THE SAMPLE MUST BE RETAKEN.
Leaving the water on the lip of the bottle, remove glass stopper and add reagents 1 and 2 to bottle.
Replace stopper without trapping bubbles and shake while holding the stopper. Repeat after 2 minutes.
Wait until visible floc settles to bottom half of bottle.
Open reagent 3, remove glass stopper, pour into bottle, replace stopper, shake until all the particulates dissolve.
Place tap water over glass stopper. Place safety cap over stopper. Place bottle in cooler.

6. Oxygen Sample collection using Niskin Bottle

Blue air vents should be in the closed position (perpendicular to the drain plug).
Pull open the top Niskin end cap with nylon string and attached ball
Holding onto the top end cap, pull open the bottom end cap and thread the loop through the loop of the top end cap. Press down on the metal piston (has line traveling through it) and place the loop inside the metal pin. This will hold the Niskin caps open. Lower Niskin to appropriate depth.
Trigger the Niskin by releasing the weight and allowing it to slide down the line, you should feel the caps close.
Raise the Niskin into the boat, open the vent on the top of the niskin and collect an oxygen sample using the sampling process above.

7. Collect nutrient samples

Sample collection using sampling pole

Attach a dark 1L bottle (chlorophyll) and a light 1L bottle (nutrients) to the sampling pole.
Lower pole to appropriate depth. Pull out stoppers. When the bubbles stop, bring pole aboard for processing.
Remove bottles from pole. Cap dark bottle, put on ice.
Put thermometer into light bottle, record temperature on data sheet. Cap and set aside.
Place filter on clear plastic filter holder; align steps in holder top and bottom and secure with screw cap.
Shake 1L light bottle, rinse and fill 60cc syringe with water from bottle
Attach filter holder to syringe. Push through and discard first 20cc of water.
Push next 20cc of water into the small white plastic bottle (60ml) provided, shake and discard water.
Push remaining water into 60ml bottle. Refill syringe and push enough water into bottle until it is 99% full (over shoulder) and cap. Check that the bottle is labeled and put on ice.
Cap 1L bottle and put on ice.
Check off space data sheet for appropriate sample.

8. Collecting nutrient samples with Niskin

Use above procedure for collecting water samples for oxygen determination
Rinse 1L bottles. Using the hose, transfer a small amount (50ml) of water to the clear and dark bottles. Cap, shake, pour out.
Fill the 1L dark bottle, cap, put on ice. Fill 1L light bottle, cap.
Proceed according to the above procedure

9. Coliform Sampling

Label sterile sample bottle with site ID, date and time.
Plunge bottle into water up to the wrist (4-5 inches) facing into the current.
Pour off ~1/2" of water to leave an air, then cap the sample tightly.
Return to the shore and immediately place the sample bottle in the cooler on ice.

APPENDIX II. Water Sampling Data Sheet

Orleans Water Quality Monitoring Program – Water Sampling Data Sheet

General Conditions

1. **Sampler Data**

Station: WMO #_____, Embayment (circle one):Pleasant Bay , Nauset Estuary , Cape Cod Bay
Further station description (optional):
Date: ____/_____/ 02 Volunteers Names:_____
Testing to be done (circle one): Stream , Surface & Bottom , Middle (if total depth is less than 1.5 M)

2. **Physical Conditions**

a) Wind Force (Beaufort Scale # 0-12) #_____
b) Wind Direction, (circle one) N, NE, E, SE, S, SW, W, NW, calm
b) Tide (circle one): Ebb (out going) Tide, Flood (incoming) Tide
c) Time of nearest low tide: _____ am / pm (use tide table)
d) last 24 hour precipitation (circle one)1. None, 2. Light , 3. Heavy = #_____
e) Weather conditions (circle as many as necessary): 1. Clear 2. Partly Cloudy 3. Overcast
4. Fog / Haze 5. Drizzle, 6. Intermit. Rain 7. Rain = #'s _____
f) Water Conditions (circle all): CLEAR, CLOUDY, ALGAE/PLANTS, FOAM, OILY SHEEN, DEAD FISH, DEBRIS/TRASH

3. **Depth Measurements**

a)Secchi Disk Transparency: Disappears (descending) at_____**(M)** , Reappears (ascending) at _____ **(M)** Average : _____ **(M)**
b) Does Secchi Disc hit bottom before it disappears? **Yes** **No** (circle one)
c) Total Depth at Station: _____**(M)**
d) I am doing a **stream sample** and **water depth is** _____ **centimeters** or _____ **inches**

4. **Oxygen Sample and Temperature (if using DO meter**)

DOM *Calibration* Value _____**mg/L**_____% Sat , with Salinity = 0.0 **Meter** # _____

Depth	**Sample Time (6-9 AM)**	**Sample Depth (M)**	**Temperature (degrees C) (0.1 units)**	**Dissolved Oxygen**	
				(% saturation) (0.1 units)	**(mg/L) (0.1 units)**
Surface (down .15 m)					
Middle (half of total depth)					
Bottom (up .5 m from bottom)					

* **Winkler** being done because (circle one) : No DOM, or A DOM reading was less than 5 mg/L (do at bottom" depth")

5. **Circle ALL bottles collected and stored in cooler** (properly labeled with ice packs):

1 L brown bottle, Surface 1 L white bottle Surface 60 ml FILTERED white bottle Surface
1 L brown bottle, Mid-level 1 L white bottle Mid-level 60 ml FILTERED white bottle, Mid-level
1 L brown bottle, Bottom 1 L white bottle, Bottom 60 ml FILTERED white bottle, Bottom
Winkler,capped, with "water seal" and with 3 chemicals 250 ml "Bacteria (scoop surface water)

6. Other Comments:_____

7. Chain of custody :

Relinquished by _____ Received by :_____ Received at WQ Lab _____

Date / Time_____ Date /Time _____ Date / Time _____

APPENDIX III. Water Sampling Chain of Custody Form

Orleans Water Quality Monitoring Program Chain of Custody Form

COASTAL SYSTEMS GROUP
Chain of Custody Record

Personnel Contacts

RECEIVED at Orleans		RECEIVED at SMAST	
name:		name:	
date:	time:	date:	time:
Project: Orleans WQ Monitoring			
Embayment ID:			
COLLECTED By:		Orleans Coordinator CONTACT	
name:		name:	
date:	local	phone:	

Sample Notes

Special notes/ Sample Handling	Total number of samples Stream: Bay:

Sample Bottle & Assay Check-In

Sample ID	PO4	NH4	NOx	TDN	POC/N	Chla	Salinity	Winklers	Coliform	
Planned for Streams	**x**	**x**	**x**	**x**	**x**	**x**	**x**		**x**	
Planned for Bay	**x**	**x**	**x**	**x**	**x**	**x**	**x**	footnote	**x**	
Actual Samples Collected:										
Station ID / depth										

footnote: Winkler bottles are collected from some stations routinely and others only when <5 mg/L DO is found on meter.

APPENDIX IV Laboratory Bacterial SOP: Barnstable Co. Public Health Department

Bacteria Sampling Techniques and Protocol

Samples will be collected by the grab sampling technique. Depending on outfall volumes, and beach access, samples will be collected in one of two ways. If flow volumes and hazards are low, samples will be collected by hand filling a sterile 500 mL nalgene bottle placed directly into the outflow. If flow volumes are high and/or there is a potential for hazard at the site (slippery access, etc.), samples will be collected using a sampling pole. A pole that holds a sample bottle securely in place during collection. Samples will be collected according to the following procedures:

1. Using a new surgical glove pick up a sterile sample container and label it with site ID, date and time.
2. Remove the lid on the bottle taking care not to contaminate inside the lid or bottle. Hold the lid.
3. Turn the bottle upside down so that the opening is facing straight down and plunge the bottle into the water approximately 12 inches in the upward flow or up current side of where you are standing.
4. Turn the bottle upright into the current and allow to fill as you sweep the bottle up and out of the water.
5. Raise the bottle out of the water and pour off enough water to leave an air space of approximately ½ inch (this allows for the laboratory to shake the sample) and then cap the sample tightly.
6. Return to the shore and immediately place the sample bottle in the cooler on ice.
7. If using a sample pole, lower the sampling pole into the flow of water at an angle, just below the water surface. Position the bottle so the opening is upstream from the pole. Water should flow directly into the bottle and should not contact the pole or base of the bottle before flowing into the mouth.
8. Fill to the fill line marked on the bottle leaving a half inch of air space.
9. Cap the bottle and remove it from the sampling device and place on ice in cooler.
10. After all the samples have been collected, collect an additional sample into a graduated cylinder for temperature and salinity.
11. Record sample ID, collection time, air temperature, water temperature, and salinity on the data sheet. Include tide if it is a beach sample.
12. Move to next location, use a new glove (to prevent any cross contamination) and repeat steps 1-12.Place all samples into the cooler with ice and ensure bottles are capped tightly.
13. Complete and sign data sheet (Chain of Custody form) before delivering samples to the laboratory or drop off location as soon as possible.

Submittal of Samples during Lab Hours
Iced samples will be delivered to The Coastal Systems Program Lab, or directly to Barnstable County lab, or New Bedford Health Lab.

Sample Processing
The laboratory will filter and culture samples for fecal coliform in accordance with the Membrane Filtration Technique (Standard Methods, 18th Edition) using m-FC agar by DIFCO. Samples will be filtered within 6 hours of collection time.

Sampling Equipment
- cooler
- blue ice
- 500 mL sterile bottles (minimum size – 100ml)
- graduated cylinder for temperature and salinity parameters
- field thermometer
- Hydrometer or refractometer
- sampling pole
- disposable surgical gloves
- (4) large rubber bands to attach bottle to pole
- waterproof pen
- sharpies
- data sheet (chain of custody)

Orleans Water Quality Monitoring Program Bacteria Sampling Data Sheet

Embayment_____Area description_____

Town/City _____Volunteer Name_____

Date of Collection _____

Shore/Boat_____ Last Rain_____Amount_____Wind Direction_____

Low Tide_____ High Tide_____ Air Temperature °C _____

Remarks_____

Lab ID	Station ID	Location Description EX. Pipe, stream	Collection Time	Tide E/F	Grab or Composite	Pipe Flow (estimate)	Temp. °C	Salinity (ppt)	pH	Comments	Lab Results

Relinquished by: Date: Time: Received by: Date: Time:

1_____ 2_____

3_____ 4_____

APPENDIX V. Orleans Sampling Station Coordinates* and Location

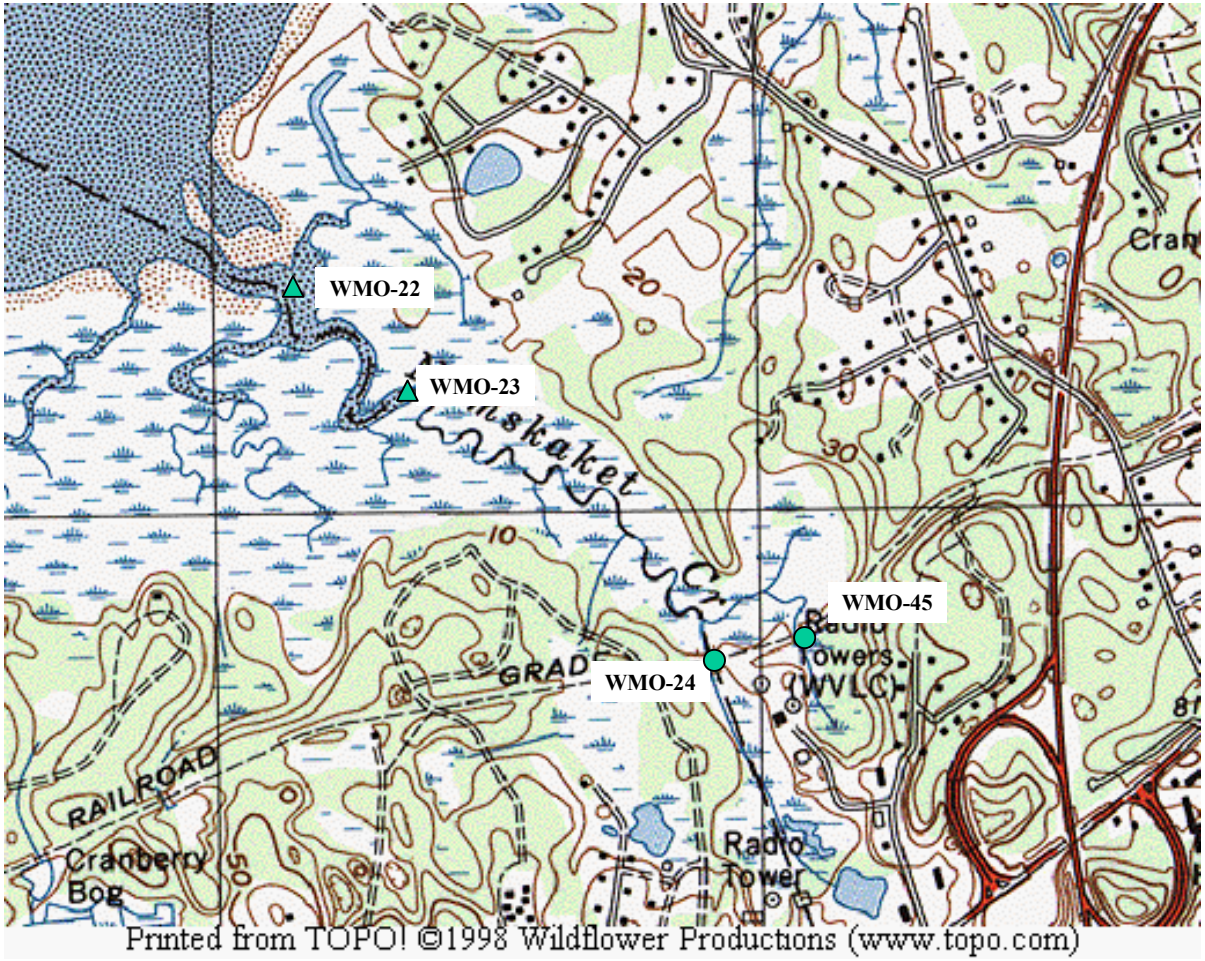
Type	Sample ID		Nutrients 1=mid 2=surf.+btm. Depths	Meter / Winkler	GPS-Garmin Lat	GPS-Garmin Long	(uncorrected) GPS-Trimble Lat	(uncorrected) GPS-Trimble Long
-- --	-- --	GPS Reference on Dock at start of trip			41046.744	69058.274	41046'44.57	69058'16.23
PLEASANT BAY SYSTEM:								
Quanset Pond								
Stream	WMO-11	Outflow-Meadow Bog Pond	1	No D.O.	41044.364	69058.650	41044'21.58	69058'40.34
Bay	WMO-12	Little Quanset Pond	1	M-2	41044.352	69058.699	41044'21.11	69058'42.01
Bay	WMO-01	Quanset Pond	2	M-2	41044.229	69058.768	41044'14.93	69058'49.32
Bay	WMO-02	Pleas.Bay off Q.Pond	2	M-3	41044.065	69058.946	41044'04.31	69058'56.35
Paw Wah Pond								
Stream	WMO-13	Stream from Duck Marsh into Paw Wah Pond	1	No D.O.	41045.385	69058.180	41045'23.12	69058'10.97
Pochet Inlet								
Bay	WMO-03	Off North Tip Sampson Island & Mid Barley Neck	2	M-3	41045.698	69057.041	41045'41.18	69057'02.14
Bay	WMO-04	Off 1st Town Landing, Barley Neck-Lower Pochet Inlet	1	M-4	41046.205	69056.986	41046'12.20	69056'59.04
Bay	WMO-05	Off Pochet Nect Town Landing- Upper Pochet Inlet	1	M-4	41046.453	69056.605	41046'26.59	69056'36.62
Stream	WMO-44	Stream into Areys Pond	1	No D.O.				
Areys Pond								
Bay	WMO-06	Mid Namequoit River (pre-narrowing to Areys pond	1	M-5	41045.56	69058.464	41045'33.61	69058'27.55
Bay	WMO-07	Lower Namequoit River, Basin before mouth	1	M-5	41045.674	69058.206	41045'40.51	69058'12.34
Lonnies Pond								
Stream	WMO-42	Cranberry Bog Inflow to Lonnies Pond	1	No D.O.				
Stream	WNO-43	Pilgrim Lake Inflow to Lonnies Pond	1	No D.O.				
Bay	WMO-08	The River - Off Lonnies Pond	1	M-6	41046.189	69057.971	41046'11.20	69057'58.45
Bay	WMO-09	Mouth of Frost Fish Cove	1	M-6	41046.454	69058.004	41046'27.15	69058'00.48
Bay	WMO-10	Tom Rattles-Locust Tree Dock off Lucy Point	2	W-2	41046.652	69058.234	41046'38.90	69058'14.50

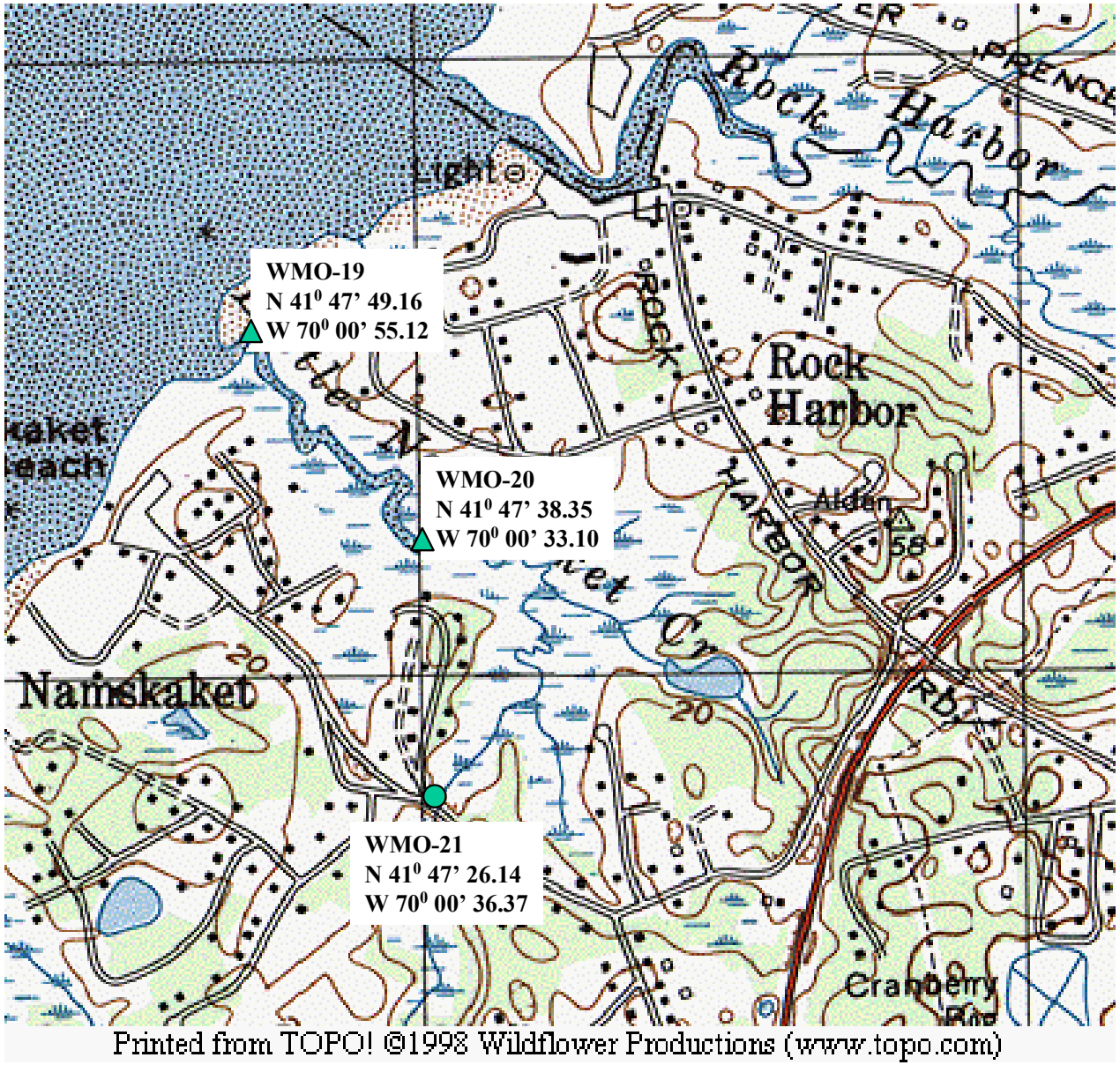
NAUSET INLET SYSTEM:								
Town Cove								
Bay	WMO-25	Head of TC: To Buoy then go 100 feet out to channel	2	M-7	41047.358	69059.037	41047'21.81	69059'02.79
Bay	WMO-26	3 houses "up" from Nauset Marine	1	M-8	41047.736	69058.739	41047'44.23	69058'43.83
Bay	WMO-27	Green Channel Marker #13 to shellfish grant side	1	M-7	41048.062	69058.470	41048'03.79	69058'28.26
Bay	WMO-28	20 feet south of Red Channel Marker #8	1	M-8	41048.416	69057.971	41048'25.16	69057'58.27
Bay	WMO-29	Red Channel Marker #6, near tiny marsh island (past Rachels Cove)	1	M-9	41048.774	69057.846	41048'46.23	69057'51.00
Bay	WMO-30	100 yards off Stony Island	1	M-10	41048.673	69057.105	41048'40.48	69057'06.49
Bay	WMO-31	Woods Cove - Center	1	M-9	41048.638	69057.477	41048'37.91	69057'28.29
Bay	WMO-32	Channel off Southern large marsh Island, near Inlet	2	M-11	41048.623	69056.821	41048'37.54	69056'49.06
Mill Pond								
Bay	WMO-33	Outer Mill Pond, outside "Dike" (called Roberts Cove)	1	M-10	41047.825	69056.838	41047'49.44	69056'50.26
Bay	WMO-34	Mill Pond Main Inner Basin, inside "Dike"	2	M-12	41047.693	69057.043	41047'41.56	69057'02.10
Bay	WMO-35	Little Cove (Innermost Basin of Mill Pond)	1	M-12	41047.711	69057.301	41047'42.60	69057'18.16
Upper Nauset System								
Bay	WMO-36	Marsh Channel to Salt Pond Bay off Town Landing	1	M-13	41049.439	69057.834	41049'26.48	69057'50.31
Bay	WMO-37	Salt Pond Bay - Central Basin (south of Salt Pond) Large Rock on Shore	1	M-14	41049.685	69058.004	41049'41.06	69058'00.14
Bay	WMO-38	Salt Pond - Basin (vistors center)	2	M-14	41050.141	69058.286	41050'08.60	69058'17.48
Bay	WMO-39	Nauset Bay - Basin (off from greenhead fly boxes-as far as can get up bay)	1	W	41050.239	69057.284	41050'14.42	69057'17.24
Bay	WMO-40	Central Marsh Channel - Adjacent Tall Pole in edge of Marsh	1	M-13	41049.653	69059.161	41049'39.09	69057'10.26
Bay	WMO-41	Outside Nauset Harbor "Ocean Station"	2	M-11				
CAPE COD BAY SYSTEMS								
Rock Harbor								
Bay	WMO-14	Offshore Reference: 100feet past last pine in channel	2	M-1				

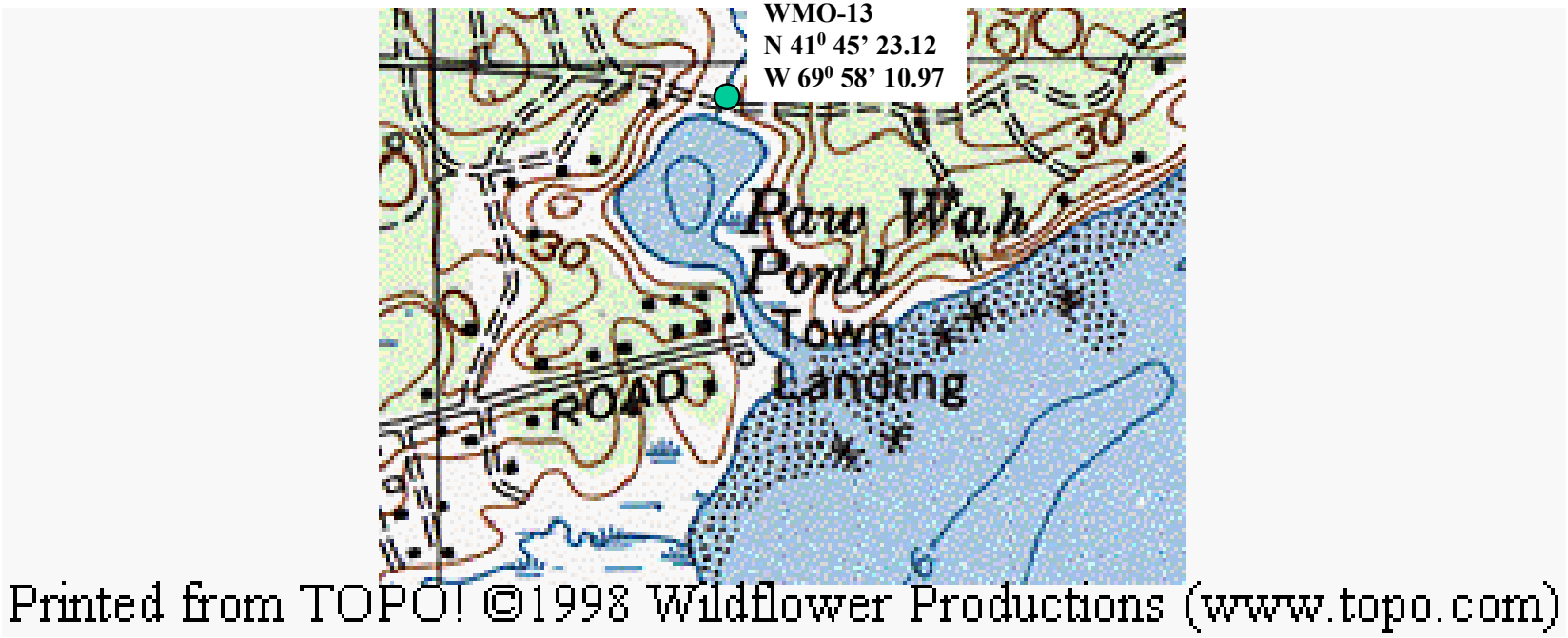
Bay	WMO-15	Outer Rock Harbor at outer end of Marina Dock	1	W	41048.003	70000.499	41048'00.18	70000'30.00
Bay	WMO-16	Mid Rock Harbor between light post in front of boat launch	1	M-1	41048.035	70000.328	41048'02.50	70000'19.88
Bay	WMO-17	Upper Rock Harbor in Marsh Channel off small dock (across marsh)	1	W	41048.031	70000.280	41048'01.85	70000'16.86
Stream	WMO-18	Headwaters to Rock Harbor (near granite post/Town line-DPR)	1	No D.O.	41047.914	69059.567	41047'54.80	69059'34.04
Little Namskaket Bay	WMO-19	Mouth of Creek off sandy beach area after first bend (walk into flow)	1	W	41047.819	70000.918	41047'49.16	70000'55.12
Bay	WMO-20	Mid Marsh - off dock at #25 Gull Lane	1	W	41047.637	70000.552	41047'38.35	70000'33.10
Stream	WMO-21	Headwaters to marsh at Roadway	1	No D.O.	41047.441	70000.606	41047'26.14	70000'36.37
Namskaket Creek Bay	WMO-22	Mouth of Creek at confluence of 3 tributaries	1	W	NA	NA	NA	NA
Bay	WMO-23	Mid Marsh - (pick spot)	1	W	NA	NA	NA	NA
Stream	WMO-24	Bog side of stream leaving Radio Tower bog (FW outflow)	1	No D.O.	NA	NA	NA	NA
Stream	WMO-45	Bog side of stream leaving Hurleys Bog (FW outflow)	1	No D.O.	NA	NA	NA	NA

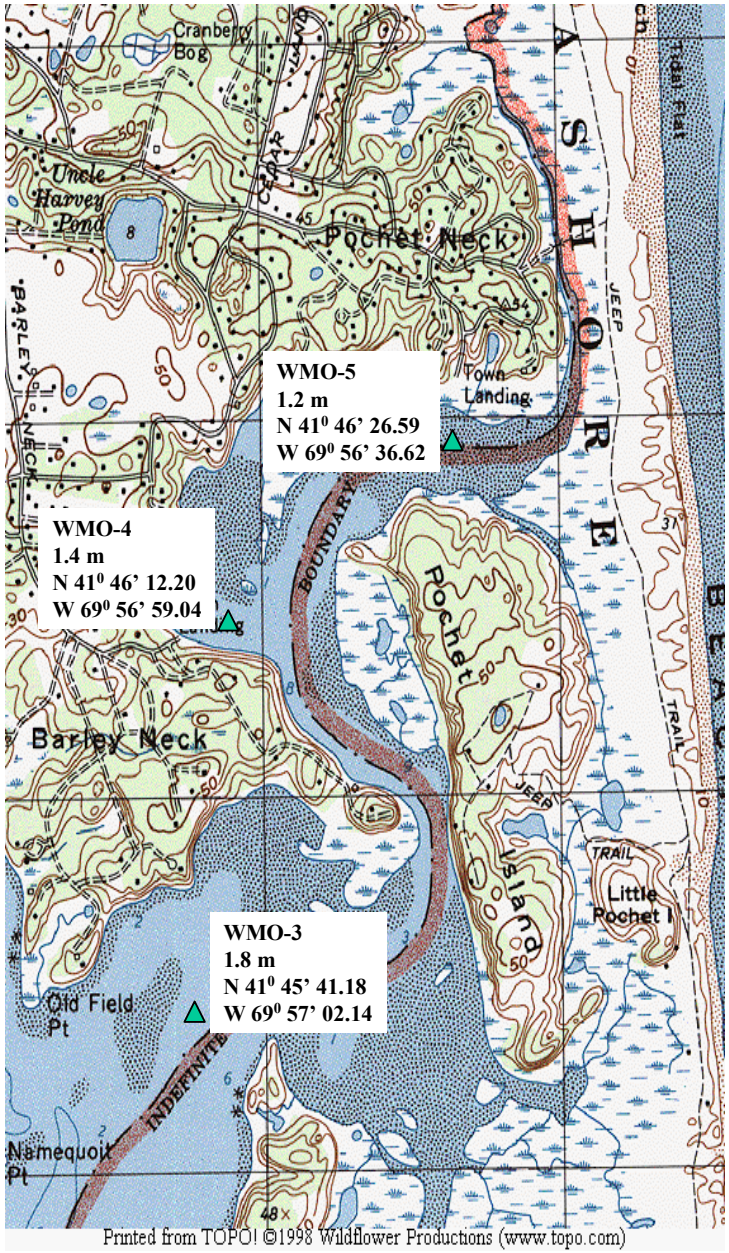
*Missing GPS coordinates to be obtained during 2002 sampling season

APPENDIX VI. Maps of Sampling Stations U.S.G.S. Quads
MAPS OF SAMPLING STATIONS USGS QUADS

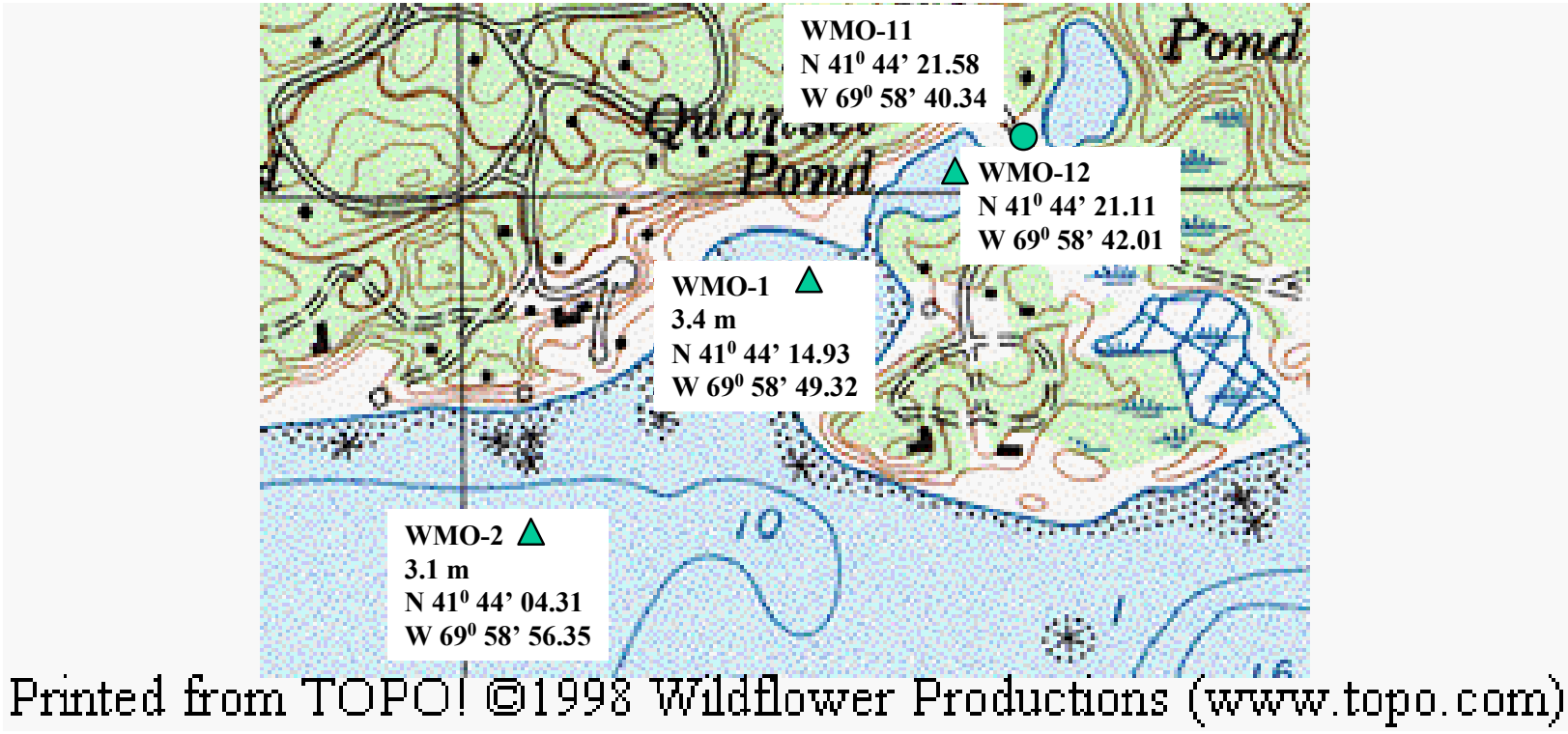


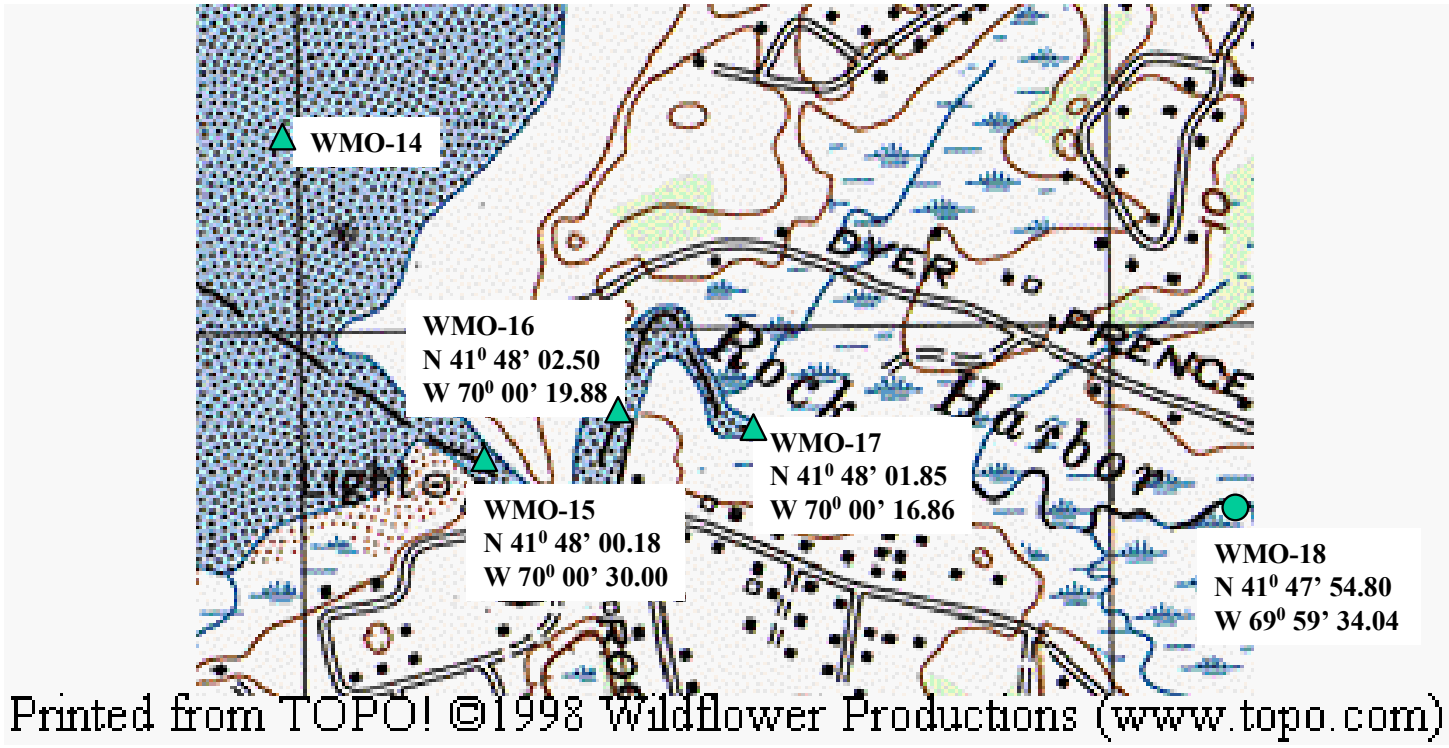

Rock Harbor
WMO-19
N 41⁰ 47’ 49.16
W 70⁰ 00’ 55.12
Rock Harbor
WMO-20
N 41⁰ 47’ 38.35
W 70⁰ 00’ 33.10
Alden
58
Namskaket
WMO-21
N 41⁰ 47’ 26.14
W 70⁰ 00’ 36.37
Cranberry
Printed from TOPO! ©1998 Wildflower Productions (www.topo.com)

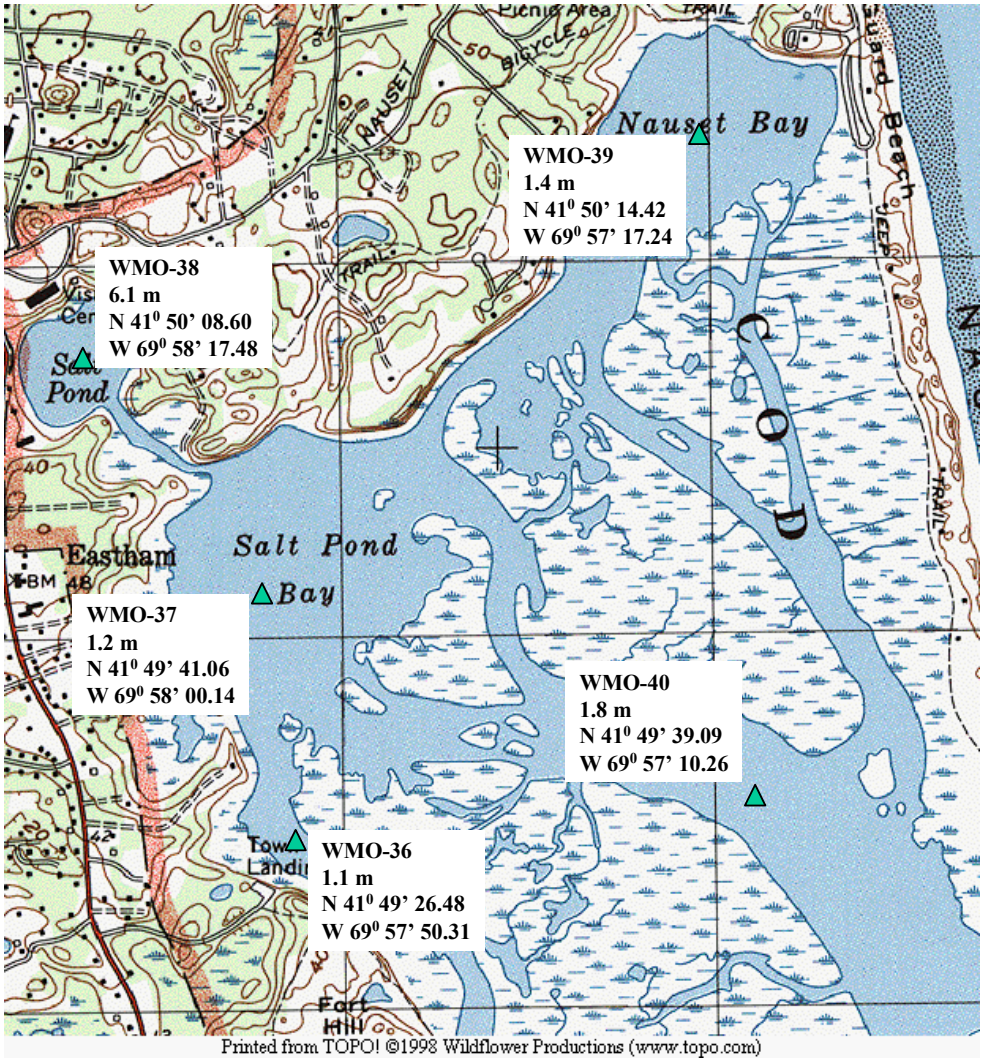

WMO-13
N 41⁰ 45’ 23.12
W 69⁰ 58’ 10.97
Pond
Town
Landing
ROAD
30
30
6
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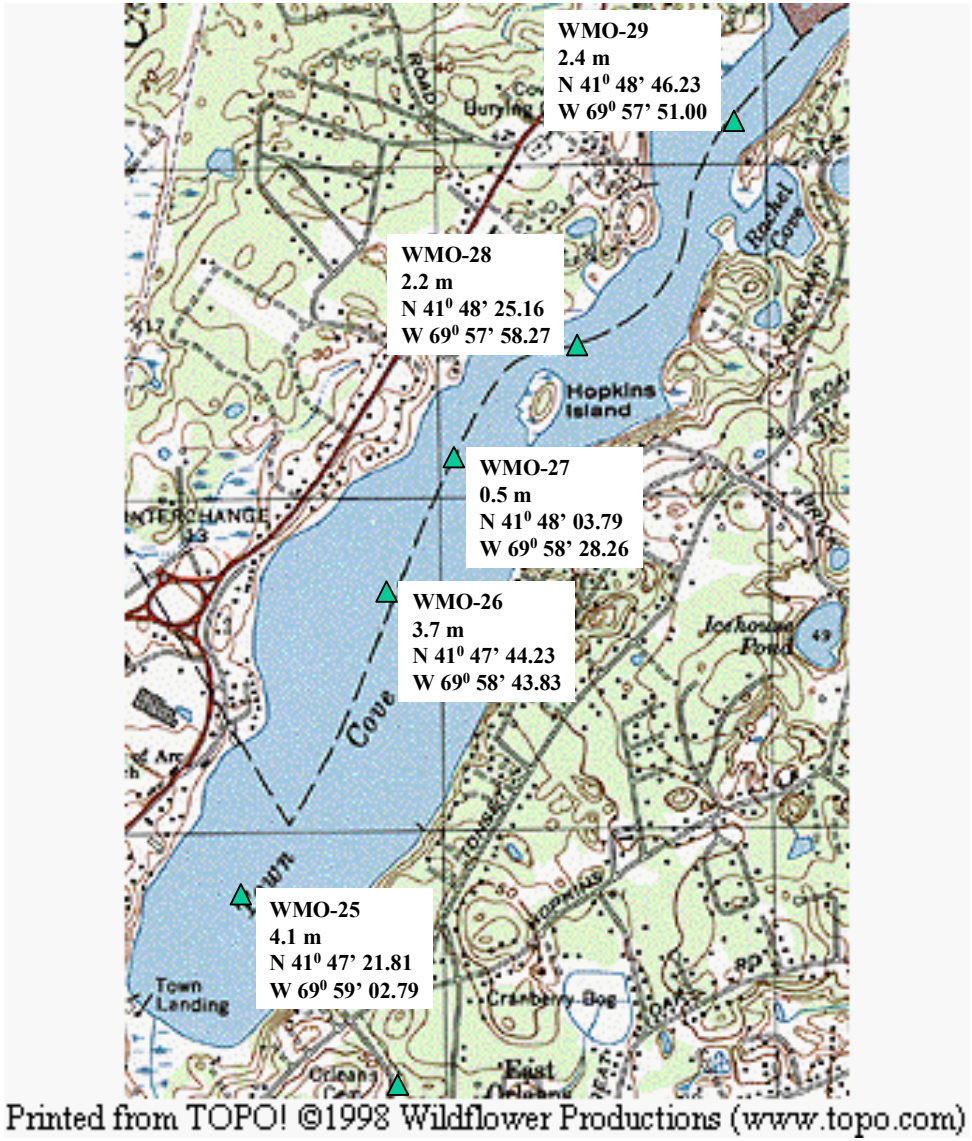
ınce\Orlean_CoastalWQ_database\OrleansQAPP2002B


WMO-11
N 41⁰ 44’ 21.58
W 69⁰ 58’ 40.34
Pond
Pond
WMO-12
N 41⁰ 44’ 21.11
W 69⁰ 58’ 42.01
WMO-1
3.4 m
N 41⁰ 44’ 14.93
W 69⁰ 58’ 49.32
WMO-2
3.1 m
N 41⁰ 44’ 04.31
W 69⁰ 58’ 56.35
10
Printed from TOPO! ©1998 Wildflower Productions (www.topo.com)


WMO-14
WMO-16
N 41⁰ 48’ 02.50
W 70⁰ 00’ 19.88
WMO-17
N 41⁰ 48’ 01.85
W 70⁰ 00’ 16.86
WMO-15
N 41⁰ 48’ 00.18
W 70⁰ 00’ 30.00
WMO-18
N 41⁰ 47’ 54.80
W 69⁰ 59’ 34.04
BYER
Rock Harbor
Printed from TOPO! ©1998 Wildflower Productions (www.topo.com)



ınce\Orlean_CoastalWQ_database\OrleansQAPP2002B


WMO-29
2.4 m
N 41⁰ 48’ 46.23
W 69⁰ 57’ 51.00
WMO-28
2.2 m
N 41⁰ 48’ 25.16
W 69⁰ 57’ 58.27
WMO-27
0.5 m
N 41⁰ 48’ 03.79
W 69⁰ 58’ 28.26
WMO-26
3.7 m
N 41⁰ 47’ 44.23
W 69⁰ 58’ 43.83
WMO-25
4.1 m
N 41⁰ 47’ 21.81
W 69⁰ 59’ 02.79
Hopkins Island
Rachel Cove
Cove
Town Landing
Cranberry Bog
Printed from TOPO! ©1998 Wildflower Productions (www.topo.com)

APPENDIX VII. Water Sampling Instrument Calibration Procedures

GPS Station Location:

Garmin Global Positioning Units will be used to locate all sample stations by each team. Location measurements will proceed only with at least 5 satellites available to assure accuracy. The goal will be a minimum of six satellites using the High Precision setting. Station locations will be corrected with the download data available at the National Geodetic Survey CORS site (continuously operating reference system). Corrected station locations are expected to be accurate within 3 meters and probably within 1 meter.

YSI 55 Field Meter:

The YSI-55 model field monitoring equipment will be maintained and checked as per manufacturers' instruction. The probe is a non-detachable, combination sensor that reads dissolved oxygen and temperature. As suggested, the probe and its storage cell will be rinsed with clean tap water after each use and stored in the cell as per manufacturers specification.

It will be the responsibility of SMAST Laboratory Manager to check the calibration status of any meter prior to using the instrument and to check its calibration periodically during use. A log documenting problems experienced with the instruments and corrective measures taken will be maintained by the Sampling Coordinator for each instrument (identified by serial number).

All equipment to be utilized during the field analysis and laboratory analysis will be checked, prior to its use, to see that it is in operating condition. This includes checking the manufacturer's operating manuals and the instructions with each instrument to ensure that all maintenance items are being observed.

The YSI 55 Meter and Probe will be calibrated for dissolved oxygen before each sampling event following manufacturers recommended procedures. The accuracy of dissolved oxygen readings will be checked by collection of samples for Winkler method DO determination at two-week intervals. Additional QA data is provided from Winkler assays conducted when a meter reading is <5 mg L^{-1}.

Any issues relating to calibration will be documented in the field logbooks and the monitoring of the work plan. Instruments will be left on for the duration of the sampling round, at station and en route. At the beginning and end of each field season a two-point calibration will be performed for each dissolved oxygen probe. Temperature will be calibrated quarterly, by validating the temperature in a known temperature water bath.

CALIBRATION OF DISSOLVED OXYGEN PROBE

The probe is equipped with a polargraphic Clark-type sensor. A new dissolved oxygen membrane will be installed at the beginning of the field season and at 8-week intervals as per the manufacturer's recommendations outlined below:

1. Before departing from the shore, turn the meter on by pressing the ON/OFF button, and then press MODE button until dissolved oxygen is displayed in mg/l or %. Allow the readings of dissolved oxygen and temperature to stabilize for 15 minutes.

2. The meter has two buttons with arrows; one pointing up and the other pointing down. Push both buttons simultaneously. The screen will read "0", press "enter" if at sea level to set altitude. If above sea level, use the arrow keys to set the altitude in units of 100 feet (i.e. 12 is 1200 feet). For work on all coastal ponds the altitude will be set at zero. When correct altitude is shown, press ENTER.

3. The YSI 55 will now display CAL in the lower left of the display screen. The calibration value should be displayed in the lower right of the screen and the current % reading shows in the main display of the screen. This reading should be within the range of 99 to 101 percent. When the current reading display is stable, press ENTER button thus proceeding to the salinity menu. In the salinity menu enter 0 salinity (salinity will be corrected for data processing). Press the ENTER key. The display will then read SAVE and return automatically to the Normal Operation Mode. Meter is ready to take readings but needs to be returned to mg/l mode, therefore press the mode key to do so.

DISSOLVED OXYGEN MEMBRANE CAP REPLACEMENT

The membrane cap will be replaced annually at the beginning of field season and again at 8-week intervals or as needed based on inspection of the membrane for defects.

1. Unscrew and remove the probe sensor guard.
2. Unscrew and remove the old membrane cap.
3. Thoroughly rinse the sensor tip with distilled water.
4. Prepare the KCl electrolyte according to the directions provided by the manufacturer with the solution .
5. Hold the membrane cap and fill at least ½ full with electrolyte solution.
6. Screw the membrane cap onto the probe moderately tight. A small amount of electrolyte should overflow.
7. Screw the probe sensor guard on moderately tight.

APPENDIX C: Massachusetts Estuaries Project QAPP

Massachusetts Estuaries Project
Quality Assurance Project Plan (QAPP)
Year 1 Final

SMAST
University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection



Quality Assurance Project Plan

The DEP/SMAST Massachusetts Estuaries Project

Year One Final

June 13, 2003

Dr. Brian Howes
Roland Samimy
School of Marine Science & Technology, UMass Dartmouth

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MA DEP Quality Assurance Officer:

Art Screpetis, MA DEP / DWM
627 Main Street, 2nd Floor, Worcester, MA 01608; Tel: 508-767-2875

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A. PROJECT MANAGEMENT

A.1 Title and Approval Page

A.2 Table of Contents: Estuaries Project, Quality Assurance Project Plan

A.3 Distribution List

Name (#copies)	**Address**
Coastal Systems Program (10 copies)	School of Marine Science & Technology University of Massachusetts-Dartmouth 706 Rodney French Blvd. New Bedford, MA 02744 508-910-6316
Department of Environmental Protection (5 copies)	Brian Dudley DEP-SERO 20 Riverside Drive Lakeville, MA 02347 508-946-2753
Department of Environmental Protection (1 Copy)	Art Screpetis, MA DEP / DWM 627 Main Street, 2nd Floor Worcester, MA 01608 508-767-2875
Environmental Protection Agency (1 copy)	Mary Jo Feurbach USEPA Region 1 One Congress Street Boston, MA 02203 617-918-1578
Environmental Protection Agency (2 copy)	Arthur E. Clark, U.S. EPA 11 Technology Drive N. Chelmsford, MA 01863 617-918-8374
Cape Cod Commission (2 copies)	Ed Eichner Cape Cod Commission Rt. 6A Barnstable, MA 508-328-3828

A.4 Project Organization and Responsibilities

The Estuaries Project was established in December 2001 as a joint effort between The Massachusetts Department of Environmental Protection and scientists from the School of Marine Science and Technology at UMass-Dartmouth (SMAST). The goal of this effort is to provide technical guidance to DEP relative to policies on nitrogen sensitive embayments and to perform the data collection and modeling required for the management and restoration of southeastern Massachusetts' 89 embayment systems. These 89 embayments are contained within the 5 EOEA Massachusetts Watershed Initiative Basins (Cape Cod & Islands, Buzzards Bay, South Coastal, Mt. Hope Bay and Taunton River). This program will also provide the scientific foundation for the development of MA DEP nitrogen (and to a lesser extent bacterial) TMDLs on these estuaries. SMAST technical experts will work with DEP to classify the nitrogen sensitivity of Massachusetts shallow coastal water bodies, conduct quantitative linked watershed-embayment water quality modeling and site-specific thresholds analysis while also putting forward some available options for meeting nitrogen goals (or targets) for these embayments. Additional key technical partners include the Cape Cod Commission and the U.S. Geological Survey.

The Estuaries Project requires three years of baseline nutrient related water quality data on an embayment prior to the implementation of its full field data collection, modeling and thresholds development program. These data are needed both to guide field sampling and to validate the water quality model. At present the SMAST Coastal Systems Program is responsible for training guidance, development of sampling methodologies, preparation of field sampling gear, database preparation and preparation of reports for almost all baseline water quality monitoring programs within the study area. SMAST scientists will be responsible for review of existing monitoring data for suitability of inclusion into the Estuaries Project database. The SMAST Team will be responsible for identification of gaps in monitoring data needs for participating embayments and will work together with DEP to assist participating municipalities in establishing monitoring programs to acquire the necessary long term data as appropriate. All nutrient analyses are conducted within the Coastal Systems Analytical Facility at SMAST; bacterial analyses will be conducted primarily by the Barnstable County Health Laboratory. Alterations in program, quality assurance issues, and any other technical issues are dealt with through regular discussions between individual monitoring program coordinators and the Coastal Systems Program Manager/Project QA Officer.

While water quality monitoring data is a precursor to implementation of the Estuaries Project Approach in a specific embayment, the core of the Project is a detailed quantitative assessment and modeling approach to provide site-specific thresholds for management and restoration. Field data to be collected by the Project relates to site-specific determinations of hydrodynamics, habitat indicators, nitrogen attenuation and

recycling, and current and future land-use. These data are used in the Linked Watershed-Embayment Approach (Phase I, Estuaries Project Report: Howes et al. 2001). SMAST will be responsible for review of existing estuarine process data to determine suitability for inclusion into the water quality modeling, synthesis and development of site specific thresholds. Decisions regarding data incorporation will be made by the Estuaries Project Technical Team (which includes the DEP Project Manager, see below).

The technical and scientific aspects of the Estuaries Project are under the direction of Dr. Brian Howes, SMAST-UMassD (Technical Manager). He will be assisted by Roland Samimy (Technical Coordinator) in the coordination of this effort with DEP. Given the scope of the work, SMAST has established an Estuaries Project Technical Team (Technical Team) consisting of experts in each of the major data collection and modeling areas that comprise the Linked Watershed-Embayment Approach to be used. The Technical Team will provide judgment as to the suitability of historic data for inclusion into the Project database, develop project schedules, provide technical resources for outreach for DEP, and oversee each of the specific data collection efforts. The Technical Team will also serve to forward recommendations to the DEP Project Steering Committee as to alterations of approach, needs/issues arising on the local level that might be addressed, etc.

DEP is responsible for the regulatory aspects of this program, including implementation of results, completing the TMDL process and interfacing with town boards and local authorities on regulatory and wastewater management issues surrounding this effort. Brian Dudley is the primary responsible person representing DEP and serves as an interface between the scientific effort and other DEP, EPA and USGS officials. Together DEP and SMAST will work with individual towns as needed to establish water quality monitoring efforts where lacking so as to enable participation of these towns in the overall project.

The overall organization and primary personnel for the scientific aspects of the Estuaries Project are is follows:

Name	Roles	Responsibilities	Affiliation
Technical Team Personnel:			
Dr. Brian Howes	Technical Manager Technical Team, Chair	Science Oversight Synthesis/Thresholds	SMAST-UMassD
Roland Samimy	Technical Coordinator Technical Team	Science/DEP Coordination Surface Water Hydrology	SMAST-UMassD
Dr. Dave Schlezinger	Technical Team	N regeneration, D.O. Instrumentation	SMAST-UMassD
John Ramsey, P.E.	Technical Team	Modeling	ACRE
Dr. David White	Technical Team	Laboratory Analytical	SMAST-UMassD
Dr. Robert Hamersley	Technical Team	N attenuation in lakes	SMAST-UMassD
Paul Henderson	Technical Team / Lab Manager	General Field Program	SMAST-UMassD
Charlie Costello	Technical Team	Macrophyte Mapping	DEP
Ed Eichner	Technical Team	Land-use Analysis	Cape Cod Comm.
Tom Cambereri	Technical Team	Land-use Analysis	Cape Cod Comm.
Dale Goehringer	Lab Coordinator	Water Quality Monitoring	SMAST-UMassD
Mike Rapacz	Science/Policy Liaison	SMAST-DEP Coordinator	SMAST-UMassD
DEP / EPA Personnel:			
Brian Dudley	DEP–Project Manager Technical Team	DEP Oversight & input to Planning/Steering Comm. Communication to MWI	DEP-SERO
Arthur Screpetis	MA DEP Quality Assurance Officer	Guidance to DEP needs for TMDL Program	DEP/DWM
Mary Jo Feurbach	EPA Project Officer	Policy & Coordination	USEPA, Region I
Arthur Clark	EPA Quality Assurance Officer	QA/QC Guidance	USEPA, Region I
Affiliated Personnel:			
John Masterson Don Walter Peter Weiskel	Technical Team (as needed)	Watershed Delineation & Aquifer Modeling	USGS
Dr. Tom Bourne	Lab Director (sub-contractor)	Bacteria assays and VOCs as necessary	Barnstable County Laboratory

The USGS is performing the watershed delineations for the Cape Cod watersheds as part of another DEP project, to support water supply planning. However, after model development and parameterization for this project, the model will be used to support the watershed delineation needs of the Estuaries Project. The USGS is be responsible for providing that information to the Estuaries Project and for evaluating and assisting in the watershed delineation of embayment watersheds in the other regions of the study area.

The USGS will use its West Cape Model with an increased discretization to map the watershed each of the embayments on Cape Cod. The model will also yield watersheds to freshwater ponds (greater than 16 acres) and streams. Additional model output will include both time of time of travel contours (<>10 years) and freshwater discharge volumes for sub-watersheds. The USGS will confirm watersheds to embayments not on Cape Cod using the USGS Watershed Tools approach.

Bacterial assays will be performed by a DEP certified laboratory (generally Barnstable County Health Laboratory (Dr. Tom Bourne, director, 508-375-6608). The Coastal Systems Program at SMAST-UMassD will oversee the sample collection. DEP and SMAST in cooperation with the Massachusetts Watershed Initiative, Cape Cod Commission, EPA and various organizations will be responsible for the dissemination of results.

A.5 Project Background and Introduction

Purpose

The overarching project mission is the protection and restoration of the health of each of the each coastal embayments within Southeastern Massachusetts through integrated watershed-embayment nitrogen management planning. Embayment health is directly connected to the concentrations of specific nutrient species. Nitrogen is the limiting nutrient in coastal marine waters. It is the addition of nitrogen to estuaries which is causing their declining habitat quality through the process of eutrophication. The increasing nitrogen load to our estuaries results primarily through changing watershed land-use, converting forests to residential housing and associated development. This land-use shift typically results in increased wastewater discharges, fertilizer applications, and surface runoff, all of which contain high concentrations of nitrogen. This nitrogen reaches the estuaries through both stream and groundwater pathways. It is the stimulation of plant production (algae, phytoplankton and nuisance plants) by the increased nitrogen inputs that ultimately results in declines in oxygen levels within the bay waters and loss of diverse animal and plant populations. Therefore it is critical to quantify its sources and sinks for its multiple forms and manage its loading to an embayment.

The proposed effort will provide technical guidance to DEP relative to policies on nitrogen sensitive embayments and will perform the data collection and modeling required for the management and restoration of southeastern Massachusetts' 89 embayment systems. This program will also provide the scientific foundation for DEP's development of nitrogen (and to a lesser extent bacterial) TMDL's on these estuaries. Technical experts through SMAST will work with DEP to classify the nitrogen sensitivity of Massachusetts shallow coastal water bodies, conduct quantitative linked watershed-embayment water quality modeling and site-specific thresholds analysis and put forward some available options for meeting nitrogen goals (or targets) for these embayments.

In support of the overall Estuaries Project mission, the long-term project goal is to conduct the quantitative assessments of nitrogen within all of the 89 embayments of Southeastern Massachusetts (from Duxbury south: including Cape Cod and the Islands.)

Rationale

Coastal embayments throughout the State of Massachusetts (and throughout the U.S. seaboard) are becoming impaired by a host of pollutants and nutrient enriched, also a form of aquatic pollution. As such, the federal government (USEPA) through the implementation of the Clean Water Act, is mandating that states assess the health of their water resources. For those waters that have been identified by states as being impaired, the state must submit to the USEPA the names of the impaired water resources for listing on the federal 303(d) list of impaired waters. Water resources listed

on the federal 303(d) listing must then be studied adequately and Total Maximum Daily Loads (TMDLs) must be developed for the pollutants of concern in the water resource under investigation.

Recently, excessive nutrient loading to a water resource has been identified as a form of water pollution that leads to the deterioration of the ecological health of the water resource, even though a certain level of naturally occurring nutrient is necessary for the healthy function of aquatic habitat. Many of Massachusetts' embayments are approaching or are currently over the level of watershed nutrient loading which begins to cause declines in their ecological health. The primary nutrient causing the increasing impairment of the State's coastal systems is nitrogen and the primary watershed source of this nitrogen is wastewater disposal.

At present there is a critical need for state-of -the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within southeastern Massachusetts alone, almost all of the municipalities are grappling with Comprehensive Wastewater Planning. These municipalities are seeking guidance on the assessment of nitrogen sensitive embayments and the available options for setting nitrogen loading thresholds and for meeting nitrogen management goals. For example, the Towns of Chatham, Falmouth, Mashpee, Wareham and Fairhaven are in the midst of determining the nitrogen sensitivity of their embayments as part of wastewater planning and have encountered problems with existing approaches. In addition, the Towns of Wareham and Bourne are concerned with non-WWTF related nitrogen issues, and the Town of Orleans' Nutrient Management Project and the Slocums/Little River Project in Dartmouth are moving forward towards nitrogen planning aimed at nutrient remediation. DEP and SMAST are currently involved with each of these nitrogen planning efforts. The present effort by DEP and SMAST aims at creating a more quantitative, site-specific, and consistent approach and efficient and expansive collaboration for addressing the critical nutrient issues relative to coastal resources.

Project Objectives

The primary objectives of the Massachusetts Estuary Project are to:

- develop an embayment working group for program prioritization and rapid transfer of results;
- determine the nutrient sensitivity of each embayment;
- determine and fill in "data-gaps" required for management modeling;
- collect needed site-specific watershed and embayment data for each embayment to parameterize the Linked Watershed-Embayment Management Model;
- conduct the scientific portion of nutrient TMDL's, through the use of Linked Approach including development of site-specific ecological thresholds, using models which are both accepted and directly validated for each system;

- conduct bacteria data collection in the embayments which have identified bacterial contamination in support of bacteria TMDL development;
- provide immediate and on-going access to results for DEP managers;
- keep each embayment's model "alive" to address future regulatory needs. The embayment model for a particular community will be useable at anytime should a community request a specific model run to evaluate a nutrient management alternative.

Overview of Approach

A general overview of the Linked Watershed-Embayment Management Modeling Technical Approach is provided here. A complete description and sensitivity analysis of the approach has been performed (Howes, Ramsey & Kelley 2001) and is available through the DEP Program Manager or can be downloaded directly from the DEP Estuaries Project Web Site. The Watershed-Embayment Management Model was selected over other available watershed nitrogen loading approaches based upon its (a) ability to predict embayment nitrogen distributions (associated with habitat quality) over a range of estuarine types and watershed loads, (b) accounting for both watershed and embayment processes and (c) utility in conducting evaluation of alternative nitrogen management alternatives.

SMAST has been developing nutrient related TMDL methodologies for coastal systems since the mid 1980's. SMAST researchers with their collaborators have developed a quantitative approach for determining an embayment: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels and (3) quantitatively evaluating effects of changes in loading rate (predictive scenario runs on management alternatives). The approach is fully field validated (model results are confirmed by direct measurement) and unlike many approaches accounts for nutrient sources and their spatial distribution, nitrogen attenuation and recycling, and variations in tidal hydrodynamics. The validation requires that the parameterized model predict the average nitrogen concentrations at multiple points within the estuary (as derived from independent long-term measurements). The approach allows for direct and immediate analysis of management options and recommendations suggested by DEP or the DEP/SMAST Team. To apply this methodology a variety of field data collections and models must be employed.

The scientific component of a TMDL analysis (DEP will use this to complete the TMDL process) for each embayment is planned to be completed in 2 years, however, this requires that a baseline water quality monitoring program is underway. The baseline data includes warm weather sampling of nutrients (inorganic and organic), dissolved oxygen, chlorophyll, etc. (see Section B.1). The major time limitation is the need to collect three years of baseline nutrient data on each of the 89 embayments to support full nitrogen management planning. The collection of data on parameters requiring the use of more complex protocols (nitrogen recycling, hydrodynamics, etc.) will be conducted in parallel with the more basic "monitoring" sampling in order to maximize efficiency (lower costs) and provide evaluation of various proposed draft nutrient

management solutions as the project progresses (rather than having to wait until the full project is completed). This approach allows the DEP and the Towns' work on management planning and long-range facilities planning as the project moves forward.

The overall technical aspects of the project (estuarine monitoring and assessment, modeling and synthesis) will be under the direction of Dr. Brian L. Howes, Manager of the Coastal Systems Program at SMAST-UMD, who will work closely with the DEP Project Manager, Brian Dudley (SERO). The University will serve as the prime technical center for this effort, although technical specialists with proven capabilities and experience within the region will be integrated into the project as required. This effort will require a variety of technical specialists at SMAST who will directly oversee their area of expertise and will be responsible for data collection and synthesis. It is envisioned that these specialists will be in place for the duration of the Project (i.e. the same individuals will be conducting the work throughout). This will provide the consistency and efficiency to the Project. The technical aspects of the project will be coordinated through the Technical Team which is composed of each of the technical leaders (surface water flow, land-use, modeling, watershed delineation, eelgrass mapping, etc.) and the DEP Program Manager. The overall technical staff, technical leaders and support staff, comprise the overall Project Team.

The general project tasks for TMDL analysis of <u>each</u> embayment will include data collection focusing on: watershed land-use and nitrogen source analysis, watershed nitrogen attenuation, regeneration of nitrogen within the embayment (recycling load), embayment nutrient distributions, field data collection and development of a hydrodynamic model, habitat indicators (eelgrass/macrophytes, benthic animals, summer oxygen minimum and duration). These parameters provide the data base for synthesis of nitrogen dynamics within the system, enabling construction of a water quality numerical model, site specific thresholds development and overall evaluation of the current and potential future ecological health of each embayment system. The synthesis, model and evaluation will then support management and restoration planning for each system.

The basic components of the Linked Watershed-Embayment Approach:

Nitrogen Related Water Quality Monitoring

(this baseline water quality monitoring data is to be provided external to the Estuary Project, but the Project will work with the Massachusetts Watershed Initiative (MWI) to initiate monitoring programs to fill existing data gaps)

Hydrodynamic Modeling

- bathymetric survey
- data collection on tidal exchange, salinity, validation by Acoustic Doppler Current Profiling (ADCP) of velocity

- quantitative numerical modeling & validation

Watershed Nitrogen Loading
- confirmation of delineation
- data collection on stream flow & nitrogen load (annual)
- land-use data (from Town Planning or CCC or other agency)
- watershed nitrogen model (present, build-out, tidal flow, and “best case”)

Quantitative Watershed-Embayment Nitrogen Model
- nitrogen regeneration within embayments
- system predictive model, with validation

Habitat Assessment
- dissolved oxygen (high frequency measurements in targeted areas)
- macrophyte surveys (eelgrass & macroalgae) & incorporated historical data
- benthic infauna community (indicators of stress)

Synthesis of Modeling and Habitat Assessments
- determination of embayment nitrogen loading tolerances (spatially)
- projection of embayment health under build-out, best case potential loadings and hydrodynamic alteration
- evaluation of soft and hard nitrogen management options (initial screening)

Information Transfers
- monthly meetings with Planning Committee
- quarterly presentations and discussions with Advisory Committee
- quarterly presentations and discussions with Executive Office of Environmental Affairs (EOEA) Watershed Team
- public meetings and workshops
- reports and data displays

The tasks required to fulfill all of the data needs and goals of the project are detailed below:

B. ESTUARIES PROJECT TASKS

The Estuaries Project has 3 basic types of tasks:

- Review and evaluation of existing data, particularly from water quality monitoring programs
- Collection of habitat data or data to implement the Linked Watershed-Embayment Management Model
- Hydrodynamic and water quality modeling and synthesis

The specific tasks to be undertaken in order to implement the Linked Watershed-Embayment Management Approach were detailed in the previous section and fall into 7 functional categories as follows:

(1) review of nitrogen related water quality monitoring data
(2) hydrodynamic modeling
(3) watershed nitrogen loading
(4) nitrogen regeneration within embayments
(5) linked watershed-embayment nitrogen modeling
(6) habitat assessment
(7) synthesis of modeling and habitat assessments

Each one of the 7 task categories is developed in its own section B.1 – B.7, below. The site-specific details, field protocols, data sheets and chain of custody forms are provided in the Appendices (I-XXII). Protocols which cross all task categories are generally presented in an B-I.

B.1 Review of Nitrogen Related Water Quality Monitoring Data

Overview:
The Estuaries Project requires three years of baseline nutrient related water quality data on an embayment prior to the implementation of its full field data collection, modeling and thresholds development program. These data are needed both to guide field sampling and to validate the water quality model.

At present, the SMAST Team has reviewed coastal monitoring programs throughout southeastern Massachusetts as to applicability of data to the Estuaries Project. Programs typically consist of trained volunteer monitors, although some are fully conducted by professional staff. Almost all of the present programs are associated with the SMAST Coastal Systems Program for technical guidance and sample analysis. In almost all cases nutrient analyses have been conducted within the Coastal Systems Analytical Facility at SMAST and all potentially acceptable bacterial analyses have been conducted in DEP certified laboratories (primarily the Barnstable County Health Laboratory).

In almost all programs, SMAST has been responsible for training guidance, development of sampling methodologies, preparation of field sampling gear, and database preparation. In many of the programs, SMAST also conducts the assessments and prepares the monitoring reports. This existing association will facilitate the evaluation and incorporation of monitoring data by the Estuaries Project Technical Team.

The review and evaluation criteria for monitoring data (and all other data) is detailed in B-II. Briefly, the Technical Team scientists will be responsible for review of existing monitoring data relative to the quality assurance criteria detailed in this section of the QAPP. Of course, there may be some site specific exceptions which permit data inclusion, but for the most part the Technical Team will use the criteria below to ensure consistency throughout the monitoring database.

In addition, the SMAST Team will be responsible for identification of gaps in monitoring data needs for participating embayments and will work together with DEP and MWI to assist participating municipalities in establishing monitoring programs to acquire the necessary long term data as appropriate.

Background:
Long-term population growth and associated increases in nitrogen loads has resulted in the increased eutrophication of estuaries, not only along the Southeastern Massachusetts shoreline, but along many of the world's coastlines. To address the ecological problems associated with this increase in nutrient loads, new TMDL methodologies have been developed to provide the quantitative approaches needed to

model current and future nitrogen loads and their environmental impacts. Fundamental to these models is the availability of long-term high quality monitoring data that takes into account year to year variations in key environmental variables, and on a time scale suitable to identify any trends that may follow changes in land use and/or discharge along the coastline. This baseline data is therefore essential to the development of appropriate nitrogen management and land use strategies for coastal ecosystems.

The primary goal of the **Review of Nitrogen Related Water Quality Monitoring Data Task** is to assemble and review all available long-term water quality monitoring data suitable for incorporation into the Estuaries Project. In many cases, this data has become available in recent years through the use of citizen-based water quality monitoring programs operating in Southeastern Massachusetts under the technical guidance of the Coastal Systems Program at SMAST. These water quality monitoring programs are staffed with trained volunteers, given both technical hands-on training of equipment use and sample collection, as well as fundamental information on ecological processes upon which sampling techniques were based. The goal of these programs is to collect research quality data using techniques appropriate for use by trained citizens; the techniques were developed to answer basic research questions and have been tested against more sophisticated (and expensive) approaches utilizing the tools of basic ecological research (Taylor, C.T. and B.L. Howes, 1994).

Each individual monitoring program within southeastern Massachusetts generally maintains the same goals of providing reliable water quality data to assist environmental managers to:

- Establish baseline water quality,
- Evaluate nitrogen loading inputs,
- Characterize and identifying sources of pollution,
- Document long-term environmental trends in water quality,
- Evaluate the relative success of clean-up efforts,
- Facilitate implementation of management recommendations

<u>Data Sought from Water Quality Monitoring Programs</u>:
This focus is also driven by the Regulatory Agencies, including EOEA's Watershed Initiative, as well as the Public's concern relating to nutrient issues. Regulation of nutrients is changing relative to watershed-based water quality management and the public interest in clean water. As well, management of nutrients continues to be at the top of the US EPA's Agenda.

In addition to nutrient measurements some of the monitoring programs collect parallel measurements of fecal coliform levels. Almost all of this bacterial data has been collected by Division of Marine Fisheries (DMF) and will be assembled with their help for use by the Estuaries Project. Limited additional bacterial data has been collected by

water quality monitoring programs. Bacterial contamination is the primary cause of embayment closures to shell fishing and swimming. Review of existing coliform data from state and local programs as well as ongoing monitoring programs will determine the need for additional measurements of fecal bacteria within specific estuaries within the Estuary Project study area. As available (and appropriate) this information will be evaluated for incorporation into Estuaries Project database **(see B-II)**.

The overall information and data sets desired from nutrient and bacterial related water quality monitoring efforts are as follows:

- Sampling and analytical protocols, QAPP if available
- Current site locations (with differential GPS as available)
- Volunteer training materials and procedures
- D.O./temperature/salinity/secchi depth data
- Dissolved and particulate nutrients data
- Bacterial data and laboratory contact information

The following sections detail the levels of quality assurance sought by the Estuaries Project, both for field and laboratory components of nutrient and bacterial monitoring programs. The field program includes both the procedures for sample collection and any field sample processing. The laboratory program includes sample holding, analytical and QA/QC procedures, chain of custody procedures and data transmission.

Guidelines for Acceptable Water Quality Monitoring Sampling Approaches: Samples are collected routinely for basic parameters (**B-I for guidance Field Sampling Protocols**):

- dissolved oxygen
- temperature
- salinity
- water clarity
- water samples for laboratory nutrient analysis
- weather/tide observations

Sampling stations should be placed along the long axis of an embayment and within major coves or tidally restricted basins. On a prescribed date selected based on tidal regime, generally 0600-0900 hrs during the 3 hours around mid-ebb tide, 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 dissolved oxygen levels can be identified and nutrient related water quality is typically at its annual

minimum. Additional cold season samples are also useful for to derive an annual assessment of water quality. Similarly, additional samples during periods of overcast weather when reduced sunlight and photosynthesis yield important process information to assess the nutrient sensitivity of an embayment.

Water samples should be collected from near 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 D.O. affects. Surface water samples should be collected at a depth of 15 centimeters below the surface and bottom water samples from a depth of 30-50 centimeters above the bottom. These depths have been determined by SMAST as representative. Collection of a sample 15 cm below surface prevents entrainment of the overlying air into D.O. samples and of floating material into nutrient samples. Sampling 30-50 cm above bottom prevents stirring of the bottom sediments and subsequent contamination of the nutrient sample.

It is important that a specific volunteer or professional sampler be identified for each sampling event for each station. Ideally the Monitoring Coordinator assigns each sampling station to an appropriate volunteer and conducts a joint visit to each site prior to sampling. Each station must have a unique identification code.

Station selection should seek locations that are representative of embayment water quality conditions and not just focus on small localized “hot spots”. Stations should be placed to give good geographic coverage throughout the inner and outer (where possible) portions of an embayment. Sample stations can include central basins sampled by boat (best) or boatyard docks, town landings and piers. An offshore reference station needs to be sampled for each embayment (several embayments can be associated with a single reference), ideally located by a navigational marker. Offshore stations need to be outside of the influence of the ebb tidal plume from adjacent embayments. All sampling stations need to be identified on a U.S.G.S. Quadrangle sheet or Nautical Chart, and ideally have either lat/long. Coordinates by GPS (**see Appendix I - XX**).

Bacterial sampling can be conducted in parallel with the nutrient sampling, although typically samples are only collected from the surface (-15 cm). In addition, storm water bacteria sampling may be conducted which focuses upon land-based point inputs, primarily from direct storm water inflows. This sampling generally centers upon rainfall events. Sampling is usually conducted during daylight hours 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 from the discharge pipe within river systems. The Estuaries Project bacterial sampling will focus primarily on comparison of dry versus wet weather bacterial distributions and the synthesis of existing long-term data sets **(B-III**). Samples need to be collected as per protocols in **B-I**.

To be acceptable to the Estuaries Project, all samples must be collected by trained staff or specially trained volunteers.

B.1.1 Data Quality Objectives

Data quality objectives have been selected as criteria for the **Review of Nitrogen Related Water Quality Monitoring Data Task** in order to fit with the goals of the Water Quality Monitoring Task and the concentrations and natural variability found within the tidal estuarine environments throughout southeastern Massachusetts. The methods and approaches which render data acceptable for inclusion of data into the Estuaries Project must meet the required levels of precision, accuracy, field blank cleanliness (analyte free), and detection limits. Although site-specific exceptions may be made after review by the Technical Team (B-II), the minimum performance criteria for the basic physical sampling is given in **Table B.1-1**, for the nutrient sampling in Table **B.1-2** and the bacteria sampling in **Table B.1-3**, below.

Table B.1-1 Water Quality Program, field parameters measured & data objectives

Parameter	Method	Range	Sensitivity	Precision	Accuracy	Calibration
Temperature[a]	Thermometer	-5°C to +40°C	0.5°C	±0.5°C	1°C	Certified thermometer over temperature range[b]
Temperature	Thermister	-5°C to +40°C	0.1°C	±0.1°C	0.2°C	Factory calibration & Certified Thermometer
Salinity	Conductivity Meter	0-35 ppt	0.1 ppt	±0.1 ppt	0.2 ppt	Certified Conductivity Standards
Salinity[c]	Hydrometer	1.000 to 1.050/ Specific Gravity	0.5 ppt	±1 ppt	1-2 ppt	Conductivity Meter & certified stds
Dissolved Oxygen	Modified Winkler Titration	0-16 ppm	0.5 ppm	±0.5 ppm	1 ppm	Dissolved gas standards
Dissolved Oxygen	Hach OX2P Oxygen Meter	0-16 ppm	0.1 ppm	±0.1 ppm	0.2 ppm	Dissolved gas standards
Water Clarity	Secchi Disk disappearance/ meters	0-15 m	1 cm	±10 cm	20 cm	NA

[a] Not preferred method for measuring temperature (Thermister Method is preferred). However, this method is acceptable if it is only used for calculating oxygen saturation for monitoring purposes.
[b] Calibration uses regression of field thermometer vs. certified thermometer with 5 temperature points and an $R^2 > 0.99$ and no pair of temperature points should exhibit a difference greater than ±1.0 degree.
[c] Not preferred method for measuring salinity (Specific Conductivity Method preferred). This method should not be used to determine stratification unless differences > 2 ppt.

Note: Field staff or trained volunteers collect water samples that are analyzed for the parameters listed in Table B.1-1 & B.1-2 and also record observations about weather and embayment conditions during sampling.

The nutrient sampling program must use accepted analytical methods for salt water analysis. These methods are accepted by the best marine research laboratories in the United States. Where EPA or Standard Methods techniques are available, they should be employed. Minimum performance criteria for water chemistry assays are listed in **Table B.1-2**, although the methods used in the program generally exceed these minima. The acceptable criteria for field blank cleanliness is generally a reading less than the detection limit. In occasional instances where high sensitivity methods are employed, the field blank must be less than 10% of the sample value.

Table B.1-2 Minimum Objectives for Nutrient Monitoring Parameters

Parameter	Matrix[a]	Field Precision	Laboratory Precision	Accuracy	Detection Limit
Nitrate + Nitrite	1	<30% RPD[b]	<20% RPD	75%-125% of matrix spike	0.25 uM[c]
Ammonium	1	<30% RPD	<20% RPD	75%-125% of matrix spike	0.25 uM
Total Phosphorus	1,2	<30% RPD	<20% RPD	75%-125% of matrix spike	1 uM
Orthophosphate	1	<30% RPD	<20% RPD	75%-125% of matrix spike	0.1uM
Chlorophyll *a*	1	<30% RPD	<20% RPD	75%-125% of matrix spike	0.1 ug/L
Total dissolved N	1	<30% RPD	<20% RPD	75%-125% of matrix spike	1 uM
Particulate C& N	1	<30% RPD	<20% RPD	75%-125% of matrix standard	1 uM

[a] 1 = saltwater, 2 = freshwater
[b] RPD = relative percent difference
[c] uM = micromolar, to convert to mg N/L multiply X 0.014, to convert to mg P/L X 0.031.

Table B.1-3 Bacterial Monitoring Parameters

Parameter	Matrix[a]	Sample Volume/ Container	Maximum Holding Time	Field Processing/ Preservation[b]	Units[c]
Fecal Coliform	1, 2	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice in cooler	1 CFU./100ml
Enterococci	1	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice in cooler	1 CFU./100ml
E. Coil	2	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice in cooler	1 CFU./100ml

[a] 1 = saltwater , 2 = freshwater
[b] field samples need to be held at 4oC until analysis at laboratory
[c] CFU = colony forming units
Note: Bacterial parameters should be assayed by Barnstable County Health Laboratory, New Bedford Health Laboratory or other DEP Certified Laboratory.

Appropriate sample bottles and filters need to have been employed in sample collection and proper QA samples, generally 5%-10% of field samples and 10% laboratory

duplicates need to have been run. Matrix spike and recovery procedures need to have been run where appropriate.

Precision

The precision of each laboratory chemical assay needs to have been determined from duplicate assays of five standards. The field precision is from duplicate assay of five blind field duplicates. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R^2 of the linear regression of each set of standards (N>5).

Accuracy

Accuracy of laboratory assays is determined from the analysis of standards for the standard curves, analysis of the matrix spikes and use of Performance and Evaluation Samples (commercially available). Accuracy is determined as the RPD of the assay of five standards run as samples within a series of analytical runs. This is compared to the RPD of five sets of Performance and Evaluation Samples. In addition, the accuracy of the method within the sample matrix is determined from the RPD of five matrix spikes experiments (standard additions), where appropriate.

Measurement Range

The usable measurement range for each chemical assay is only within the linear range as determined from least squares linear regression of laboratory standards (the upper limit and lower limit are set by the upper and lower standard concentrations). Concentrations above the linear range require standard dilutions for acceptable analysis. Since high values can be readily diluted and re-assayed the same day, the upper range of measurement is variable. Sample dilutions attempt to bring the concentration of the diluted sample into the middle of the linear range for the assay. The natural range for any analyte is typically less than 1000 fold.

Bacterial assays require a priori determination of dilutions. For fecal coliform analysis by membrane filtration, only 100 colonies can be counted per plate. Therefore, if more than 100 colonies per 100 mL are anticipated (based on previous experience) a dilution series by the laboratory will be requested (1X, 10X, 100X).

Representativeness

The goals of the monitoring programs are to provide data needed to evaluate overall water quality conditions throughout the sub-embayments and to determine changes over the long-term. Through the use of trained volunteers, we can effectively collect the substantial amount of spatial and temporal water quality data. The number and locations of sample stations is specific to each embayment and depends in part upon the embayment's size and shape, access, and navigational passages. Sampling is to be conducted throughout each estuary from its headwaters to its mouth under the same

conditions of tide and weather. This is possible due to the coordinated efforts of a large number of volunteers. The data collected by the volunteers is of sufficient quality to represent environmental conditions since (1) volunteers are trained each year and are constantly checked by the Coordinator, (2) volunteers collect physical data and D.O. which are performed in the field and (3) all nutrient assays are conducted at the SMAST laboratory.

Comparability

The results from each individual monitoring program will be directly comparable to each other. All of these programs use the same training and field sampling approaches and the Coastal Systems Analytical Facility at SMAST. The results are also comparable to many national programs, both volunteer and research, since the timing and distribution of sampling within the estuaries and the level of analysis is based upon understanding the whole system. As long the methods requirements meet those set forth in this QAPP, the data from any program should be able to be integrated into the Estuaries Project.

Completeness

The ultimate goal of the Water Quality Monitoring Program Task is to obtain comparable data from each estuarine ecosystem, enabling both inter- and intra-estuarine comparisons using consistent and reliable methods of sample collection and analysis. Completeness is gauged as the number of actual measurements divided by the number of planned measurements times 100%.

B.1.2 Training certification

Monitoring Program coordinators need to provide the Technical Team with sampling techniques and training materials. Volunteers should be taught the monitoring program's objectives and their role and responsibilities. The seriousness of the enterprise and the need for completeness of sample collection should be emphasized. Volunteers need to have received a formal hands-on training session prior to each field season. Specifically, volunteers need to be instructed in the importance of taking accurate and timely measurements and following the written field protocols provided. They should have been given a demonstration of the protocol and been observed collecting the samples and performing the tests. Retraining sessions should be held at the beginning of each sampling season. Ideally coordinators conduct individual follow up with field checks on new volunteers and seasoned volunteers are teamed with newly trained volunteers to assure consistent sampling technique. Volunteer assessment should be checked by evaluation of data against previous sample data from earlier assessments. The program coordinators should have a contact database for all volunteers. In reviewing data from water quality monitoring programs, the Estuaries Project will ascertain that field and laboratory approaches are related to a formal QAPP or sampling plan.

B.1.3 Documentation and Records

For acceptance into the Estuaries Project Database, monitoring programs need to have records of their standardized field datasheets **(example B-l)**. The nutrient data requires that Chain of Custody forms (COC) be extant.

Data will be reviewed for adherence to analytical protocols and to pre-established criteria (e.g., holding times, surrogate recoveries, initial and continuing calibration, matrix spikes, laboratory duplicates, blank contamination). Students t-test for paired samples, analysis of variance, may be used for interpretation. Data is transcribed only for the statistical analysis and each point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in the project files.

B.1.4 Data Acceptance Requirements

The level of repeatability of the data collected by the monitoring programs and the chemical assays conducted by the SMAST Coastal Systems Analytical Laboratory are presented in **Table B.1- 4**. In some cases they are more rigorous than the minimum requirements put forth in **Tables B.1-1, B.1-2, B.1-3**.

Table B.1-4 Acceptance criteria for Duplicate samples

Parameter	Acceptable % difference	Acceptable absolute difference
Temperature:	[a]	
Thermometer		1.0C
Thermister		0.2C
Salinity:	[a]	
Conductivity Meter		0.2 ppt
Hydrometer		1 ppt
Dissolved Oxygen:	[a]	
Hach Winkler		1 ppm
DO Meter		0.2 ppm
Water Clarity	[a]	0.2 m
Nitrate + Nitrite coastal water	20 %	0.5 µM
Ammonium coastal water	20%	0.5 µM
Orthophosphate coastal water	20%	0.5 µM
Chlorophyll *a*	20%	0.5 µM
Total dissolved N	20%	0.5 µM
Particulate N & C coastal water	20%	2 & 10 µM
Total Phosphorus	20%	1 uM
Fecal Coliform	30%	NA
E. Coil	30%	NA
Enterococci	30%	NA

[a] Acceptable percent difference not applicable, absolute acceptable difference takes precedence.

B.1.5 Data Acquisition Requirements

For the water quality monitoring program, U.S.G.S. topographic maps or nautical charts (or suitable location information) should have been used to identify site locations for the samplers. Printed scanned copies with marked site ID's need to have been provided to each volunteer. The exception is where sampling markers or moorings are placed by the project coordinator.

B.1.6 Data Management

Data from field observations should be recorded on standardized data sheets (**B-I**) on-site at the time the measurements are taken. Sampling personnel check that all data is accurate and legible before transferring it to the monitoring coordinator and/or laboratory supporting the specific monitoring program.

Data entry into the Estuaries Project database requires data entry checks by two laboratory personnel and the QA/QC checks are completed by the Project QA Officer

(after checks by the specific program's monitoring coordinator). Final use of the data by the Estuaries Project will be after review by the Technical Team.

B.2 Hydrodynamic Modeling

The Linked Watershed-Embayment Water Quality Model is based, in part, upon a site-specific numerical model of each embayment. The hydrodynamic model requires spatial data on the system configuration, as well as bathymetry and time-series tidal data. The model is calibrated based upon predicting tidal records at the inner tide gage locations and is validated based upon comparison of modeled versus observed (ADCP) current velocities over tidal cycles at key locations within appropriate embayments.

To ensure the Estuary Project provides the DEP with an efficient approach which results in a final product that provides the basis for sound engineering and management decisions, the project team has developed a phased hydrodynamic and water quality modeling approach. The approach focuses a high level of analyses and modeling on the more complex estuarine systems with simpler evaluations for some of the smaller embayments. A complex embayment is one with multiple tributary systems or with deep water that may periodically undergo stratification. Typically, a simple embayment has a single basin and single inlet and is relatively small (1 km in length).

The hydrodynamic task is divided into (a) field data collection and (b) modeling.

B.2.1 Data Quality Objectives for Measurement Data

The data quality objectives have been selected to fit with the goals of the Hydrodynamic Modeling Task and the natural variability of the tidal characteristics of the estuarine environments of southeastern Massachusetts. The methods and approaches establish the criteria for evaluating both data collected by the Estuaries Project and existing data being evaluated by the Technical Team for inclusion into Project database **(see B-II)**. All data must meet the required levels of precision, accuracy, and detection limits. The minimum performance criteria for the hydrodynamic instrument measurements are given in **Table B.2-1** below.

Table B.2-1
Hydrodynamic Program, field parameters measured & data objectives

Parameter	Method	Accuracy	Precision	Sampling Frequency	QC Samples	Required % Data Recovery[2]
Water Elevation	Strain Gage pressure sensor	±0.12 ft	±0.12 ft	@10 min. intervals for 40 days	Calibrated at known temp and atmos. pressure prior to and after each deployment	>75%
Depth Measurement (Bathymetry)	Single beam Echo sounder	±0.5 ft	±0.5 ft	2 soundings per second across transects 250-500ft apart	Comparison with soundings with survey rod	100%
Horizontal Position	Trimble Pro XR Differential Global Position System	± 2 ft in the horizontal	± 2 ft in the horizontal	1 position reading per second	Visual check with known points on rectified map	95%
Current speed and direction	Acoustic Doppler Current Profiler	±0.3 ft/sec	±0.3 ft/sec	1 measure per 5 seconds across a transect, repeated each hour for 13 hrs	Factory calibrated. Internal testing of compass, tilt sensors, beam integrity	>85%

[1] The ability to determine the change (or difference) in a measured parameter.

[2] % Data Recovery is calculated as the # of successful instrument days (days in which an instrument performs to specifications) divided by the number of total instrument days (# instruments times days of deployment) in a deployment. However, depending upon which instrument "fails", the total deployment may still be rejected, for example the reference station always need to have >90% instrument success.

Precision

The precision of the physical determinations is established by multiple measurements at each calibration point (standards). In addition, precision is generally factory determined and provided with the instrument. Field precision is from duplicate assay of multiple field duplicates measurements. For the bathymetric measurements, transects are crossed to provide multiple measurements of the same site during the survey. For the current speed and direction, multiple measurements are made at the same site. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R^2 of the linear regression of the calibration standard measurements.

Accuracy
Accuracy is determined from the analysis of known physical standards (levels, flows, locations). Most accuracy determinations are provided by the manufacturer, but the Project also checks the accuracy of the instruments during each field survey.

Measurement Range
The usable measurement range for each physical measurement is within the calibration determined by the factory and checked by the Project under standard conditions.

Representativeness
The goals of the hydrodynamic program are to provide data and modeling of flushing and circulation throughout the sub-embayments of each estuarine system, so that the data and model provide a valid representation of the dynamics of the real physical system. The number and locations of gauges and transects for bathymetry or current determination is specific to each embayment and depends in part upon the embayment's size and shape, and channels. Sampling is conducted throughout each estuary from its headwaters to its mouth, meaning from the inland extent to the tidal outlet to the ocean.

Comparability
The results from the hydrodynamic data collection and modeling of each individual embayment will be directly comparable among the 89 embayments. The Estuaries Project hydrodynamic program will use the same techniques, instrument requirements, modeling approach and technical personnel for all of the embayments. This is to help insure that the modeling effort for each individual system is directly comparable to the other systems in the study and also to past studies using this methodology.

Completeness
The requirement of the Estuaries Project is to obtain comparable data from each of 89 estuarine systems, enabling both inter- and intra-estuarine comparisons using consistent and reliable methods of data collection and modeling. Completeness for the Hydrodynamics field and modeling program is gauged as the number of parameterized and validated hydrodynamic models (1 per embayment) divided by the number of tasked embayments (up to 89) times 100%. Completeness of data collection for a single hydrodynamic parameter within a single estuary is gauged as the number of actual measurements of the individual parameter divided by the number of planned measurements times 100%.

B.2.2 Documentation and Records

Field observations and operational notes will be recorded in waterproof field notebooks on-site at the time the measurements are taken. The "data" from the physical measurements are collected and stored digitally within each of the instrument systems

employed. These data are then downloaded to PC's at the laboratory and kept in duplicate. The hydrodynamic modeling field team will check that all data is accurate and legible before providing a copy of the field notes and digital data to the Massachusetts Estuaries Project Technical Coordinator. Data is reviewed by the hydrodynamic program leader and the Project QA/QC Officer and the hydrodynamic field team is contacted if information is missing, questionable or incomplete. The technical coordinator maintains copies of the field notebooks, hard copies as well as computer back-up disks of entered data and digital copies of raw field data. After downloading and archiving data from instruments with self-contained memory buffers, the instruments memory buffer is cleared. Copies of data notebooks will be filed by embayment in the Massachusetts Estuaries Project library at SMAST maintained by the Technical Director and the Technical Coordinator.

B.2.3 Sampling Process Design

The basis for running the hydrodynamic model is the collection of data for measurable physical parameters (tidal effect on water level in the embayment, bathymetry of the embayment, velocity of surface water flowing through the embayment for model validation). The rationale supporting which parameters are measured is based on an understanding of the hydrodynamic function of coastal embayments as well as the data needs as defined by the hydrodynamic model of choice. Similarly, measurement locations and frequencies are also defined by the understanding of hydrodynamic circulation in an embayment. As such, tidal gage locations are typically established in such a way that it becomes possible to clearly quantify the driving head (offshore gauge) and its resultant effects on water flow through the system (gauges within the tributary sub-embayments). Tidal gages are generally placed at the headwaters of the embayment, a central location in the main body of the embayment, and offshore to establish the embayment boundary condition. Hydrodynamic data collection will focus on the warm weather months, but will not be restricted to the "summer". Tidal hydrodynamics of estuaries are not impacted significantly by season, as are water quality measurements.

A bathymetric survey of the embayment is performed along pre-established transects typically spaced 250-500 feet apart to generate a sufficiently detailed picture of the embayment bottom. Additionally, high-resolution surveying is performed along longitudinal transects mirroring the primary channel(s) in the embayment as well as the embayment mouth or in any areas where rapid changes in bathymetry occur. Location is checked by periodic measurement of known geo-referenced points during a survey.

Acoustic Doppler Current Profiling (ADCP) of the embayment will be performed for validation of the embayment hydrodynamic model. ADCP measurements are made along a transect for a complete tidal cycle to capture both flood and ebb tidal currents. ADCP measurements will be obtained along transects at critical transitions within the embayment. ADCP transect runs will be performed at the embayment mouth and

additional locations as the need is identified, specifically at the mouth of key tributary sub-embayments. The decision for performing ADCP transect runs in an embayment will be based on the size and complexity (simple versus complex embayments as discussed above in introduction to section B.2) of the embayment being modeled as well as channel geometry and water depth. Multiple ADCP transects will be performed in complex embayments and typically one transect in each simple embayment system. However, not all small simple embayments can support ADCP measurements due to shallow depth (<1 meter) or very low velocities.

B.2.4 Sampling Methods Requirements

Bathymetric Survey

Review Available Bathymetric Data and Collection of Additional Data:
Although NOAA digital bathymetry is available for southeastern Massachusetts, the NOAA depth measurements were made in the1930s. Although it is likely that bathymetric conditions within many areas of the systems have shown negligible change over the past 60-to-70 years (as determined from recent bathymetric surveys), the region adjacent to the inlets and some of the shallower areas need to have an updated bathymetric survey for this study. Significant alterations of embayment bathymetry since the NOAA charting typically result from natural inlet dynamics and dredging programs.

The Estuaries Project hydrodynamic program will collect depth data while the tide gages are collecting data within a given embayment. The depth measurements will be referenced to the measured local instantaneous water level; the local water level at all locations within a system will be referenced to the Town's vertical datum using water level measurements recorded by the tide gages (i.e., tide-corrected bathymetry measurements).

The bathymetry survey will be performed using a shallow draft boat, capable of traversing the shallow regions of the harbor adjacent to the inlet. Bathymetry transects running parallel to each other will be spaced approximately 250-500 feet apart depending upon the embayment size and structure. Detailed measurements will be obtained at the constriction points in the harbor entrance channel and a longitudinal transect running along the channel axis.

The bathymetric data will be acquired utilizing a portable bathymetric data acquisition system. A fathometer with depth resolution to 0.10 ft., will be used in conjunction with a differential geographic positioning (DGPS) system. This system records depth as a function of survey location. DGPS offers unparalleled positioning precision for the cost, typically yielding absolute horizontal accuracy to within 2 meters over 95 percent of the time. An integrated survey software package will be used to record depth and DGPS data simultaneously to a laptop computer. In addition to data recording, the survey

software is also a powerful data editing and graphics package that allows data to be corrected for tidal deviations before being output to a plotter. This system will be available to the Estuary Project through SMAST.

Positions will be recorded in Massachusetts State Plane 1983 coordinate system (X-Y) at an approximate rate of one value every two seconds. Depending upon boat speed during the survey (estimated at 3-5 knots), position measurements will be made approximately every 10-15 feet along each survey line. Depth values are recorded continuously (approximately every 0.5 seconds, or every 3 feet along the survey line).

Acoustic Doppler Current Profiler Surveys:
In addition to bathymetric data collection, the level of numerical modeling to be conducted in the more complex systems warrants model validation using tidal current data. Cross-sectional profiles of currents will be measured using an Acoustic Doppler Current Profiler (ADCP) over tidal cycles. This will be in association with other parts of the field program, but is conducted in parallel with the tide gauge measurements and bathymetric surveys.

ADCP measurements are made along a transect for a complete tidal cycle to capture both flood and ebb tidal currents. ADCP measurements will be obtained along transects at critical transitions within the embayment. ADCP transect runs will be performed at the embayment mouth and additional locations as the need is identified, specifically at the mouth of key tributary sub-embayments. The decision for performing ADCP transect runs in an embayment will be based on the size and complexity of the embayment being modeled as well as channel geometry and water depth. Multiple ADCP transects will be performed in complex embayments and typically one transect in each simple embayment system. However, not all small simple embayments can support ADCP measurements due to shallow depth (<1 meter) or very low velocities.

Tide Data Collection:
Measurements of tidal elevation will be made at 6-8 locations within the complex embayments and 2-5 locations within the more typical and simpler estuaries. Precise knowledge of tidal elevation time histories at strategic points is required to understand the flushing characteristics throughout the system. As the tide rises in the offshore system to southeastern Massachusetts embayments (Nantucket Sound, Cape Cod Bay or Buzzards Bay), water floods into the adjacent embayment and is distributed through to the upper regions. Characteristics of the embayments, such as inlet size, depth, and bottom roughness (friction), distort the tidal wave as it travels through the system. Tidal distortion may include a reduction in the range of the tide (damping) and/or a delay in the time of occurrence of low and high tides. The extent of tidal damping through the system affects the volume exchange, and hence the flushing characteristics, between the Sound and the remote portions of the system. Measurement of the tidal elevation time-series at key locations will provide information to calibrate and verify the two-

dimensional numerical model, which will be used to evaluate flushing characteristics and compute residence times.

The system forcing tides, or the offshore tides will be measured using two tide gages offshore of the embayment entrance. The two tide gages will be installed on a pipe anchor in approximately 15-20 feet water depth, preferably, but in less water depth if extensive shallow water exists in the vicinity of the tidal inlet. The gauges will be placed at depths deep enough to ensure that the gauge is submerged at all stages of the tide. Accurate measurement of the forcing tide is critical, because the forcing tide provides the basis for evaluating flushing characteristics within adjacent embayment. Therefore, two gages are used to both for quality assurance purposes and to ensure 100% data return. The forcing tide measurements are input directly to the hydrodynamic model as a forcing boundary condition.

Measurement of the tidal response in portions of each embayment quantifies the extent of tidal damping through the connecting channels and coves. Spatial distributed placement of gauges within each system allows for detailed analysis of tidal damping throughout each embayment system. Each gauge will be installed to an existing pier piling or other stable structure such that the recording sensor remains submerged at all tide stages. Exact location of each gage will be determined during a pre-survey site visit. Standard operating procedure is to obtain permission(s) from private land owners prior to tide gauge installation on their property (if required). If no fixed structures are available the gauge will be placed using a pipe anchor similar to the offshore gauge placement.

The vertical elevation of each tide gauge will be measured relative to the Town's vertical datum, as used in the bathymetry survey. If Town datums are not available benchmark data will be retrieved from equivalent sources (e.g. USGS). The Project Team assumes that each municipality will provide the location and position (both horizontal and vertical) of local benchmarks nearest to each tide gage. The Project Team will survey the gauges into the Town datum.

Hydrodynamic Model Development:
The Project Team's technical approach for evaluating estuarine hydrodynamics includes model development and calibration. The Surface Water Modeling System (SMS) will be utilized to model both hydrodynamics and water quality (an overview of the SMS package will be provided upon request). The SMS package provides a user-friendly grid generation program and post-processing software for the RMA-2 model developed by Resource Management Associates (King, 1990). The RMA-2 model is a two-dimensional, depth-averaged finite element model, capable of simulating hydrodynamics in complex river and estuary systems. The model has been standardized by the U.S. Army Corps of Engineers and is widely accepted for a broad range of estuarine applications. RMA-2 has been used for numerous hydrodynamic studies under SMAST on Cape Cod.

To develop the model grid, the Project Team will use the bathymetry data collected as part of the hydrodynamic program and cross check it to existing bathymetry information NOAA and other studies as available). Bathymetry data will be converted to the Massachusetts State Plane 1983 coordinate system (X-Y) and a map will be prepared for incorporation into the State's, regional agency's and Town's GIS. A model grid will be developed with knowledge of the system's tributary sub-embayments, bathymetry, potential regions of nutrient loading, and regions where structural modifications are proposed.

The Project Team's modeling approach utilizes a finite element model developed by Resource Management Associates (RMA-2 Model) that solves the full two-dimensional depth-averaged hydrodynamic equations. It allows for variable computation cell sizes to take advantage of limited bathymetric information. This type of model was developed to handle complex flow patterns associated with systems like those associated with Pleasant Bay, Popponesset Bay, Three Bays, Wareham River, etc. Output from the model provides complete depth-averaged, two-dimensional current velocities for all computational nodes as a function of time within the estuary system. Our modeling approach is a four-part process:

- Development: Set-up the model for each embayment system. Input shoreline positions, bathymetry data, and specify boundary conditions (i.e., offshore forcing tides).
- Calibration: Ensure model predictions are consistent with natural processes using a thorough comparison to measured field stage data.
- Validation: Comparison of calibrated model to independent direct measurements of flows as determined from the ADCP field program.
- Application: Use the calibrated model to evaluate hydrodynamic characteristics and to determine potential improvements to flushing associated with engineering alternatives.

Flushing rates and residence times are computed easily from the wealth of detailed site-specific data this model will provide. Both *local* and *system* residence times will be computed. Local residence times represent the average time required for a parcel of water in a sub-embayment to be flushed out of the sub-embayment, and will be computed as the volume of water in each sub-embayment divided by the volume of water entering the sub-embayment over an average tidal cycle (tidal prism). System residence times represent the average time required for a parcel of water to be flushed out of the estuary from the sub-embayment, and will be computed as the volume of water in the estuary divided by the tidal prism of the sub-embayment. The draft and final report will assess the significance of tidal flushing on water quality from both local and system residence time perspectives.

Since the flushing analysis will utilize a numerical hydrodynamic model, results can be incorporated into a water quality model to indicate nutrient and/or other constituents (pollutants) impact to the estuarine system **(see Section B.5)**. By incorporating the data collected for other portions of this project, the two-dimensional model can provide the basis for a water quality model (RMA-4) that incorporates the estuarine hydrodynamics and point and non-point source nutrient inputs. In addition, the hydrodynamic model can be used to evaluate potential improvement of flushing rates as a result of channel dredging and/or other engineering modifications (e.g. alterations to culverts).

Reporting:
The hydrodynamic modeling effort will be a chapter in the synthesis report for each embayment. Calibration plots will be presented showing the accuracy of the computations with respect to the measured data. Tables of system (and local) residence times will be presented for each of the Southeastern Massachusetts' study area embayments. In addition, the tidal constituents (amplitude and phase) from both the measured and computed data will be presented. Time series plots showing the measured versus model water elevations at various locations will be presented. A discussion of the system tidal versus non-tidal (or residual) processes will be presented to provide some context of the overall tidal processes within the Southeastern Massachusetts' study area embayments. Finally, the report will analyze all generated information to describe the hydrodynamics of the system to provide DEP and stakeholders with a concise understanding of the important hydrodynamic features of these systems, and how they potentially impact water quality within the study area embayments.

The model used by the Project Team, the RMA-2 numerical model, interfaces with a larger user-interface software package called SMS (Surface water Modeling System). The SMS package is a user interface, and allows a simpler method of changing model parameters as well as provides practical graphics presentation capabilities to view results. Graphical representation of results will be provided in embayment specific reports.

Bathymetric data in the form of a map for each of the Southeastern Massachusetts' study area embayments will be provided in a digital format compatible with the ArcView GIS system.

B.2.5 Sample Handling and Custody Requirements

All data is collected digitally in the hydrodynamic modeling effort and as a result there are no associated sample handling requirements for this portion of the effort. Data management is required (see below)

B.2.6 Analytical Methods Requirements

All measurements are by autonomous field instrumentation **(see table B.2-1)**, there will be no water or sediment samples collected for this task for laboratory analysis.

B.2.7 Quality Control Requirements

Bathymetric Survey:
Bathymetry is typically surveyed in a grid pattern that provides duplicate measurements, termed crossings, at multiple points within the survey area. The two measurements at the crossings are compared to check the precision of the data collection. If the difference between the two measurements is greater than 15 cm, then the region must be resurveyed. Periodic comparisons of the fathometer to a sounding rod are performed and agreement must be within 4 cm.

Tide Gauges:
Water elevation measurements from individual tide gauges are factory calibrated and the calibration checked prior to each deployment. In addition, in the field during the deployment process all gauges for an embayment are bound together with the pressure ports at the same elevation and lowered vertically to a known depth of at least 5 feet for approximately 1 hour, sampling at 1 sec intervals. After downloading the data from each instrument the water pressure readings are corrected for atmospheric pressure and density (based on measured salinity) and converted to depth. A comparison of water elevation readings from each tide gage provides a measure of the precision and accuracy of each gauge and the comparability between gauges.

Velocity (Acoustic Doppler Current Profiler, ADCP):
Velocity measurements are collected across a series of transects once every hour throughout a tidal cycle, while the tide gauge data is being collected. During the peak flow conditions within the tidal cycle, ebb and flood, velocities across the inlet transect are surveyed twice in sequence. Comparison of the two sets of velocity measurements across the transect gives a quantitative measure of the repeatability of the ADCP velocity measurements. The two velocity measurement sequences run along the prescribed transect are spaced less than 5 minutes apart. In addition, the RDI ADCP outputs two data quality parameters for each velocity measurement. A correlation value provides a measure of the acoustic signal to noise ratio for each ensemble of acoustic pings. The second parameter is percent good, which defines the percentage of acoustic pings within an ensemble that passed the data rejection criteria. Correlation and percent good values are indications of data quality.

Qualitative Numerical Modeling and Validation

Comparison of Findings with Previous Flushing Analyses:

Some flushing studies have been conducted in Southeastern Massachusetts' embayments. These will be evaluated for their applicability to the present effort **(see B-II**). Not all previous studies use methods that support numerical or quantitative modeling. In addition, even studies using the same protocols as the Estuaries Project, may not have collected sufficient field data to provide a consistent approach (for example less deployed tide gauges, or bathymetry based upon NOAA charts only).

Evaluation of Hydrodynamic Model results:
The quality control procedures for the hydrodynamic modeling consist of two approaches. First, a check of the model-predicted flushing rates relative to the embayment volume multiplied by the tide range. Second, a comparison of tidal prism from model predictions versus independently measured current and volumetric flow measurements provided by the ADCP. Calculated tidal prism from the embayment area and tide range is an independent determination of the flood and ebb volume. In the rare cases where an ADCP survey is not possible due to the embayment structure (e.g. inlet is too shallow) the tidal prism calculation will be used to validate the hydrodynamic model.

The first methodology involves summing the flow across the mouth of each embayment for every modeled time step and comparing this numerically predicted tidal prism with the mean embayment volume multiplied by the tide range (simplified tidal prism computation). This comparison is made for all embayment systems. For complex tidal embayments, where ADCP surveys are required, an additional model validation technique is performed. For these systems, the tidal prism volume measured using the ADCP current measurements are compared to model-predicted flow across the same transects. In this manner, a comparison between predicted and measured tidal flow can be made for the total tidal exchange over the complete tidal cycle, as well as for the time-varying nuances of the flow. The comparison should yield an average RPD of <5%.

B.2.8 Instrument Calibration and Frequency Procedures

Bathymetric Survey:
Single beam echosounders are typically calibrated by performing a bar check. A rigid vertical bar or weighted disk with tick marks every 1-foot is lowered directly below the transducer to a depth of 5 feet. The draft setting in the echosounder is adjusted until the depth reads 5 feet. The bar/disk is then lowered to the maximum depth that will be surveyed (rounded to an even foot) and the sound velocity setting is adjusted until the echosounder reads the appropriate depth. The bar/disk should be returned to 5 feet to check the depth since the sound velocity setting may have changed. If the depth reading is still 5 feet, than the echosounder is calibrated. If the reading has changed, the above procedure is repeated until the echosounder readings match the depth of the bar/disk. Bar checks are typically performed before each series of field surveys.

Periodic field checks are performed during each survey, both through multiple readings at the same point where transects cross and using a sounding rod. These field performance checks are used to indicate that the echosounder is in calibration.

Tidal Gauges (pressure transducers) and Current Velocity (ADCP):
The tide gauges used to measure time-series tidal elevations are factory calibrated. The tide gauges measure depth through strain gage pressure sensors. The gauge that the Estuaries Project typically employs is from Richard Brancker Research Ltd, Canada. A Druck Pressurements hydraulic deadweight tester is used in factory calibration to give a direct NIST traceable standard. The sensors are calibrated at eight points and a cubic fit to the data is used to determine the calibration coefficients.

Laboratory checks of transducer calibration are performed by (a) measuring the depth and salinity of the water over a gauge at deployment and recovery, (b) prior to deployment setting all gauges for an embayment at a known depth at high frequency sampling, and (c) periodic calibration of gauges in the SMAST Test Tank.

Velocity measurements are collected by an Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments Inc. Prior to each deployment a series of tests are run to check the acoustic signal, signal processing subsystems, integrity of the 4 transducers, and error in the compass. If the error in the compass exceeds 5° or the battery has been changed since the last calibration, the compass is recalibrated. To calibrate the compass, the ADCP the instrument is rotated 360° in three different planes. The ADCP and RDI software uses the first two rotations to recalculate the compass matrix and the third rotation to verify the calibration.

Qualitative Numerical Modeling and Validation:
The calibration of the numerical model is to ensure that the model accurately predicts the observations from each portion of each embayment using data from the field measurement program. For each embayment, numerous model simulations are required (typically 20+), specifying a range of friction and eddy viscosity coefficients, to calibrate the model. Calibration of the hydrodynamic model requires a close match between the modeled and measured tides in each of the sub-embayments where tides were measured (i.e., from the tide gauge deployments). Initially, the model is calibrated to obtain visual agreement between modeled and measured tides. Once visual agreement is achieved, an approximate five-day period (10 tide cycles) is modeled to calibrate the model based on dominant tidal constituents. The five-day period is extracted from a longer simulation to avoid effects of model spin-up, and to focus on average tidal conditions. Modeled tides for the calibration time period are evaluated for time (phase) lag and height damping of dominant tidal constituents.

B.2.9 Data Acquisition Requirements

For the hydrodynamic modeling program, U.S.G.S. topographic maps are used to identify tidal gauge sites and ADCP transect locations. Printed scanned copies with marked site ID's are provided to each field team.

For the bathymetric survey and tide gauge placements local benchmarks are needed and have always been provided by the Town's. If a Town cannot provide a datum, benchmark data will be retrieved from equivalent sources (e.g. USGS). The Project then surveys in the sampling locations within the embayment, relative to the provided Town datum.

If necessary for the hydrodynamic modeling program, rainfall data is obtained by the hydrodynamic modeling Technical Leader/SMAST scientists at the end of each sampling season. Rainfall data (date and amount) is from the Town of Falmouth gauge, Cranberry Station in Wareham, City of New Bedford. The Town of Falmouth rainfall data is processed and QA/QC's by Dick Payne at the Woods Hole Oceanographic Institution. The Cranberry Experiment Station Gauge was placed by NOAA and is maintained by the University of Amherst. The City of New Bedford Gauge is used in the NOAA network. The gauge used as reference for any specific embayment is selected based upon proximity. If site-specific rainfall is deemed necessary in the future, then Li Cor tipping bucket rain gauges may be deployed.

B.2.10 Data Management

The flow of data and information is relatively direct for this Project Task. The field notes and digital data are collected by the field personnel and copied upon return to the laboratory with copies held at (a) the originator of the data, (b) the model lead, (c) the SMAST Project Library (via the Technical Coordinator).

As the data is received by the modeling lead and the Technical Manager at SMAST, the data is evaluated for completeness and quality. The data is then used to calibrate and validate the hydrodynamic model. The calibrated model is then stored (at a minimum) on CD ROM by the hydrodynamic lead and the Project Technical Manager in the SMAST Project Library.

B.2.11 Preventative Maintenance for Field Equipment

The *echosounder transducer* is rinsed in fresh water after use to avoid corrosion and damage form salt build up. Routine visual inspection of the connectors, cabling and polyurethane transducer is performed to avoid leakage. The belts of the chart recorder are checked for wear and potential failure.

The tide gauges and Acoustic Doppler Current Profiler (ADCP) are routinely inspected prior to deployment. The pressure housings and sensors are inspected for potential corrosion and leakage. Any evidence of corrosion is cleaned and an inhibitor is applied

to the surface. The o-rings, providing a water-tight seal to the pressure cases, are cleaned and checked prior to each deployment, and flattened o-rings are replaced. Replacement parts for the tide gages and ADCP are kept in stock. The ADCP transducers are visually inspected for peeling or nicks of the polyurethane transducers. All equipment is rinsed in fresh water and stored based upon manufacturers specifications field deployments. The equipment is stored in dry heated storage between deployments.

Performance of the numerical modeling and associated validation does not have associated preventative maintenance for field equipment.

B.3 Watershed Nitrogen Loading

The watershed nitrogen loading program of the Estuaries Project is based upon 3 components:

- Land-use determined by GIS analysis
- Nitrogen Source Loads determined from field data and the watershed model
- Attenuation of Nitrogen determined from stream discharge measurements

These components require both field data collection, incorporation of previously collected land-use GIS databases and watershed nitrogen load modeling. Technical Team members have been pivotal in the development of these techniques over the past decade. The Estuaries Project will apply a standardized consistent watershed nitrogen loading model to all 89 embayment systems in southeastern Massachusetts.

B.3.1 Data Quality Objectives for Measurement Data

The data quality objectives have been selected to fit with the goals of the Watershed Nitrogen Loading Program of the Estuaries Project. The only field data collection under this program is the stream flow and stream nitrogen load measurements. The data quality objectives for these stream terms have been selected to account for the variability of stream discharge and nutrient concentrations typical of the small rivers and streams of southeastern Massachusetts. The data quality objectives were selected based upon the results of a limited number of annual investigations of stream nutrient transport in southeastern Massachusetts (e.g. Howes and Teal 1995, CDM and Howes 2000). The methods and approaches establish the criteria for evaluating both data collected by the Estuaries Project and existing data being evaluated by the Technical Team for inclusion into Project database **(see B-II**). All data must meet the required levels of precision, accuracy, and detection limits.

The stream nutrient sampling uses accepted methods for low level analysis. These methods are accepted by the best research laboratories in the United States. Where EPA or Standard Methods techniques are available, they are employed by the SMAST laboratory. All methods have been intercalibrated with a variety of methods and with various certified laboratories (freshwater only) and marine laboratories. Minimum performance criteria are listed in **Table B.3-1**, although the methods used in the program generally exceed these minima. The acceptable criteria for field blank cleanliness is generally a reading less than the detection limit. In occasional instances where high sensitivity methods are employed, the field blank must be less than 10% of the sample value.

Table B.3-1 Minimum Objectives for Stream Nutrient Assays

Parameter	Matrix[a]	Field Precision	Laboratory Precision	Accuracy	Detection Limit
Nitrate + Nitrite	1	<30% RPD[b]	<20% RPD	75%-125% of matrix spike	0.25 uM
Ammonium	1	<30% RPD	<20% RPD	75%-125% of matrix spike	0.25 uM
Total Phosphorus	1	<30% RPD	<20% RPD	75%-125% of matrix spike	1 uM
Orthophosphate	1	<30% RPD	<20% RPD	75%-125% of matrix spike	0.1uM
Total dissolved N	1	<30% RPD	<20% RPD	75%-125% of matrix spike	1 uM
Particulate C& N	1	<30% RPD	<20% RPD	75%-125% of matrix standard	1 uM

[a] 1 = Freshwater

[b] RPD = Relative Percent Difference

Note: These parameters are measured by the Coastal Systems Analytical Facility at SMAST

In embayments where bacterial contamination is an identified issue, parallel stream water samples may be collected for analysis.

Table B.3-2 Stream Bacterial Assays

Parameter	Matrix[a]	Sample Volume/ Container	Sample Holding Time	Field Processing/ Preservation[b]	Detection Limit
Fecal Coliform	1, 2	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice in cooler	1 CFU*./100ml
Enterococci	1	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice	1 CFU./100ml
E. Coil	2	100 ml sterilized polyethylene	6 hours	Collect, label, store on blue ice	1 CFU./100ml

[a] 1 = saltwater, 2 = freshwater

[b] Holding temperature will be <10 Celsius

*CFU – Colony Forming Unit

Note: Bacterial parameters measured through Barnstable County Health Laboratory, New Bedford Health Laboratory or other DEP Certified Laboratory.

Analytical requirements for stream nutrient assays:

Complete standard curves are generated for each analytical run. If more than a 10-fold range of concentrations are encountered in the samples, then both a high and low standard curve is created. In all cases the standards are prepared new each day and are chosen to give at least 5 points over the sample concentration range. Standards

well above the sample range are not used. Nitrate+Nitrite (run in duplicate) by auto-analysis has additional standards run before and after every five (5) samples. Failure of these additional standards (run as samples) to agree within 10% of their known value halts the assay line for complete recalibration and the re-running of the last sample set.

For nitrate+nitrite, dissolved ammonium, total dissolved nitrogen, ortho-phosphate, and total phosphorus, non-automated assays are all run in duplicate (at a frequency of at least 10% of the samples) with a <5% tolerance between duplicates required for acceptance. After completion of analyses, remaining sample is frozen, for possible reanalysis if required.

Analytical requirements for stream bacterial assays:
The bacterial assays will be conducted by a DEP Certified laboratory (Barnstable County Health Laboratory). The Estuaries Project requirements will follow those of certification. The data requirements are a detection limit of 1 CFU per 100 mL, unless prior data indicates a high level (>100 CFU) of Fecal Coliform bacteria are present at a specific site. In that case a dilution will be conducted at 10 and 100 fold to ensure capture of the population count. Duplicate samples will be conducted on 10% of the field samples and these need to have an RPD of <25% (N=5).

Precision
The precision of each chemical assay is determined by from duplicate assays of five standards. The field precision is from duplicate assay of five blind field duplicates. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R^2 of the linear regression of each set of standards (N>5).

Accuracy
Accuracy is determined from the analysis of standards for the standard curves, analysis of the matrix spikes and use of Performance and Evaluation Samples (commercially available). Accuracy is determined as the RPD of the assay of five standards run as samples within a series of analytical runs. This is compared to the RPD of five sets of Performance and Evaluation Samples. In addition, the accuracy of the method within the sample matrix is determined from the RPD of five matrix spikes experiments (standard additions), where appropriate.

Measurement Range
The usable measurement range for each chemical assay is only within the linear range as determined from least squares linear regression of laboratory standards. Concentrations above the linear range require standard dilutions for acceptable analysis. Since high values can be readily diluted and re-assayed the same day, the upper range of measurement is variable. Sample dilutions attempt to bring the concentration of the diluted sample into the middle of the linear range for the assay. The natural range for any analyte is typically less than 1000 fold.

Bacterial assays require a priori determination of dilutions. For fecal coliform analysis by membrane filtration, only 100 colonies can be counted per plate. Therefore, if more than 100 colonies per 100 mL are anticipated a dilution series by the laboratory will be requested (10X, 100X). The determination to conduct dilutions will be based upon prior data from a specific stream under wet and dry weather flows.

Representativeness

The goals of the stream sampling program is to provide nutrient loads from streams to coastal embayments. The sampling point will be selected as near to the embayment as possible and to avoid tidal influence. Since the stream data is compared directly to its contributing watershed, the watershed is adjusted to account for nutrient sources which would be captured by the stream prior to the gauging site.

Comparability

The results from each stream sampling program will be directly comparable to each other. In addition, since these are accepted methods, they will be directly comparable to other studies conducted by U.S.G.S. and other groups.

Completeness

The ultimate goal of the stream sampling sub-task is to obtain data for comparison to its sub-watershed nitrogen load and comparable data for each estuarine system in southeastern Massachusetts. This both provides the needed site-specific data and enables both inter- and intra-estuarine comparisons using consistent and reliable methods of sample collection and analysis. Completeness is gauged as the number of actual measurements divided by the number of planned measurements times 100%.

B.3.2 Documentation and Records

Stream flow and nutrient data will be recorded on field data sheets to be kept in notebooks for each embayment **(B-I).** Data will be recorded on-site at the time the measurements are taken and in laboratory notebooks at the Coastal Systems Analytical Facility (both data and chain of custody forms). Sampling personnel check that all data is accurate and legible before passing the field data sheets to the SMAST laboratory. As the data is received by the SMAST laboratory, it is reviewed and the samplers are contacted to clarify any numbers, issues or if any information is missing. In addition, the stream Technical Lead (Roland Samimy) will check that all data is accurate and legible before making copies for Technical Coordinator and SMAST Project Library. All data is reviewed by the Technical Manager. The nutrient sampling portion of the program requires that Chain of Custody forms (COC) be filled out as the samples are delivered at SMAST. Each COC is checked as samples are received. The stream flow and nutrient data will be stored on CD-ROM in the SMAST Project Library with copies distributed to the Stream Technical Lead and the Technical Manager.

All data entry is checked by two laboratory personnel and the QA/QC checks are completed by the Project QA Officer (A.4 Project Organization and Responsibilities.)

Nutrient Analytical data:
Raw data is maintained in duplicate notebooks. Data reduction involves the process of converting raw numbers into data that have direct chemical meaning or can be compared statistically. Calculation to concentration is done in an adjacent column for easy comparison. The calculation is based upon the regression equation calculated from the chemical standards. The results will be reported in terms of concentration, as means and standard errors. All data are subject to 100% check at all stages by everyone. All data reported are reviewed to check for errors in transcription, calculation, or computer input. If data points are judged to be aberrant, the reserved sample will be reanalyzed. Data are also reviewed for adherence to analytical protocols and to pre-established criteria (e.g., holding times, surrogate recoveries, initial and continuing calibration, matrix spikes, laboratory duplicates, blank contamination). Students t-test for paired samples, analysis of variance, are used for interpretation. Data is transcribed only for the statistical analysis and each point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in the project files.

The watershed loading model is held in spreadsheet format, which includes the land-use and loading data for each sub-watershed to an embayment. The model will be held on CD-ROM and in paper copy at three locations: (a) Cape Cod Commission, (b) Technical Coordinator, SMAST, (c) Technical Manager in the SMAST Project Library.

B.3.3 Sampling Process Design

The design of the Watershed Nitrogen Loading task is aimed at providing spatially resolved nitrogen loading data for input into the Linked Watershed-Embayment Model. To accomplish this task a GIS based land-use analysis is conducted by the Technical Lead using watershed delineations provided by or confirmed by the U.S.G.S. These data are combined with direct measurements of nitrogen discharge by streams to parameterize the Watershed Loading Model component of the Linked Model.

Phosphorous loading to freshwater systems (ponds/streams) will not be determined as it is not the focus of the Estuaries Project in and of itself. The Estuaries Project focuses primarily upon the sources, sinks, and transfers of nitrogen within the watershed-embayment complex. Nitrogen is the nutrient for managing eutrophication in Massachusetts coastal embayments, while phosphorus is the primary nutrient for management of eutrophication of freshwater systems. In specific cases where it is necessary to determine phosphorous loading in support of other analyses or

evaluations, loading may be determined. Some examples of cases where support may be requested:

- NPDES Permiting
- Nitrogen source reduction for embayment restoration, where P load to eutrophic freshwaters will also be effected. Source reduction may be by relocation of discharges or reduction in discharged load.
- Cases where a regulatory agency has a priority

In the event that phosphorus loading determinations are undertaken, a project specific plan will be developed to meet site specific needs. However, the analysis will follow the format of the nitrogen loading analysis for the embayments. This site specific project plan will be appended to the relevant embayment specific Appendix QAPP under this umbrella QAPP for the Estuaries Project.

Watershed Land Use Analysis:
Watershed land-use will be based on a parcel by parcel analysis using GIS. The land-use data will use the most recent data available, not older than 5 years. The preferred land-use data will be based upon town assessors database and will include all parcels. The watershed delineations will be based upon the U.S.G.S West Cape Model for Cape Cod embayments (Masterson and Barlow 1994, Masterson et al 1997). The sub-watersheds for each major tributary sub-embayment will undergo land-use analysis. In addition, each watershed will be partitioned into regions which nutrients flow directly to the embayment via groundwater, regions which discharge to freshwater ponds, and regions where nutrients flow to streams and are transported via surface water streams to the embayments.

GIS analysis will be supported by field surveys of major potential contributors (i.e. schools, hotels, apartment buildings, etc.).

Watershed Stream Flow and Nitrogen Load:
The goal of the stream gaging component of the Estuaries Program is to quantify the nutrient load and freshwater inflow from major streams which discharge to each estuary. These data will be used to:

- Validate the USGS watershed discharge modeling results
- Quantify the surface water nitrogen load
- Determine site-specific nitrogen attenuation values for the surface water flows to each embayment (comparison of watershed model to stream nitrogen discharge results).

Nutrient loading to an embayment through a stream is in part dependent on quantifying surface water flows (Q, volumetric discharge) and the associated nitrogen concentration in that discharge volume. For the purpose of this stream gaging protocol, flow will be

calculated from continuous measurements of water level, stream cross sectional area, and periodic measurements of velocity. Stream water levels will be measured (15 minute intervals) using a Global Waters Water Level Logger: WL-15 or equivalent. The gauges will be vented to the atmosphere. Stream cross sectional areas will be measured using a top-setting wading rod. Permanent markers will establish the cross-section location. A Marsh McBirney Flow-mate Model 2000 or equivalent current meter will be used to measure stream velocities. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities will represent the computation of stream flow (Q). A rating curve will be developed for each gauge to transform level data to discharge rates. High and low flow hydrologic regimes will be sought for development of the rating curve for each stream within the study area.

Station Location:
Selection of stream gaging station locations will be based on:

- Accessibility
- Lack of tidal influence
- Section of stream providing a generally straight channel
- Streambed is free of aquatic growth and relatively smooth
- Unchanging natural control
- Stream channel does not go dry during low flow periods
- Gage site is not influenced by backwater effects (culverts, dams, confluences)
- Stable channel cross section

It will not be likely that all the above listed criteria will be able to be satisfied by all sites being considered, however, attempts will be made to find gauging sites that meet as many of the listed criteria as possible.

Ingress and egress to a potential site will be field verified and ownership of the site will be investigated. Permission to access a potential site will be gained from the owner of the site prior to using the site as a stream gauging station location.

Tidal influence on stream flow will be assessed prior to selection of a gaging station location. The assessment of tidal influence will initially be based on observation of stream habitat flora. Observations will be made in the field to determine the presence of freshwater plant species. Should the site under consideration be selected, a water level indicator will be installed to record stream levels and lack of tidal influence will be confirmed via instrument measurement. Should a slight tidal influence be present, numerical filtering techniques will be applied to the data to screen the tidal influence out of the data.

All stream gauging locations will be selected in stream reaches that are not influenced by backwater effects resulting from the presence of stream confluences, drainage

culverts, dams or other naturally occurring or artificial structures. The gauging location will be situated down-gradient from culverts and dams and far enough up-gradient from a confluence that water level not be effected. In the absence of stage and discharge data at a potential gauge site or concurrent stage at the stream confluence, the gauging site selected will be the one located furthest away from the known confluence.

Stream Cross Section Measurements:
After having identified an acceptable stream cross section where velocity measurements will be made, the selected cross section will be waded with a top setting wading rod in order to establish the profile of the cross section. The stream channel profile will be established before each run of velocity measurements.

A measuring tape will be manually stretched across the width of the stream channel and, while facing up-stream, the left and right banks of the channel will be noted in feet using the measuring tape. The transect will be marked with permanent markers to which the tape measure will be affixed on each sampling occasion. Water depth across the width of the stream will be measured in 0.5 foot increments using the top setting wading rod. Water depth will be measured in meters. Total stream channel cross sectional area will be the summation of the total number of segment cross sectional areas.

The stream cross section location will also be described in the field record book in order to maintain a record of changes in the channel bottom or bank characteristics.

Stream Water Level Measurements:
Stream water level measurements will be obtained using a Global Waters Water Level Logger (WL-15) or some equivalent instrument. The factory calibrated water level loggers will be prepared in the laboratory for deployment in selected streams by checking that the instrument is properly sealed to prevent malfunctions resulting from moisture build up in the instrument casing. Deployments will typically be continuous for approximately one year.

The water level instrument will typically be encased in a PVC tube, open ended on the bottom so that the instrument cable can run freely and capped on the top so that moisture cannot degrade the instrument communication port. The PVC encased instrument will be mounted to a convenient and permanent natural or artificial structure and the water level probe held in the desired location in the stream reach using either a stilling well or placement on a flat weight (ca. 40 lbs) in shallow streams. The instrument cable will be run as unobtrusively as possible so as to be hidden from view and to not become an obstacle. The water level probe will be placed at the deepest point in the stream channel so as to remain submerged during low flow seasons and mean sea level will be used as the vertical datum to which the probe is referenced. The water level probe will be weighted down appropriately so as to prevent the probe from migrating down stream during increased flow rates.

Water level data will be down loaded monthly in the field via lap top computer. Water level data will be field verified each month against either an in-stream surveyed staff gage or by making a manual water level measurement of height of water over the water level probe using a tape measure. Measured height of water over the in-stream water level probe will be compared to water level data record to confirm that data record is comparable.

Stream Water Velocity Measurements:
Stream water velocity measurements will be taken, at a minimum, each time the WL-15 water level logger is down loaded. Additional velocity measurements may be taken in between instrument down loads depending on weather conditions in order to capture high or low flow events. Nutrient samples for total nitrogen will be collected on each visit to the gauge site. Bacterial samples will also be collected to determine stream loads to embayments associated with the wet and dry weather embayment sampling for bacterial contaminants (see B-III).

Field data sheet for collection of velocity data have been developed and will be used to record velocity measurements, stream depths, and distance from the right or left bank where a velocity measurement is taken. In the absence of a field sheet, the same information can be recorded in a field notebook (as used by the USGS).

Stream Flow Calculation:
Determination of stream flow will be calculated and based on the measured values obtained for stream cross sectional area and velocity (Rantz et al. 1982). Stream discharge will be represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section WILL NOT be averaged and then applied to the total stream cross sectional area.

The formula that will be used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/day)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Nitrogen discharge is calculated using the paired discharge and nitrogen concentration data to determine the mass flux of nitrogen through the gauging site. These data are expressed as nitrogen mass per unit time (kg/d). The mass flux over the period of interest (month, season, year) is determined by integrating the area under the appropriate interval of the daily mass flux versus date graph. The water samples for assay of nitrogen concentration will be collected weekly during May – September and weekly to biweekly over the rest of the year. The samples will be collected and analyzed at the Coastal Systems Analytical Facility at SMAST meeting the requirements of Section B.1 and B.3.6. The stream samples will be assayed for nitrite+nitrate, orthophosphate, ammonium, particulate organic carbon/nitrogen and total phosphorus.

Watershed Nitrogen Loading Model
The Watershed Nitrogen Loading Model consists of identifying all of the land-uses within the sub-embayments of an estuarine system. Each nitrogen source is assigned a nitrogen loading term (Howes et al. 2001) based upon:

- Seasonality
- Occupancy
- Land-use Type
- Area
- Location relative to freshwater pond watersheds
- Location relative to groundwater watersheds
- Location relative to stream watersheds

The individual loads are composited within each sub-embayment. Attenuation is determined from the modeled unattenuated stream nitrogen load versus the directly measured stream nitrogen load.

B.3.4 Sampling Methods Requirements

Watershed Land Use Analysis:
Sampling is not required as part of this analysis.

Watershed Stream Flow and Nitrogen and Bacterial Loads:
As indicated in Task 2, attenuation of watershed nitrogen during surface water transport can significantly reduce the amount of watershed nitrogen entering an estuary. We will directly measure nitrogen, and phosphorus inputs of each major stream/river discharges in the embayments undergoing the full modeling effort. These direct measurements of watershed freshwater and nutrient inputs will a) serve to validate the watershed delineation's, b) validate the land-use models, c) help to calibrate the hydrodynamic models applied to estuarine circulation in Tasks discussed below. These direct measurements are also applied to the system nitrogen loading models.

The use of the surface water inflow data to validate the loading and hydrodynamic models used for all 89 targeted embayments in the Massachusetts Estuaries Project contrasts with many other studies that rely solely on land-use data. Unfortunately the land-use only studies have often resulted in overestimates on nitrogen loading and distribution and lead to improper or ineffective management options. The use of directly measured nitrogen discharges for rivers and streams is essential to properly determine watershed nitrogen loads and to rank the nitrogen sources, and to minimize uncertainties and provide for effective watershed management decisions.

Surface water inflow volume and mass transport of nitrogen and phosphorus will be determined using site-specific flow discharge relationships and continuous records of water levels. Phosphorus sampling will only be conducted when there is a special request from DEP related to a freshwater eutrophication problem within a specific embayment watershed. Nutrient samples will be collected for inorganic and organic nitrogen and phosphorus concentrations at weekly intervals over a 14-16-month period, encompassing 2 summer seasons. Total nitrogen (not just inorganic forms) is required to accurately determine the input through this pathway. Instruments will be maintained weekly. We have recently successfully deployed a similar array of instruments within the Wareham River Estuary.

Water samples will be collected directly from the stream by syringe (60 cc) and filtered (0.45 um) into 60 cc acid leached bottles for analysis of dissolved nutrients. Additional 1 liter samples will be collected in acid leached bottles for particulate analysis and for total phosphorus **(see Table B-3.1**). Sample handling is similar as for water quality monitoring task B.1.

Bacterial samples are collected in parallel with the nutrient samples. Samples are collected directly in sterile 250 mL polyethylene bottles provided by the certified laboratory. Samples will be collected directly from the stream by plunging the bottle mouth downward and bringing horizontal facing the flow at several inches depth. The bottle is left with a 30-50mL headspace to allow mixing by shaking in the laboratory. Bottles are transported, dark and on blue ice at <10C to the laboratory in less than 6 hr after collection. Cooler temperatures are checked using a field thermometer which has been calibrated to the certified thermometer in the laboratory. Additional details on bacterial sampling are given in B-I.

Bacterial loads will only be determined in embayments which have an identified bacterial problem. Embayments with identified bacterial problems are those on the 303(d) list for bacterial contamination or those determined based upon review of existing bacterial data (primarily DMF data). In the latter case, an embayment will be receive bacterial analysis based upon review by the Technical Team and recommendation to DEP.

Table B.3-3. Stream Nutrient Monitoring Parameters

Parameter	Matrix[a]	Sample Volume/ Container	Maximum Holding Time	Processing/ Preservation	Units
Nutrients:					
Nitrate + Nitrite	1	60 ml polyethylene acid-washed	28 days (frozen)	Field filter, store dark at -20°C in Lab[b]	µg/l
Ammonium	1	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	µg/l
Total Phosphorus	1	60 ml polyethylene acid-washed	28 days (acidified)	Whole water, acidify, store dark at 4°C in Lab	µg/l
Orthophosphate	1	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	µg/l
Total dissolved N	1	1L polyethylene acid-washed	24 hours	Field filter, store on ice in dark	µg/l
Particulate C& N	1	1L polyethylene acid-washed	28 days	Collect on ashed Filter in Lab, Dry and Store in dessicator	µg/l
Bacteria					
Fecal Coliform	1	250 mL polyethylene sterile	6 hrs (<10C)	Collect and transport at <10C to Lab	CFU/100mL
E. Coli	1	250 mL polyethylene sterile	6 hrs (<10C)	Collect and transport at <10C to Lab	CFU/100mL
Enterococcus	1	250 mL polyethylene sterile	6 hrs (<10C)	Collect and transport at <10C to Lab	CFU/100mL

[a] Matrix 1 = Freshwater

[b] USGS Central Laboratory had determined that freezing filtered samples for nitrate+nitrite is acceptable, without acidification (Avanzino and Kennedy 1993).

Watershed Nitrogen Loading Model

Sampling for the Loading Model is covered in the above sub-sections of B.3.4. The bacterial loads are calculated in a similar manner to the nutrient loads discharged from the streams.

B.3.5 Sample Handling and Custody Requirements

Sampling under the Watershed Nitrogen Loading Task is limited to instrument measurements for determination of stream flow and manual collection for nutrient sampling. It is the nutrient sampling that has sample handling and chain of custody requirements.

Watershed Delineation

No sample handling is associated with this sub-task.

Watershed Land Use Analysis

No sample handling is associated with this sub-task.

Watershed Stream Flow and Nitrogen and Bacterial Loads

Sampling associated with stream sub-task is related to the need for nutrient measurements to couple with the flow measurements to determine the nitrogen load transported by a stream. Nitrogen loading based on stream flow is calculated as a

function of flow rate. Bacterial loads will only be determined in embayments which have an identified bacterial problem. Embayments with identified bacterial problems are those on the 303(d) list for bacterial contamination or those determined based upon review of existing bacterial data (primarily DMF data). In the latter case, an embayment will be receive bacterial analysis based upon review by the Technical Team and recommendation to DEP. DEP will make the ultimate judgment as part of their TMDL process. Sample handling requirements are presented in **Table B.3-3**

All samples will be assayed by the Coastal Systems Analytical Facility at SMAST, which requires Chain of Custody forms before accepting samples. A copy of the form is then given to the stream Technical Leader (R. Samimy) and a copy is kept on file in the Facility.

Watershed Nitrogen Loading Model
No sample handling is associated with this sub-task. Samples for parameterizing the model are collected under the "Stream Flow and Nitrogen and Bacterial Loads" sub-task.

B.3.6 Analytical Methods Requirements

Sampling under the Watershed Nitrogen Loading Task is limited to instrument measurements for determination of stream flow and manual collection for nutrient sampling.

Watershed Delineation
No sample handling is associated with this sub-task.

Watershed Land Use Analysis
No sample handling is associated with this sub-task.

Watershed Stream Flow and Nitrogen Load
Watershed stream flow is considered in the context of taking physical measurements. As such, nutrient loading to near shore waters is in part dependent on quantifying surface water flows (Q) to the embayment under investigation. For the purpose of this stream gaging effort, flow will be calculated from measurements of water level, stream cross sectional area, and velocity. Stream water levels will be measured using a Global Waters Water Level Logger: WL-15 or equivalent. Stream cross sectional areas will be measured using a top-setting wading rod. A Marsh McBirney Flow-mate Model 2000 or equivalent current meter will be used to measure stream velocities. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities will represent the computation of stream flow (Q).

Refer to **B-I** for the detailed stream gaging protocol that describes gaging station location, stream cross section measurement, water level measurement, stream velocity

measurement, and stream flow calculation.

Nitrogen loading to embayments through stream discharge requires both determination of stream flow and collection and analysis of stream water samples. Stream samples will be assayed for nitrate+nitrite, ammonium, total dissolved nitrogen, particulate nitrogen/carbon, ortho-phosphate and total phosphorus. The analytical methods and quality control samples are listed in **Table B.3-4**, below.

Analytical procedures used in this program have been tailored to the specific chemical environment of coastal streams and estuaries, i.e. variable salinity and analyte concentration ranges of 1000 fold. The procedures used are those commonly employed by the SMAST Coastal Systems Program for research on coastal processes. The analytical methods are being or have been used by SMAST in the measurement of water quality in a variety of monitoring programs such as the USGS Namskaket Marsh Project (required intercalibration with USGS Central Lab), MWRA-HOM Program, Falmouth PondWatch, Pleasant Bay Alliance, USAID Water Quality Program-Jamaica, MCZM Wetlands/Stormwater Monitoring Program, Assabet River TMDL Study, RIDEM-Greenwich Bay Study, WHOI Nantucket Harbor Monitoring Program, Martha's Vineyard Coastal Pond Monitoring Program (MVC), and many others. These programs over the past 15 years have QAPP's and most of them have required acceptance by either EPA or Massachusetts DEP.

Watershed Nitrogen Loading Model
No sample handling is associated with this sub-task.

B.3.7 Quality Control Requirements

The Watershed Nitrogen Loading Task has quality control requirements both for its land-use analysis, stream sampling and watershed nitrogen loading model.

Watershed Land Use Analysis
Although the GIS analysis will use local and regional databases. These databases will use assessors data rather than MassGIS and are maintained by Towns and the Cape Cod Commission and Martha's Vineyard Commission (project partners). It is envisioned that the data will be less than 5 years old. There will be a QA effort based upon ground-truthing the GIS information. This will primarily take the form of checking that the major sources are properly referenced and properly represented spatially. In addition, there will be an effort to check major changes in land-use that may have occurred since the specific database was established. Note that this is over and above the ground-truthing that has already taken place by most planning departments and agencies that oversee the databases.

Watershed Stream Flow and Nitrogen Load

The stream nitrogen loading measurements require water level, water velocity and nitrogen assays. The water level precision should be an RPD of 1%. The velocity will checked in a control flume and should be within 5% of that determined using the factory calibration **(see details B-II).**

The nutrient analyses used in the stream program follow standard laboratory procedures. However, not all analytes are amenable to matrix spikes (eg. PC/PN). In the analysis of field samples, for each chemical assay, a complete standard curve is generated for each analytical run. In addition, reagent blanks and standards are prepared and analyzed with each new batch of reagent. These blanks are compared to previous data on blanks to evaluate the potential of contamination and the standard curve compared to previous records. If this initial blank and standard curve are deemed satisfactory, samples using the new reagent batch can then analyzed.

Calibration blanks are prepared and analyzed simultaneously with the creation of each standard curve which is created for each sample series. If more than a 10 fold range of concentrations are encountered in the samples, then both a high and low standard curve is created. In all cases the standards are prepared new each day and are chosen to give at least 5 points over the sample concentration range. Least Squares Linear Regression is used to calculate the standard relationship and a minimum $R^2 = 0.99$ is required for acceptance. Standards well above the sample range are not used. In addition to the R2 criterion, each curve will be visually inspected to determine that each standard, especially the lower standards, lie close to the curve. Nitrate+Nitrite (run in duplicate) and Particulate C & N by autoanalysis have additional standards run before and after every five (5-6) samples. Failure of these additional “check” standards (run as samples) to agree within 10% of their known value halts the assay line for complete recalibration and the re-running of the last sample set. These “check” standards are used to adjust the calculated sample values for instrument efficiency. For all assays, “check” standards are run at the end of each run and compared to the standard curve.

For nitrate+nitrite, dissolved ammonium, total dissolved nitrogen, ortho-phosphate, and total phosphorus are all assayed in duplicate at a frequency of more than 15% of the samples and with a <5% tolerance between duplicates required for acceptance. After completion of analyses, remaining sample is frozen, for possible reanalysis if required (and appropriate). For the particulate analyses (PN, PC), only field duplicates and laboratory standards can be assayed as the analysis consumes the entire sample.

Spiked samples are periodically analyzed as analytical checks in dissolved ammonium, nitrate+nitrite, total dissolved nitrogen and ortho-phosphate assays. Spiked samples are not widely run, as the standards are made up in the same matrix as the samples. Greater numbers of spiked samples are sometimes run as unknowns” similar to field duplicates. Recovery of spikes must be within 15%-20% of expected to meet QA. Spikes for PN/PC samples are not available. Therefore, PC/PN at known

concentrations is added directly to filters. This is done during machine calibration as an internal QA check after every fifth field sample assayed.

As available (eg. PC/PN not available, TC is not appropriate for PC evaluation) Performance and Evaluation Samples for the nutrient assays will be purchased and run during the course of this study. These data will be used to evaluate the accuracy of the SMAST laboratory.

Table B.3-4. Stream Analytical Procedures/Quality Control Samples

Parameter	Essential or Correlative data	Method	Detection Limits	QC Samples	Acceptable %Recovery
Temperature	Correlative	Thermometer -5 °C to 40°C	0.5 C	Field Dups ± 1C	
Salinity	Correlative	Specific Conductivity Meter	0.1 ppt	Field Dups ± 0.2ppt	
Dissolved Oxygen	Correlative	Modified Winkler Titration/Hach OX2P	0.5 ppm	Field Dups ± 0.5 ppm	
Fecal coliform	**	Standard Method Membrane Filtration with m-FC Difco Agar	1 fc/100 ml	Lab Dups 30%"	
Enterococci	**	Standard Method 1600 w/ mEI media, EPA	1 /100 ml	Lab Dups 30%"	
E. Coli	**	Standard Method 1600 w M-tech media, EPA KF Strep Media	1 /100 ml	Lab Dups 30%" Trip Blanks	
Nitrate + Nitrite-	Essential	LACHAT Autoanalyzer[a] (Cd Reduction)	0.1 µM	Lab/Field Dups ± 10%	85%-115% of spike
Ammonium-	Essential	Indophenol[b]	0.1 µM	Lab/Field Dups ± 10%	85%-115% of spike
Orthophosphate-	Essential	Molybdenum Blue[c]	0.05 µM	Lab/Field Dups ± 10%	85%-115% of spike
Total Dissolved Nitrogen	Essential	Persulfate digestion[d]	0.5 µM	Lab/Field Dups ± 20%	80%-120% of spike
Particulate Nitrogen & Carbon -	Essential	Elemental analysis[f], 440.0	0.5 µM	Field Dups ± 20%	95%-115% of check std
Total Phosphorus	Essential	Persulfate Digestion	0.5 uM	Lab/Field Dups ± 20%	80%-120% of spike

** samples to be collected only where bacterial contamination has been identified.

a Standard Methods 19th Edition, Method 4500-NO3-F using Lachat Autoanalysis procedures based upon:
Wood, E., F. Armstrong and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11:87-96.

b Standard Methods 19th Edition, Method 4500-NH3-F and Schneider, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10:31-36.

c Standard Methods 19th Edition, Method 4500-P-E Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.

d Standard Methods 19th Edition, Method 4500-Norg-D D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.

e Parsons, T.R., Y. Maita and C. Lalli. 1989. Manual of Chemical and Biological Methods for seawater analysis. Pergamon Press, 173 pp.

f Perkin-Elmer Model 2400 CHN Analyzer Technical Manual.

g Standard Methods 19th Edition, Method 4500-P-B.5, persulfate digestion and assay as orthophosphate.

Watershed Nitrogen Loading Model

The watershed loading model will be checked in sub-watersheds where the stream discharge can be expected to be unattenuated (for example as was done in upper Mashapaquit Creek in Falmouth). These circumstances are predictable, but do not occur in each embayment. However, they are frequent enough that we should be able to perform this type of confirmation at least once in each embayment cycle. The predicted nitrogen load should be within 10% of the measured load.

B.3.8 Instrument Calibration and Frequency Procedures

Sampling under the Watershed Nitrogen Loading Task is limited to instrument measurements for determination of stream flow and nutrient analysis.

Stream Flow and Nitrogen Load

Instrumentation deployed or utilized as part of the stream gauging program are factory calibrated. The factory calibration is checked for the Marsh McBirney Flow mate 2000 velocity meter by placing the velocity probe into a test tank containing still water. The velocity meter probe is mounted on a sled that runs the length of the test tank at a constant speed. The speed of the sled is varied in order to check the velocity meter function at low, medium, and high flow rates. Sled runs should be conducted at speeds that capture the range of flow rates that are encountered in the field program. Four sled speeds have been traditionally used in previous SMAST studies to check the calibration of the velocity meter (2.0 cm/s, 20cm/s, 40cm/s, and 80cm/s). Multiple repetitions at a selected sled speed are performed. A three to ten minute time interval is typically used between runs to allow the water in the test tank to return to still conditions. Potassium permanganate is introduced to the tank between the runs at higher speeds to check that the water in the test was sufficiently still to begin the next run.

The velocity meter calibration check is begun by running the test tank sled at the lowest check speed of interest and then increasing the speed of the calibration check runs incrementally until the highest check speed is reached. Afterwards, the lowest speed is re-run to check that instrument drift is not occurring. If a drift of more than 5% is encountered the instrument is sent back to the manufacturer for maintenance.

Water level loggers are factory calibrated prior to the start of the field season. Calibration for these sensors is the same as for the tide gauges in Section B.2. In addition, each probe is field verified each time a velocity profile is being run by measuring the height of water over the probe with a measuring tape and comparing the manual measurement with the instrument measurement. Manual measurements are subsequently plotted against instrument measurements and simple linear regression analysis is performed on the data to determine the linear relationship. The calibration is acceptable if the $r^2 > 0.98$.

Laboratory analytical instruments are calibrated for each analytical run and standards are run as part of the Facility's analytical process **(see B.3.6 & B.3.7)**. The instruments are also serviced by factory representatives if they fall outside of factory specifications. Balances and spectrophotometers are checked weekly with calibration standards.

B.3.9 Data Acquisition Requirements

For the location of stream sites, U.S.G.S. topographic maps are used to identify site locations (sites are GPS referenced for input into GIS).

Rainfall data is needed as corroborating data for the stream program. This data (date and amount) is obtained by the Stream Technical Lead from: is from the Town of Falmouth (via the WHOI WEB site), OTIS Air Force Base, Massachusetts Cranberry Station in Wareham, City of New Bedford, and other sources as they are identified.

Daily temperature and wind records may be required for some studies and they can be obtained from the same sites. Temperature and wind data are sampled at high frequency, generally continuously and then integrated into max/min and average statistics. The selected meteorological sites are all used for research or forecasting purposes.

B.3.10 Data Management

Watershed land-use will be presented both in maps and in spreadsheet formats. The GIS information, spreadsheets and any associated digital records will be help on CD-ROM with copies with the Land-use Technical Lead (Ed Eichner), the Technical Coordinator (R. Samimy) and with the Technical Manager (B. Howes) in the SMAST Project Library.

Stream flow and nutrient data will be recorded on field data sheets and kept in embayment specific notebooks **(B-I).** Data is recorded using the field data sheets while on-site at the time the measurements are taken and in laboratory notebooks at the Coastal Systems Analytical Facility (both data and chain of custody forms are filed). The stream Technical Lead will be asked to check that all data is accurate and legible before making copies for Technical Coordinator and SMAST Project Library. All data is reviewed by the Technical Manager. The nutrient sampling portion of the program requires that Chain of Custody forms (COC) be filled out as the samples are delivered at SMAST. Each COC is checked as samples are received. The stream flow and nutrient data will be stored on CD-ROM with copies held by the Analytical Facility, the Stream Technical Lead and the Technical Manager at the SMAST Project Library. Hard copies of data are also maintained by the same persons.

Nutrient Analytical data:
Raw data is maintained in duplicate notebooks. Data reduction involves the process of converting raw numbers into data that have direct chemical meaning or can be compared statistically. Calculation to concentration is done in an adjacent column for easy comparison. The calculation is based upon the regression equation calculated from the chemical standards. The results will be reported in terms of concentration, as means and standard errors. All data are subject to 100% check at all stages by the Estuaries Project Technical Director (B. Howes), the technical lead in N-regeneration (D. Schlezinger), the Coastal Systems Lab Manager (P. Henderson), and the Lab Coordinator for water quality monitoring (D. Goehringer). All data reported are reviewed to check for errors in transcription, calculation, or computer input. If data points are judged to be aberrant, the reserved sample will be reanalyzed. Data are also reviewed for adherence to analytical protocols and to pre-established criteria (e.g., holding times, surrogate recoveries, initial and continuing calibration, matrix spikes, laboratory duplicates, blank contamination). Students t-test for paired samples, analysis of variance, are used for interpretation. Data is transcribed only for the statistical analysis and each point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in the project files.

The watershed loading model is held in spreadsheet format, which includes the land-use and loading data for each sub-watershed to an embayment. The model will be held on CD-ROM and in paper copy at three locations: (a) Cape Cod Commission, (b) Technical Coordinator, SMAST, (c) Technical Manager in the SMAST Project Library.

B.3.11 Preventative Maintenance for Field Equipment

The only field equipment used in the watershed nitrogen loading task is associated with the stream flow measurements.

Watershed Land Use Analysis
No field equipment associated with this sub-task.

Watershed Stream Flow and Nitrogen Load
Preventative maintenance on the water level loggers deployed in streams for the continuous measurement of stream water height is limited due to the nature of the instrument itself. Field maintenance requires checking the installation to confirm that sediment is not accumulating on top of the water level probe. Additionally, batteries that power the water level loggers must be replaced every three months for proper function of the instrument.

When a water level logger is retrieved from a stream at the end of a measurement

period, it is brought back to the coastal systems lab and inspected for moisture accumulation. The probe is placed in a test tank at SMAST to confirm that it is recording water level accurately and precisely. The probes are cleaned and the logging portion of the instrument is wrapped in a breathable plastic baggy to add an extra layer of protection against the elements.

The current meter is calibrated at the factory and periodically checked in a research flume (at WHOI) during the field season. Batteries are replaced every two months to ensure adequate power in the field. The instrument is stored dry as per manufacturer specifications and no special storage procedures are recommended by the company. When not in use all field equipment is stored in dry heated storage.

Watershed Nitrogen Loading Model

No instruments are associated with this sub-task.

B.4 Nitrogen Regeneration Within Embayments

Overview: In addition to "new" nitrogen entering the estuary from the surrounding watershed, nitrogen is recycled within the sediments and watercolumn. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that the Estuaries Project Technical Team have previously investigated, recycled nitrogen can account for about half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. **Failure to account for this recycled nitrogen generally results in significant errors in determination of threshold nitrogen loadings.** In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data is needed to determine the best approaches for nitrogen mitigation.

The organic rich nature and relatively shallow waters of coastal systems like many of those on Cape Cod result in sediments having a significant role in system biogeochemical cycles. Organic matter deposition to sediments, hence benthic respiration, tends to decrease with increasing depth of overlying waters due to interception by watercolumn heterotrophic processes. The result is that Harbor respiration rates are typically many times higher than in the adjacent offshore waters. With stratification of harbor waters, sediment metabolism plays a major role in bottom water oxygen declines (an ecosystem structuring parameter).

The critical period for determining sediment nitrogen regeneration is during the warmer summer months (July-August) when the systems are most sensitive to nitrogen inputs. This is also the period of minimum dissolved oxygen and habitat quality and therefore the critical period for management. Sediment nitrogen regeneration will be determined throughout each embayment during this most sensitive summer interval (July-August) for parameterizing the site-specific water quality model.

B.4.1 Data Quality Objectives for Measurement Data

The data quality objectives have been selected to fit with the goals of the Sediment Regeneration Program of the Estuaries Project. The field data collection under this program involves water quality samples and observations during sediment collections. Data is also collected during the sediment incubations at a shore-side field lab and in the analysis of sampled waters at the SMAST Facility. The data quality objectives have been selected to account for the spatial and seasonal nature (summer) of sediment regeneration rates typical of the estuarine systems of southeastern Massachusetts. The methods and approaches establish the criteria for evaluating both data collected by the Estuaries Project and existing data being evaluated by the Technical Team for

inclusion into Project database **(see B-II)**. All data must meet the required levels of precision, accuracy, and detection limits.

The sediment regeneration program uses accepted methods for low level analysis in saltwater. These methods are accepted by the best marine research laboratories in the United States. EPA or Standard Methods techniques are employed by the SMAST laboratory when available. All methods have been inter-calibrated with a variety of methods and with various certified laboratories (freshwater only) and marine laboratories. Minimum performance criteria are listed in **Table B.4-1**, although the methods used in the program generally exceed these minima. The acceptable criteria for field blank cleanliness is generally a reading less than the detection limit. In occasional instances where high sensitivity methods are employed, the field blank must be less than 10% of the sample value.

Table B.4-1. Minimum Objectives for Sediment Regeneration Parameters

Parameter	Matrix[a]	Field Precision	Laboratory Precision	Accuracy	Detection Limit
Nitrate + Nitrite	1	<20% RPD[b]	<10% RPD	85%-115% of matrix spike	0.25 uM
Ammonium	1	<20% RPD	<10% RPD	85%-115% of matrix spike	0.25 uM
Orthophosphate	1	<20% RPD	<10% RPD	85%-115% of matrix spike	0.1uM
Dissolved organic N	1	<20% RPD	<10% RPD	85%-115% of matrix spike	1 uM
Dissolved Oxygen[b]	1	±0.25 mg/L	±0.1 mg/L	1% of air equilibration	0.2 mg/L
Temperature	1	±0.25 C	±0.1 C	±0.2 C	-10C – 40C
Salinity	1	±0.2 ppt	±0.1ppt	±0.2 ppt	0.3 ppt
1 – saltwater					

[a] 1 = saltwater
[b] dissolved oxygen is kept above 4 mg/L in these studies
Note: These parameters are measured by the Coastal Systems Analytical Facility at SMAST

Analytical requirements for sediment regeneration nutrient assays:
Complete standard curves are generated for each analytical run. If more than a 10-fold range of concentrations are encountered in the samples, then both a high and low standard curve is created. In all cases the standards are prepared new each day and are chosen to give at least 5 points over the sample concentration range. Standards well above the sample range are not used. Nitrate+Nitrite (run in duplicate) by autoanalysis has additional standards run before and after every five (5) samples. Failure of these additional standards (run as samples) to agree within 10% of their known value halts the assay line for complete recalibration and the re-running of the last sample set.

For nitrate+nitrite, dissolved ammonium, dissolved organic nitrogen, and ortho-phosphate, non-automated assays are all run in duplicate (at a frequency of at least 10% of the samples) with a <5% tolerance between duplicates required for acceptance.

After completion of analyses, remaining sample is frozen, for possible reanalysis if required. Oxygen analyses are performed within the headspace overlying the sediments using a stirred oxygen electrode. The electrode is calibrated at known oxygen concentrations, at the incubation temperature and salinity prior to and after each measurement. The calibrated electrode reading must be within 0.2 mg/L of the standard for a headspace measurement to be accepted.

Precision

The precision of each laboratory chemical assay needs to have been determined from duplicate assays of five standards. The field precision is from duplicate assay of five blind field duplicates. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R^2 of the linear regression of each set of standards (N>5).

Accuracy

Accuracy is determined from the analysis of standards for the standard curves and use of Performance and Evaluation Samples (commercially available). Accuracy is determined as the RPD of the assay of five standards run as samples within a series of analytical runs. This is compared to the RPD of five sets of Performance and Evaluation Samples. In addition, the accuracy of the method within the sample matrix is "checked" using the results and RPD of five matrix spikes experiments (standard additions) for comparison to the results and RPD of the standards, where appropriate.

Measurement Range

The usable measurement range for each chemical assay is only within the linear range as determined from least squares linear regression of laboratory standards. Concentrations above the linear range require standard dilutions for acceptable analysis. Since high values can be readily diluted and re-assayed the same day, the upper range of measurement is variable. Sample dilutions attempt to bring the concentration of the diluted sample into the middle of the linear range for the assay. The natural range for any analyte is typically less than 1000 fold.

Representativeness

The goal of the sediment nitrogen regeneration program is to provide nutrient inputs from sediments to the overlying waters of coastal embayments. The sampling points will be selected to encompass the tributary sub-embayments and to be representative of system sediment distribution. Sampling will focus on summer when embayments are most sensitive to nitrogen inputs and regeneration rates are highest.

Comparability

The results from each sediment nitrogen regeneration program will be directly comparable to each other. In addition, since these are accepted methods, they will be directly comparable to other studies conducted by EPA in other regions and other groups.

Completeness
The ultimate goal of the sediment regeneration task is to obtain data for determination of summer nitrogen inputs from sediments for the water quality model and to provide comparable data for each estuarine system in southeastern Massachusetts. This both provides the needed site-specific data and enables both inter- and intra-estuarine comparisons using consistent and reliable methods of sample collection and analysis. Completeness is gauged as the number of actual measurements divided by the number of planned measurements times 100%.

B.4.2 Documentation and Records

Field data associated with the collection of the sediment cores will be recorded on field data sheets to be kept in embayment specific notebooks **(B-I).** Data will be recorded on the field data sheets on-site at the time the measurements are taken. Similarly, data collected during the incubation of the sediments at the shore-side facility is recorded in field notebooks. Data associated with the handling and analysis of the resulting nutrient samples is kept in laboratory notebooks at the Coastal Systems Analytical Facility (both data and chain of custody forms are kept on file).

Nutrient Analytical data:
Raw data is maintained in duplicate laboratory notebooks. Data reduction involves the process of converting raw numbers into data that have direct chemical meaning or can be compared statistically. Calculation to concentration is done in an adjacent column for easy comparison. The calculation is based upon the regression equation calculated from the chemical standards.

B.4.3 Sampling Process Design

Sediment nitrogen regeneration will be determined throughout each embayment during the most sensitive summer interval (July-August) for parameterizing the site-specific water quality model. Rates of oxygen uptake and nutrient release are made incubating undisturbed sediment cores for ca. 24-36 hours at *in situ* temperature.

Sediment cores (15 cm id) will be collected by SCUBA divers or in very shallow waters from a small boat. Cores are maintained from collection through incubation at *in situ* temperatures. Temperature control is maintained through mixed circulating water baths and constant temperature monitoring.

Bottom water (1-2 meters above bottom) is collected by submerging a 20 liter acid leached polycarbonate container from the region of each core site. The container is capped and returned to the field laboratory, filtered (ca. 1 um) and used to replace the headspace water of the flux cores prior to incubation. The water overlying the sediment is gently mixed with a magnetic stirrer and the headspace is sealed with a gas-tight

closure fitted with sampling ports during incubation. Bottom water samples for water quality assays (nitrate+nitrite, ammonium, dissolved organic nitrogen, particulate organic nitrogen/carbon, ortho-phosphate, chlorophyll a/pheophytin a, salinity) are collected, held and assayed as in Section B.1. These data provide interpretive information for the sediment program, but become part of the water quality "monitoring" database.

The time series measurements of total dissolved nitrogen, nitrate+nitrite, ammonium and ortho-phosphate and dissolved oxygen made on the water overlying each sediment core sample allows calculation of the rates of nutrient and oxygen exchange. Exchange rates are determined from linear regression of analyte concentrations through time. The rate of oxygen uptake is similarly determined in order to support (1) evaluation of the sensitivity to oxygen depletion of each embayment area under periodic stratification, (2) ranking of sediments as to organic matter deposition rates (not possible using organic content), and (3) parameterization of nitrogen models. Water column oxygen uptake rates will also be determined at each core site on at least three dates.

Sampling sites within an embayment are distributed relatively uniformly from the upper tributary sub-embayments to the tidal inlet. When collecting a sediment sample, divers avoid small localized disturbed areas (mooring, rocks, single large shells, etc.). An attempt is made to collect samples that are representative of the condition of a general area, based upon visual survey by the SCUBA divers and observations from the boat when possible. During sampling the location is noted both using land marks on an aerial photo or USGS topographic map and by GPS. Temperature of bottom water and sediment characteristics are recorded (descriptions of macrophytes, infaunal burrows, epifauna, and sediment oxidation conditions, grain size, organic content) being made in the field and again in the laboratory as appropriate.

Typically up to 24 sites will be measured in the more complex systems and between 4-12 in the more typical and simple systems. Duplicate sediment samples are collected and incubated at 10% of the sites within an embayment.

The results allow the spatial pattern and rate of nutrient inputs from the sediments to the water column to be entered into the nutrient model. From our experience, sediment regeneration during the summer is a large and important source of nutrients Ramsey et al. 2000, Howes and Taylor 1990) supporting both phytoplankton and macroalgal blooms in embayments throughout Southeastern Massachusetts.

B.4.4 Sampling Methods Requirements

The concept in determining sediment nutrient regeneration rates is to collect an undisturbed sediment sample and incubate it under in situ conditions to allow natural exchange of nutrients between the sediment and overlying water under controlled conditions. The approach and methods which we employ in this program were also

used by Estuaries Project Technical Team members for numerous estuarine studies including the MWRA HOM Program (Combined Work/Quality Assurance Project Plan, MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-36).

Benthic nutrient flux cores (6" diameter) are collected by diver and maintained at in situ temperatures until returned to the laboratory. All of the sediment incubations will be performed immediately upon return. Estuary Project Technical Team members have all of the equipment required for this purpose and have routinely conducted these incubations in a variety of field conditions (including a remote interior site in Antarctica). Baffles and appropriate anti-mixing procedures are used during the transport of the cores. While much effort is generally spent in achieving highly accurate chemical assays (accuracy to 10%) to determine flux rates, handling of the sediment cores themselves (the source of the fluxes) is generally not well controlled and yet can create several fold errors in rates. In fact, our long experience in these measures in a variety of coastal sediment systems indicates that core handling can be a major source of error in benthic nutrient flux measures. For these reasons, incubations are conducted at a shore-side site to avoid overland transport of sediment samples.

Upon arrival at the shore-side field laboratory sediment cores are inspected for any surface disturbance or large megafauna (for example crabs or fish) which cause rejection of these cores. Acceptable flux cores are then sealed from the atmosphere with machined core tops fitted with magnetic stirrers that gently mix the overlying water without disturbing the sediment surface. Oxygen will be determined using an Orbisphere meter and electrode (the probe fitted through an opening in the core top) calibrated at 100% and 50% of atmospheric equilibration at the temperature and salinity of the headspace water of the cores. The headspace of the cores from each of the seven stations will be replaced with 0.22 micron filtered water (collected from each core site). Subsamples of the filtered water will be incubated to control for oxygen and nutrient changes in the headspace not associated with sediment flux. In all cases the incubation will continue until a significant flux is detected or to 36 hours. A “significant flux” is defined as one where the least squares regression of the headspace analyte concentration over time has a slope different from zero. The headspace will be set so as to maximize the signal and minimize the incubation time (ideally 18 hours).

At least four to five time points (plus time zero) will be conducted per core incubation. Dissolved oxygen will not be allowed to decline to less than 50 percent of air equilibration. Since oxygen disappearance rates may exceed those of other solutes, we will continue the incubations after completion of the oxygen uptake assay by aerating the headspace until the solute flux assays are completed. At each time point, headspace water will be removed through a port in the gas tight headspace with equal replacement with the setup water; samples are immediately filtered (Millipore 0.22 micron in-line filtration) into acid leached 60cc polyethylene bottles upon removal **(Table B.4-2).** Our system allows water removal without even brief pressure changes to the headspace (negative pressures can increase fluxes in some incubation systems). All

fluxes will be adjusted for water removals and measured activities within the headspace water.

Table B.4-2. Sediment Regeneration, Nutrient Parameters

Parameter	Matrix[a]	Sample Volume/ Container	Maximum Holding Time	Field Processing/ Preservation	Units
Nitrate + Nitrite[b]	1	60 ml polyethylene acid-washed	28 days (frozen)	Field filter, store dark in lab -20°C	μg/l
Ammonium	1	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	μg/l
Orthophosphate	1	60 ml polyethylene acid-washed	24 hours (4C)	Field filter, store on ice in dark	μg/l
Dissolved Organic Nitrogen	1	1L polyethylene acid-washed	24 hours	Field filter, store on ice in dark	μg/l
Dissolved Oxygen	1	none	none	Direct DO Meter Assay	mg/l
1 – seawater					

[a] 1 = saltwater

[b] USGS Central Laboratory had determined that freezing filtered samples for nitrate+nitrite is acceptable, without acidification (Avanzino and Kennedy 1993).

Note: These parameters are measured by the Coastal Systems Analytical Facility at SMAST

Ammonium, nitrate + nitrite and ortho-phosphate and dissolved organic nitrogen (and oxygen) will be analyzed for each of the time point sample volumes. Temporal changes in headspace concentrations will be used to calculate flux rates. The time-course measures will be used to ensure calculations from linear increases.

Samples for ammonia, nitrate/nitrite, and phosphate will be analyzed against reference standards having nutrient concentrations bracketing those of the samples. Standards will be analyzed daily, and checked for linearity (r^2 >0.99) and acceptability of blanks. All standards and blanks are run in duplicate. The dissolved oxygen meter will be calibrated against air-saturated water and the calibration will be checked prior to each oxygen measurement. Deviations from 100% saturation will be noted and appropriate corrections will be applied to the data following the manufacturer's manual. Nutrient samples will be analyzed in conformance with the same standards as applied to the nutrient water quality monitoring program (B.1) and stream program (B.3).

B.4.5 Sample Handling and Custody Requirements

Measurements of benthic nutrient flux will be conducted by the measurement of oxygen and nutrient flux across the sediment/water interface in cores collected from throughout

each embayment system. Cores are collected by diver and maintained at in situ temperatures on board the vessel until return to the shore-side field laboratory. Incubations will be performed at a "field" laboratory very near the ship landing in order to prevent disturbance to the cores in transit. All of the sediment incubations will be incubated immediately upon return to the remote field laboratory. The potential for disturbance to the sediment matrix of the cores due to transport over land (even a short distance) requires this procedure. It is nearly impossible to prevent vibrational mixing of the surficial sediment matrix during long distance transport over land. The problem with benthic flux measurements is that both disturbed and undisturbed cores yield linear rates, the only difference being that highly disturbed cores sometimes show less inter-core variance. Baffles and appropriate anti-mixing procedures will be used during the transport of the cores. While much effort is generally spent in achieving highly accurate chemical assays (accuracy to 1%) to determine flux rates, handling of the sediment cores themselves (the source of the fluxes) is generally not well controlled and yet can create several fold errors in rates. In fact, our long experience in these measures in a variety of coastal sediment systems indicates that core handling is the single major source of error in benthic oxygen and nutrient flux measures.

Sample analyses are performed for most parameters by the Coastal Systems Analytical Facility at SMAST. Samples are transported to the laboratory in coolers on ice. The methods employed are the standard methods of research level environmental laboratories. The methods used by the laboratory have been through many EPA and other agency reviews as part of QAPP procedures over the past 2 decades (5 years at SMAST, 15 years Woods Hole Oceanographic Institution).

Samples are logged-in upon delivery to the SMAST Coastal Systems Laboratory based upon field logs and Chain of Custody forms prior to signature by the authorized laboratory staff member. Staff are on-call 24 hours when field teams are sampling, both to assist in any sample handling issues which might arise and to allow drop-offs and assay within the proscribed holding times. During log-in, sample integrity and clarity of label are checked and any unusual sample characteristics (identified by visual inspection or information from sample courier) noted on the COC and in the appropriate laboratory notebook. All frozen and/or archived samples are stored in a freezer (-20^{o}C) accessible only to authorized laboratory personnel. The laboratory analysts are responsible for the samples from arrival to analysis and data entry.

Some of the sampling data is observational or collected by instrument (i.e. dissolved oxygen and therefore the information enters the laboratory via field data books. However, the nutrient sampling requires the transport of water samples to laboratories and therefore has additional documentation and handling requirements to ensure sample and information integrity.

All samples collected for nutrient analysis are labeled in the field with Embayment name, program name (i.e. Sed Flux), Sample ID, date (m/d/y), time of collection, and

any other specialized information. Identical information is recorded on a data sheet/chain of custody, which also include notes as to environmental conditions, problems encountered, names of personnel, etc. Samples are all held on ice in coolers from collection through transport to SMAST. Upon reaching the SMAST laboratory, all samples are cross-checked to the COC's and recorded by lab personnel. Copies of the sample list, COC's and data sheets are made and kept by the laboratory, the sediment regeneration Technical Lead, the Technical Coordinator and in the SMAST Project Library.

B.4.6 Analytical Methods Requirements

Sampling under the Sediment Regeneration Task includes analysis of headspace water samples for nutrients and dissolved oxygen measurements by electrode in the sediment incubations. In addition, field water quality samples collected from the fill water sites are analyzed under requirements of Section B.1 and are part of the water quality monitoring database.

Sediment incubation water samples will be assayed for nitrate+nitrite, ammonium, dissolved organic nitrogen, and ortho-phosphate by the Coastal Systems Analytical Facility at SMAST. Headspace dissolved oxygen will be assayed during the incubations using a YSI meter with a stirred BOD oxygen electrode. The analytical methods and quality control samples are listed in Table B.4-3, below.

Analytical procedures used in this program have been tailored to the specific chemical environment of coastal waters, i.e. variable salinity and analyte concentration ranges of 1000 fold. The procedures used are those commonly employed by the SMAST Coastal Systems Program for research on coastal processes. The analytical methods are being, or have been, used by SMAST in the measurement of water quality in a variety of monitoring programs such as: the USGS Namskaket Marsh Project (required intercalibration with USGS Central Lab), MWRA-HOM Program, Falmouth PondWatch, Pleasant Bay Alliance, USAID Water Quality Program-Jamaica, MCZM Wetlands/Stormwater Monitoring Program, Assabet River TMDL Study, RIDEM-Greenwich Bay Study, WHOI Nantucket Harbor Monitoring Program, Martha's Vineyard Coastal Pond Monitoring Program (MVC), and many others. These programs over the past 15 years have QAPP's and most of them have required acceptance by either EPA or Massachusetts DEP.

B.4.7 Quality Control Requirements

The nutrient analyses used in the sediment regeneration program follow standard laboratory procedures. In the analysis of incubation water samples, for each chemical assay, a complete set of standard curves is generated for each analytical run. In addition, reagent blanks and standards are prepared and analyzed with each new batch of reagent. These blanks are compared to previous data on blanks to evaluate the

potential of contamination and the standard curve compared to previous records. If this initial blank and standard curve is deemed satisfactory, samples using the new reagent batch can then analyzed. Calibration blanks are prepared and analyzed simultaneously with the creation of each standard curve that is created for each sample series. If more than a 10-fold range of concentrations is encountered in the samples, then both a high and low standard curve is created. In all cases the standards are prepared new each day and are chosen to give at least 5 points over the sample concentration range. Least Squares Linear Regression is used to calculate the standard relationship and a minimum $R^2 = 0.99$ is required for acceptance. Standards well above the sample range are not used. Nitrate+Nitrite (run in duplicate) by autoanalysis has additional standards run before and after every five (5-6) samples. Failure of these additional "check" standards (run as samples) to agree within 10% of their known value halts the assay line for complete recalibration and the re-running of the last sample set. These "check" standards are used to adjust the calculated sample values for instrument efficiency.

Nitrate+nitrite, dissolved ammonium, dissolved organic nitrogen, and ortho-phosphate are all assayed in duplicate at a frequency of more than 15% of the samples and with a <5% tolerance between duplicates required for acceptance. After completion of analyses, remaining sample is frozen, for possible reanalysis if required (and appropriate).

Spiked samples are periodically analyzed as analytical checks in dissolved ammonium, nitrate+nitrite, dissolved organic nitrogen and ortho-phosphate assays. Spiked samples are not widely run, as the standards are made up in the same matrix as the samples. Greater numbers of spiked samples are sometimes run as unknowns" similar to field duplicates. Recovery of spikes must be within 15%-20% of expected to meet QA.

As available Performance and Evaluation Samples (Ultra Scientific Inc.) for the nutrient assays will be purchased and run during the course of this study. These data will be used to evaluate the accuracy of the SMAST laboratory.

Table B.4-3. Analytical Procedures/Quality Control Samples

Parameter	Site	Method	Detection Limits	QC Samples	Acceptable %Recovery
Temperature	Core Headspace*	Thermister -10 °C to 40°C	0.1 C	Field Dups	
Salinity	Core Headspace	Specific Conductivity Meter	0.1 ppt	Field Dups ± 0.25ppt	
Dissolved Oxygen	Core Headspace	Dissolved Oxygen Electrode/Meter	0.1 ppm	Field Dups ± 0.5 ppm	
Nitrate + Nitrite-	Core Headspace	LACHAT Autoanalyzer[a] (Cd Reduction)	0.1 µM	Lab/Field Dups ± 10%	85%-115% of spike
Ammonium-	Core Headspace	Indophenol[b]	0.1 µM	Lab/Field Dups ± 10%	85%-115% of spike
Orthophosphate-	Core Headspace	Molybdenum Blue[c]	0.05 µM	Lab/Field Dups ± 10%	85%-115% of spike
Dissolved Organic Nitrogen	Core Headspace	Persulfate digestion[d]	0.5 µM	Lab/Field Dups ± 20%	80%-120% of spike

* Core Headspace – water overlying the sediment cores during incubation, Core Site – field location during core collection.

a Standard Methods 19th Edition, Method 4500-NO3-F using Lachat Autoanalysis procedures based upon:
Wood, E., F. Armstrong and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11:87-96.

b Standard Methods 19th Edition, Method 4500-NH3-F and Schneider, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10:31-36.

c Standard Methods 19th Edition, Method 4500-P-E Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.

d Standard Methods 19th Edition, Method 4500-Norg-D D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.

B.4.8 Instrument Calibration and Frequency Procedures

The sediment regeneration program requires 2 types of instrumentation: (a) dissolved oxygen equipment for assay during the core incubation and (b) analytical instruments associated with the assay of water samples collected during the incubations.

The dissolved oxygen meter (YSI digital meter with stirred BOD probe) is calibrated during use in a humidified temperature controlled calibration vessel at the temperature of the core incubations. Calibration is conducted before each time point and deviations from calibration measured immediately after. Before each incubation, the meter is multi-point calibrated using air a 10% oxygen certified gas mix and a zero oxygen gas at anticipated field temperatures. This is done to confirm instrument function before

deploying to the field site. The probe and meters are maintained according to the YSI manual.

The digital temperature meter and probe are checked with a certified thermometer prior to deployment to the field. Incubation water temperature is monitored with this thermocouple probe and with a standard thermometer (less sensitive, but also cross-referenced to a certified thermometer).

Laboratory analytical equipment (Bausch and Lomb, Genesis Spectrophotometers, Lachat Autoanalyzer, conductivity meters, etc.) is calibrated through the processing of standards in the normal analytical procedure. Meters and electrodes are multi-point calibrated. Laboratory analytical balances are under annual manufacturer service and calibration. SMAST also maintains and routinely uses certified calibration weights and thermometers. The freezer has a chart record of temperature and a temperature alarm to ensure the maintenance of frozen (nitrate+nitrite) samples below -20ºC.

Any field sampling equipment (refractometers, CTD, light meters, etc) are maintained and calibrated under the manufactures specifications and requirements with assistance from the SMAST Laboratory.

B.4.9 Data Acquisition Requirements

For the sediment regeneration program, U.S.G.S. topographic maps and aerial photographs are used to identify site locations. Printed scanned copies with marked site ID's are used by the field team.

Data on sediment types and eelgrass distribution is used, as available. The eelgrass data is available within the Technical Team (C. Costello). Sediment distribution data is sought from dredging permits and existing scientific studies.

B.4.10 Data Management

Field observations and data collected during the sediment incubations will be recorded in field data sheets to be filed in embayment specific notebooks **(B-I).** Data will be recorded on the field data sheets on-site at the time the measurements are taken and in laboratory notebooks at the Coastal Systems Analytical Facility (both data and chain of custody forms). The sediment regeneration Technical Lead will be asked to check that all data is accurate and legible before making copies for Technical Coordinator and SMAST Project Library. All data is reviewed by the Technical Manager. The nutrient sampling portion of the program requires that Chain of Custody forms (COC) be filled out as the samples are delivered at SMAST. Each COC is checked as samples are received.

The field observations, incubation data and laboratory nutrient data will be stored on CD-ROM with copies held by the Analytical Facility, the Sediment Regeneration Technical Lead and the Technical Manager at the SMAST Project Library. Hard copies of data are also maintained by the same persons.

Nutrient Analytical data:
Raw data is maintained in duplicate notebooks. Data reduction involves the process of converting raw numbers into data that have direct chemical meaning or can be compared statistically. Calculation to concentration is done in an adjacent column for easy comparison. The calculation is based upon the regression equation calculated from the chemical standards. The results will be reported in terms of concentration, as means and standard errors. All data are subject to 100% check at all stages by everyone. All data reported are reviewed to check for errors in transcription, calculation, or computer input. If data points are judged to be aberrant, the reserved sample will be re-analyzed. Data are also reviewed for adherence to analytical protocols and to pre-established criteria (e.g., holding times, surrogate recoveries, initial and continuing calibration, matrix spikes, laboratory duplicates, blank contamination). Students t-test for paired samples, analysis of variance, are used for interpretation. Data is transcribed only for the statistical analysis and each point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in the project files.

The determination of nutrient and oxygen exchange rates are held in spreadsheet format, which includes both the concentration data and the rate calculations and the field conditions for each site in an embayment. This will be held on CD-ROM and in paper copy at three locations: (a) Sediment Technical Leader, (b) Technical Coordinator, SMAST, (c) Technical Manager in the SMAST Project Library.

B.4.11 Preventative Maintenance for Field Equipment

SMAST laboratory staff will perform a routine inspection and maintenance of field sampling equipment prior to each use. Throughout the season spare parts and replacement equipment is available to keep field operations running smoothly in the event of equipment failure. Temperature control units used in the incubations are periodically serviced by the manufacturer and backup units are deployed to the field site for each incubation.

All equipment (Niskin Bottles, SCUBA gear, pumps, and other mechanical gear) is cleaned, freshwater rinsed and put away in good working order at the completion of a sampling event. Dissolved oxygen equipment is stored as indicated by the manufacturer (humidified membrane). Conductivity meter is rinsed in freshwater and stored as per manufacturer specifications. All mechanical and electrical gear is held in dry heated storage.

B.5 Linked Watershed-Embayment Nitrogen Model

The Linked Watershed-Embayment Nitrogen Model integrates the data and models derived from tasks described above:

- watershed nitrogen loading model (Section B.3)
- embayment regeneration of nitrogen from sediments (Section B.4)
- hydrodynamic model (Section B.2)

In addition, the Linked Model is validated using water quality monitoring data (Section B.1). The model has been compared to other available approaches and had a sensitivity analysis conducted as part of the Estuaries Project Phase I (Howes et al. 2001).

Cumulative Nitrogen Loading Assessment

The ecological health of each of Southeastern Massachusetts' embayments is the integration of the amount and distribution of nutrient inputs from their surrounding upland watersheds, the rate at which these nutrients are removed by tidal flushing and the physical structure of the embayments. This Task focuses on the rate of nutrient input from the surrounding watershed as determined in Section B.3, above.

The total nitrogen input to each embayment (Section B.3) was determined using GIS based land-use analysis and direct measurements of nitrogen discharge from streams. These parameterize a loading model which is consistent with that used by the Cape Cod Commission and the Buzzards Bay Project and has been accepted by the general estuarine community for over a decade. The loading model uses land-use distributions and loading rates specific to each land-use to determine total system loading. The land-use loading terms are all from regional studies conducted in similar aquifer soils. Attenuation of nitrogen during transport through the aquifer and surface freshwater systems of the watershed will be included in the modeling effort. This attenuation of nitrogen is a critical part of the land-use model, in that omitting this process can result in significant errors in the determined nitrogen loads.

The watershed will be divided into regions a) contributing directly via groundwater to the estuaries, b) contributing to freshwater lakes and ponds, c) contributing to streams and rivers. A full land-use loading model will be applied to each of these sub-watersheds (where they exist) to determine the spatial distribution and amount of nitrogen loading to the estuarine portions each watershed-embayment system.

In support of the loading models is data collection on land-use and its validation, physical and biogeochemical data collection on the freshwater lakes and ponds, and the

spatial and areal distribution of wetlands. However, the lake/pond and wetlands data will be gathered from existing sources (See Section 5.9, below). The land-use modeling will rely heavily on GIS approaches, but field data collection will also be required. Lake and pond field data collection of stratification, nutrient and chlorophyll levels is important for determining attenuation rates. GIS work will be conducted in collaboration with Town Departments and the SMAST Project Team (and where appropriate with regional agencies CCC or MVC), with field studies directed by SMAST staff scientists.

Embayment regeneration of nitrogen from sediments (Section B.4)
The survey of nitrogen regeneration rates from sediments yields a spatial distribution of nitrogen inputs to the embayment water column from this source. These data are incorporated into the embayment portion of the Linked Watershed-Embayment Nitrogen Model.

Embayment hydrodynamic model (Section B.2)
The calibrated and validated hydrodynamic model (RMA-2) is used as the foundation to the water quality model (RMA-4).

Embayment Water Quality Model
Provides the distribution of nitrogen within an embayment relative to the watershed and sediment inputs, circulation and flushing. The concentrations are spatially and temporally distributed, with variations in concentration predicted through the tidal cycle. The model output is validated by measured nitrogen levels determined from water quality sampling programs. The nitrogen levels in the waters of an embayment (at the appropriate tide stage) are predicted by the water quality model for comparison to the levels determined by the multi-year water quality sampling program. The average percent difference between observed and predicted over the estuary should have an RPD of 5% to 10%.

B.5.1 Data Quality Objectives for Measurement Data

There is no field data collection under this task. The task is an integration of data collected under other tasks into the Linked Watershed-Embayment Model. The watershed nitrogen loading model and the embayment sediment nitrogen regeneration provide spatially applied nitrogen input terms, the water quality monitoring data provides both average summer nitrogen concentration distribution (including offshore boundary conditions) and the hydrodynamic model provides the circulation and flushing within the embayment.

B.5.2 Documentation and Records

The data used in the Linked Model will be fully documented and stored with the model on CD-ROM. However, this input data is generally in spreadsheet format (or as a digital

model in the case of the hydrodynamics), so that the original base data will be stored under the individual Task categories (i.e. sediment regeneration, stream flow, etc.).

B.5.3 Linked Model Process Design

The movement or transport of water quality constituents within the waters of an estuary is the result of two primary hydrodynamic mechanisms, advection and dispersion. Advection is the transport of a constituent contained within a fluid flow, as in the case of a tidal estuary, where the flow of sea water in and out over the course of a tidal cycle carries along with it dissolved and suspended matter. Dispersion is a small-scale process that results from the random scattering of particles by the combined effects of shear within the flow (velocity gradients and eddies) and diffusion (concentration gradients and molecular motion). The Estuaries Project will use the RMA-4 Model to account for these processes in order to determine nitrogen transport and distribution within each of the embayments of southeastern Massachusetts. In the RMA-4 water quality model, the advective mechanism of constituent transport results from the hydrodynamic output of the RMA-2 model (Section B.2). Dispersion is included in RMA-4 through the use of coefficients that are set by the user. Non-primary hydrodynamic mechanisms will not be evaluated by the Estuaries Project as a source of transport of water quality constituents. However, some are incorporated into the field measurements. For example, the effects of bioturbation is incorporated into the benthic regeneration studies and the effect of tidal resuspension of nitrogen in particulate form is included in the water quality data used to validate the model. The effects of storm water inflows on estuarine transport tends to be small given the dominance of groundwater in the freshwater hydrologic balance of these systems. Overall, these secondary mechanisms appear to be very small compared to the roles of advection and dispersion in the transport and distribution of nitrogen within these small enclosed or semi-enclosed estuarine systems.

Each RMA-4 application to a specific estuary is calibrated by making adjustments to the dispersion coefficients applied in the model. Typically, values between 10 and 50 m^2/sec^{-1} are observed in relatively quiescent waters and values up to 300 m^2 sec^{-1} in moderately sized flows (Fischer et al. 1979). By adjusting the longitudinal dispersion coefficients until the model prediction match the field observations, estuary specific diffusion characteristics are determined.

Estimates for the dispersion coefficients (i.e. model calibration) required by the water quality model are determined by evaluating natural dispersion of salt within each embayment. Salinity measurement during slack and/or ebbing tide conditions along the central axis and tributary sub-embayments provides the basis for dispersion estimates. Since salt is a conservative constituent (the only source is the offshore tidal waters and there are no sinks); measurement of salt in combination with an analysis of freshwater

inflow allows determination of dispersion/diffusion along the longitudinal axis of each pond. The freshwater stream discharge data is provided by the stream program (Section B.3) and the groundwater inflow is part of the USGS watershed program database.

Using dispersion relationships from salinity analysis, the nitrogen loading data, water quality and hydrodynamic models are integrated in order to generate estimate of the spatial and temporal distribution of total nitrogen resulting from site-specific hydrodynamic processes. The distributions, strengths and discharge locations of nitrogen loads from the watershed and sediment sources are distributed based upon spatial information into the model. The model is validated with both water quality data collected by the Estuaries Project and the long-term monitoring database for each embayment. The model output is validated by measured nitrogen levels determined from water quality sampling programs. The nitrogen levels in the waters of an embayment (at the appropriate tide stage) are predicted by the water quality model for comparison to the levels determined by the multi-year water quality sampling program. The average percent difference between observed and predicted over the estuary should have an RPD of 5% to 10%.

Once the Linked model is calibrated and validated for current conditions in a specific embayment, 4-5 scenarios will be conducted:

- Watershed build-out under the most likely conditions
- Removal of all wastewater inputs
- Unrestricted tidal flow through the inlet (or possibly to specific sub-embayments)
- A site-specific scenario to be determined
- And if tidally restricted wetlands are identified, restoration of tidal flow

B.5.4 Sampling Methods Requirements

There is no field sampling or equipment associated with this task.

B.5.5 Sample Handling and Custody Requirements

There is no field sampling or equipment associated with this task.

B.5.6 Analytical Methods Requirements

There is no field sampling or equipment associated with this task.

B.5.7 Quality Control Requirements

The Linked Model must agree with the observed nitrogen distribution under current conditions to an RPD of 5%-10% depending on the quality of the available long-term

water quality baseline. If this is not achieved, additional water quality, input or calibration data may have to be collected. If this occurs, the same stations occupied by the baseline monitoring program will be assayed by Estuaries Project staff, focusing on June-September months. In addition, the watershed nitrogen model will be re-examined seeking missed nitrogen sources or sinks.

Review of Existing Studies and Water Quality and Hydrodynamic Data.
We will perform a review of all existing studies of Southeastern Massachusetts embayments and watersheds. We will review the water quality data and hydrodynamic data and models which have been previously collected for: (1) quality of sampling approach, (2) quality and capability of chemical analysis, (3) quality assurance procedures, (4) completeness, (5) applicability to the nitrogen modeling, engineering and management effort which is the focus of this project. The protocol is presented in **B-II**. The purpose of this data review is to allow incorporation of needed water quality (Section B.1) and hydrodynamic data (Section B.2) to support the Linked Watershed-Embayment Management Approach. The data may include water quality constituents, dissolved oxygen, stage records, bathymetric maps, and circulation data.

B.5.8 Linked Model Calibration

See Section B.5.3.

B.5.9 Data Acquisition Requirements

Baseline water quality data is required for the validation of the Linked Model. This data is being compiled by the Technical Manager and Technical Coordinator from the various monitoring programs in southeastern Massachusetts. The monitoring data that is currently available includes:

Coalition for Buzzards Bay
Falmouth PondWatch
Popponesset Bay Monitoring Program
Pleasant Bay Alliance
Chatham WaterWatch
Three Bays Monitoring Program
Orleans Monitoring Program
Barnstable Monitoring Program
Wellfleet Harbor Monitoring Program
Nantucket Harbor – WHOI Study
Martha's Vineyard Monitoring Programs
Plymouth Harbor/Eel River Monitoring
Scorton Creek Monitoring Program

Additional data on groundwater inflow rates is to be provided by the USGS watershed effort that is partnered to the Estuaries Project. Data on lakes and ponds will be gathered as available from studies such as the CCC/SMAST Cape Cod lake survey or the National Seashore Lake studies, however, this data is used as correlative to the Linked Model. Wetland data will be acquired (as available) through the DEP wetland mapping program.

B.5.10 Data Management

Data will be transferred by the Technical Coordinator from the Technical Leads for: watershed nitrogen loading modeling, hydrodynamics and sediment nitrogen regeneration, to the water quality modeling Technical Lead and the Technical Manager.

As the information is received by the modeling Technical Lead and the Technical Manager at SMAST, the data is evaluated for completeness and quality. The data is then used to calibrate and validate the Linked Watershed-Embayment Model. The calibrated model is then stored (at a minimum) on CD ROM by the Technical Lead and the Project Technical Manager in the SMAST Project Library.

B.5.11 Preventative Maintenance for Field Equipment

There is no field sampling or equipment associated with this task.

B.6 Habitat Assessment

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (infauna) which it supports. The Estuaries Project Technical Specialists will conduct surveys of these parameters during the field data collection part of the 2 year embayment cycle. Additional historic data will be used, as available, to determine trends. These data will be synthesized into an assessment of the systems present health and will also be used for projections of future conditions based upon the water quality modeling effort (Section B.5, B.7). These data will be collected in each of the 89 embayment systems in southeastern Massachusetts.

This Indicator Task involves sediment collections for benthic animals by traditional oceanographic methods (grab sampling or large cores and wet sieving), placement of continuously recording dissolved oxygen sensors at key locations for 30 days and underwater surveys for macrophyte mapping. The macrophyte mapping program will also provide a historic trend analysis for some embayments since the Technical Lead for this sub-task, C. Costello, has been conducting mapping throughout southeastern Massachusetts since 1993.

B.6.1 Data Quality Objectives for Measurement Data

The data quality objectives have been selected to fit with the goals of the Habitat Assessment Project Task of the Estuaries Project and to be relevant to the natural variability of habitat indicators both spatially and seasonally in southeastern Massachusett's estuaries. The indicator measurements are primarily to map distribution (macrophytes) or to identify and count numbers of organisms (benthic infauna), the instrument program collects analytical data. The minimum performance criteria for inclusion into the habitat assessment program database for the relevant parameters are given in **Table B.6-1**, below.

Table B.6-1. Habitat Assessment Program, field parameters measured & data objectives

Parameter	Method	Detection Limits	Frequency	QC Samples	Acceptable %Recovery
Macrophytes	Video Survey	Individual shoots	1 survey May-Oct.	Spot checks by diver	95%
Benthic Animals	Van Veen Grab or Coring as appropriate Microscope sorting	1 animal	1 survey Aug-Oct	Spot checks by different specialist	95%
Dissolved Oxygen	Rapid Pulse Clark Electrode	0.2 mg/L	15 min. for 1-2 months, July-August	Winkler Titration of water from sensor depth	75 %
Temperature	Bead Thermistor (sensitivity of 0.1^{o}C)	NA	15 min. for 1-2 months, July-August	Calibrated to certified thermometer prior to deployment	75 %
Conductivity/ Salinity	2-electrode platinum conductivity cell 1 cm. Path length	0.1 mS/cm	15 min. for 1-2 months, July-August	Whole water collected at sensor depth	75 %
Depth	Differential Strain gauge transducer	0.02 m	15 min. for 1-2 months, July-August	Calibrated to measured tape level at beginning and end of deployment	75 %
Chlorophyll a	Fixed wavelength fluorometer, 470 nm	0.1 ug/L	15 min. for 1-2 months, July-August	Chlorophyll extraction	75 %

Precision

The precision of each chemical assay is determined by from repetitive assays in well mixed seawater of known composition under standard conditions. The precision is calculated as the relative percent difference (RPD). An additional estimate of precision is determined from the R^2 of the linear regression of each set of standard solutions (N>5).

Accuracy

Accuracy is determined from the analysis of standards for the standard curves. Accuracy is determined as the RPD of the assay of five standards solutions run as samples within a series of analytical runs. This is compared to the RPD of five sets of Performance and Evaluation Samples.

Measurement Range

The usable measurement range for each chemical assay is only within the linear range of the instrument as determined the factory calibration and field checks

Representativeness
The goal of the indicator program is to provide data needed to conduct habitat assessments throughout the sub-embayments of each embayment system in southeastern Massachusetts and to determine changes over the long-term. Benthic infauna sampling sites are paired to the sediment regeneration sites. The results of the indicator program will be compared to previous data sets.

Comparability
The results from each embayment's indicator sampling will be directly comparable to the others within the Estuaries Project. In addition, since these are accepted methods, they will be directly comparable to other studies conducted by NOAA and EPA in other regions and by other groups. The results are also comparable to many national programs and to the EPA Coastal Survey.

Completeness
The ultimate goal of the Water Quality Monitoring Program Task is to obtain comparable data from each estuarine ecosystem, enabling both inter- and intra-estuarine comparisons using consistent and reliable methods of sample collection and analysis. Completeness is gauged as the number of actual measurements divided by the number of planned measurements times 100%.

B.6.2 Documentation and Records

Field data from will be recorded in field books or on standardized data sheets **(B-I)** on-site at the time the measurements are taken. The Technical Leads will be asked to check that all data is accurate and legible before making a copy for the Technical Coordinator and the Technical Manager for the SMAST Project Library. The benthic animal samples require that Chain of Custody forms (COC) be filled out. Each COC is checked to verify the sample id's and locations. A copy of the database is maintained both at the program offices and at SMAST.

B.6.3 Sampling Process Design

The indicator program is composed of 3 basic components:

- Eelgrass and macroalgal surveys
- Benthic Animal Surveys
- Dissolved Oxygen and chlorophyll *a* records from key sites

Sampling will be conducted at long-term baseline water quality monitoring stations and the macrophyte surveys along transects throughout the embayment systems. Sampling will be most intense during the critical warmer months.

Mapping of eelgrass and macroalgal communities will be conducted during the summer months. SMAST has refined these survey and mapping techniques for recent studies in the Town of Chatham and for MA DEP in West Falmouth Harbor. Macroalgal mapping will include distribution. Macroalgae are a natural part of estuarine systems, but become “excessive” under nutrient enrichment. Existing data on the system collected over the past decades will be used to assess changes in distribution or community structure. For Protocol see **B-I**.

Benthic animals are a key indicator of the health of estuarine systems. Benthic sampling and analysis will be performed primarily SMAST staff, who have more than 30 years of experience in Cape Cod embayments. Samples will be collected either by Van Veen Grab (25 cm x 25 cm) or large cores (15 cm id). Samples will be collected and the animals separated using a 300 um sieve. The animals and any remaining particles on the sieve are washed with seawater into 1 gallon jars, preserved with ethanol and the final sorting of the animals conducted under a dissecting scope.

Dissolved oxygen is a critical indicator of nutrient over-enrichment and eutrophication. The problem with quantifying dissolved oxygen conditions stems from the high temporal variability of this parameter. However, determining the level of oxygen depletion and the duration of low oxygen conditions is a key indicator and one with regulatory implications. Therefore, the Estuary Project will deploy ENDECO/YSI 6600 sensor systems in the target embayments throughout July and August of the field data collection year or possibly 2 years. We have extensive experience with using these instruments and they are a routine part of SMAST field Programs. The sensors will also measure temperature, salinity and chlorophyll a. They will be placed within “areas of concern” and other areas throughout each system, as indicated from the long-term monitoring baseline. The sensors will be deployed on fixed moorings generally within the upper reaches of embayments or where baseline water quality monitoring suggests that D.O. depletion may be occurring. The sites will be selected based upon (1) measured dissolved oxygen levels of <4mg/L by water quality monitoring programs or (2) indications based upon algal blooms and circulation that a low dissolved oxygen environment may exist. Sensors will be placed 0.3 m above the sediment surface and will sample at 10-15 minute intervals. Membrane fouling and sensor maintenance will follow manufacturer specifications, but membranes and batteries will be replaced every 30 days.

These water quality and habitat data sets will be synthesized and integrated with the modeling efforts, for both hind and forecasting of habitat quality changes linked to watershed management.

B.6.4 Sampling Methods Requirements

Macrophyte Survey:
Overview: The State of Massachusetts has protected wetlands for over 30 years. During this time, eelgrass bed and *Zostera marina*, has been a relatively unknown wetlands resource. Recognizing this lack of information, the Department of Environmental Protection Wetlands Conservancy Program has conducted a statewide mapping inventory of eelgrass resources over the past 8 years. This mapping inventory was completed using 1:20,000 scale color aerial photography metric and extensive field surveys. The eelgrass resources have been compiled on a 1: 10,000 scale digital orthophoto base map. There are currently over 26,000 acres of eelgrass meadows in Massachusetts. This eelgrass meadow spatial data represents an accurate statewide inventory of the eelgrass resources. Currently, the data is used in project review and project permitting.

During the summer months of 2002, the DEP Wetlands Conservancy Program will conduct field surveys in the prioritized embayments as identified by Phase III of the Massachusetts Estuaries Project. This work will be conducted during the scheduled fieldwork of the Program's ongoing eelgrass monitoring efforts.

The purpose of this study is to continue the project of collecting eelgrass site information in areas where water quality conditions would be expected to adversely impact the eelgrass resources. Data will be recorded and displayed on a digital base map that will include the accurate location of field note information and graphic representation of specific sampling points. Transects will be surveyed by differentially-corrected GPS to provide accurate coordinates for subsequent monitoring efforts. High-resolution underwater digital videography (GPS stamped) will be collected and stored for the specific point and transect sites. This digital imagery will be included in the database and will be available for distribution.

The overall objectives of the Macrophyte sub-task and field protocols are provided in **B-I**.

Benthic Infauna Community:
Sampling of sediments are routinely conducted by the SMAST laboratory for infaunal sampling. Samples are collected by benthic grab, generally Van Veen grab, or diver collected cores), sieved (0.300 mm) and sorted according to species by SMAST Coastal Systems Program benthic ecologists familiar with the needs of the research. There is seasonality in benthic animal populations with the minimum numbers and diversity generally found at the end of the summer (particularly is there is summer hypoxia). Therefore, sampling will focus on late summer and early fall to capture samples

indicative of potential summer stresses. Each station will be located both by visual data on USGS topographic charts and by GPS. All of the procedures employed are standard methods and are currently in use in our laboratory.

Moored instrumentation:
Moorings will be placed at key sites within each embayment to record dissolved oxygen, salinity, temperature and chlorophyll levels. Locations will be identified both using visual references and GPS coordinates.

Dissolved Oxygen: Calibrated oxygen sensors are kept in a protective cap from the time of calibration until field deployment. Humidity is maintained near 100% within the protective cap through additions of distilled water. Sensors are prevented from becoming immersed until deployment thus preventing the growth of performance degrading bio-films upon the sensors surfaces. When instruments are recovered, sensors are rinsed with distilled water and maintained in a 100% humidity environment until post-deployment calibrations are performed at the SMAST Coastal Systems Laboratory. Both pre and post deployment calibrations are performed within 48 hours of field deployment.

Conductivity: Whole water samples are collected after the dissolved oxygen sample in a 1 liter amber bottle after being rinsed with 100 mL of sample. Samples are held in a sealed bottle until analysis by bench top conductivity meter within 48 hours. The meter is calibrated using three certified calibration standards before each use and with a single calibration standard after each use.

Temperature: There is no sample handling requirements for temperature. Pre and post deployment the temperature sensor is checked using a mixed water bath and a certified thermometer.

Chlorophyll: Whole water samples are collected after the dissolved oxygen sample in a 1 liter amber bottle after being rinsed with 100 mL of sample. Samples are held on blue ice and filtered within 12 hours of collection. The sensor operates on fluorescence. The laboratory analysis uses acetone extraction and fluorometric assay, as in section B.1.

B.6.5 Sample Handling and Custody Requirements

Macrophyte Survey:
The macrophyte (eelgrass and macroalgae) survey data is collected digitally in the field and transported to the DEP Mapping Laboratory on disc. No analytical samples are collected, however, when necessary specimens are collected to confirm identification. These samples are collected by grab, net or diver and kept in seawater in a cooler for laboratory identification.

Benthic animal survey:

Sediment samples for benthic animal analysis are wet sieved in the field and the fraction retained on the sieve is transferred to a 1 gallon polyethylene wide mouth jar. The jar is labeled with the embayment name, site id, date/time and lat/long. The samples are preserved with buffered ethanol. These data are also placed upon a Chain of Custody form as the samples move to the SMAST laboratory for sorting.

Moored Instrumentation
The data collected by the moorings is held in memory within the instrument until download in the SMAST Coastal Systems Laboratory. This data carries its own chain of custody and ID's and placement information as a header in the file. However, each instrument has an external ID reference which is entered onto a COC during transport and handling through download.

Dissolved Oxygen: Calibrated oxygen sensors are kept in a protective cap from the time of calibration until field deployment. Humidity is maintained near 100% within the protective cap through additions of distilled water. Sensors are prevented from becoming immersed during transport, thus preventing the growth of performance degrading bio-films upon the sensors surfaces. When instruments are recovered, sensors are rinsed with distilled water and maintained in a 100% humidity environment until post-deployment calibrations are performed. Both pre and post deployment calibrations are performed within 48 hours of field deployment.

Chlorophyll and conductivity: The field samples collected for QC of these instruments are entered onto a COC form and the samples processed through the SMAST Analytical Facility as for other water quality samples.

B.6.6 Analytical Methods Requirements

The macrophyte mapping sub-task does not require analysis. Identifications will be confirmed using the Marine Biological Laboratory Museum collection.

The benthic infaunal samples are assayed at the SMAST Facility. The field collected samples are dyed with a vital stain and preserved with ethanol. The samples are hand sorted under a binocular dissecting microscope and the animals placed in vials of ethanol for later identification and counting. After a sample is sorted, a different technical member checks the sample for "missed" organisms. The harvested organisms are then divided by species and identified based upon standard keys and local museum collections. Most of the identifications are confirmed using the Marine Biological Laboratory Museum collection and the Woods Hole Oceanographic benthic collection. The most used keys are the Woods Hole key to the invertebrates and Gosner's key of invertebrates from Cape Hatteras to the Gulf of Maine. The technical staff conducting the identifications are recognized experts, but confirmations are requested as needed from outside experts in Woods Hole. The sorted organisms are then archived by SMAST.

Moored Instrumentation
The moored instruments are performance checked weekly by collection and analysis of samples from the sensor depth for dissolved oxygen, conductivity, temperature and chlorophyll. Samples associated with the moorings will be assayed at the SMAST Facility.

Dissolved Oxygen: Winkler titrations for dissolved oxygen form the criterion for determining instrument performance. Assays are conducted in the SMAST Coastal Systems Analytical Facility. Triplicate 300 mL dark BOD bottles are filled by peristaltic pump. The inlet tubing is placed adjacent to the dissolved oxygen sensor and after flushing the pump and tubing with three volumes of water the outlet tubing is inserted to the bottom of a BOD bottle. 1 liter of water is allowed to overflow the bottle before the stopper is inserted. Once collected, oxygen samples in BOD bottles are fixed by first adding Manganous sulfate and alkaline iodide azide powders (Hach Company, Loveland, CO) to the sample. After replacing the stopper the bottle is shaken for 3 minutes allowed to rest for 30 seconds and shaken for another three minutes to ensure full reaction of dissolved oxygen with the combined reagents. The precipitate produced by the reaction is allowed to settle to the bottom third of the bottle before the sulfamic acid powder reagent is added. Following addition of the sulfamic acid the sample is shaken until all of the precipitate is dissolved. Sample collection is repeated if at any time air bubbles are introduced into the sample bottle. Samples are stored on blue ice (10C) water sealed in the dark and analyzed within 24 hours of collection. Although Standard Methods indicates that 8 hours is the preferred holding time for dissolved oxygen samples, marine research and monitoring programs (for example the MWRA HOM Program) have determined that fixed samples of coastal waters can be held for more than 24 hours without loss of signal. Holding experiments conducted by the University of New Hampshire (Ted Loder pers. comm.) indicate a loss of less than 1 uM per day for dark water sealed samples at 10^{o}C. Experiments by the SMAST Coastal Systems Group support the UNH findings.

Oxygen determinations are made on 100 mL sub samples analyzed by potentiometric titration using an ABU91 Autoburette (Radiometer America Inc., Westlake, OH). The instrument is calibrated once daily prior to sample analysis by titrating a 100 mL sample of known concentration.

Conductivity: Samples are collected in parallel with the dissolved oxygen water samples, transported at 10^{o}C in the dark in a cooler and assayed in the SMAST Coastal Systems Analytical Facility. Conductivity samples are analyzed on a YSI 3900 Bench top Conductivity meter equipped with a 1 cm cell. Prior to sample analysis the meter is

calibrated using a three-point calibration method with a range of standards that brackets the expected sample range. Following calibration the slope of the calibration line is noted and if it differs by more than 2% from the expected slope of 100, then the calibration procedure is repeated until the criterion is met. Samples are analyzed after equilibrating to room temperature.

Temperature: A visual inspection of the mercury column within the certified thermometer is performed prior to use. If the mercury column is separated, the thermometer is not used until continuity of the mercury column is restored and the thermometer recertified. The certified thermometer is used for comparison to the sensor on the YSI/Endeco 6600 sonde in the laboratory during pre and post deployment check out.

Chlorophyll: Whole water samples are filtered and analyzed for Chlorophyll a +Pheophytin a by collection of phytoplankton on membrane filters (0.45 um Millipore) and cold extraction under 90% acetone in the dark. Assay is by fluorometric analysis. Standardization uses "pure" chlorophyll a (Sigma Scientific) and quantification using the trichromatic equations on a scanning spectrophotometer.

B.6.7 Quality Control Requirements

Macrophyte Survey:
Macrophyte survey data will be checked using diver observations at multiple points within an embayment. In addition, the areas with macroalgae will be observed by divers to confirm species and density. Divers will use a percent cover approach to macrophyte density and checks will be performed only occasionally (<5% of transects). The primary QC check will be the detailed revisiting of "point 3" in the video transects as explained in B-I (Eelgrass Survey Protocols). Video transects will also have "cross-over" points where a second determination is made of the same location.

Benthic Animal Survey:
Triplicate grabs will be collected at each site within an embayment. Duplicates will be fully sorted and identified. If the samples differ by more than 30%, the third replicate sample will be sorted. The species identifications will be periodically checked by an independent expert on local fauna, on about 5% of the samples. However, all species of uncertain identification will be confirmed by an independent expert. Cross checks will also be made using museum collections (WHOI and MBL).

Moored Instrumentation:
Dissolved Oxygen: During instrument deployment triplicate BOD bottles are collected by peristaltic pump at the precise depth of the dissolved oxygen sensor to validate sensor operation. Oxygen determinations by Winkler titration are made on sub-samples of the collected BOD bottles according to the above protocol. Instrument output is corrected to the titration data and data between field data validation samplings is

adjusted linearly. If instrument and titration values differ by more than 10% then the calibration data is re-examined. If the differences between the types of data cannot be rectified the data is invalidated and the sampling location is re-occupied. The D.O. unit is calibrated in the laboratory pre and post deployment, the in situ samples are collected to validate sensor operation in the field.

Salinity: During instrument deployment whole water samples are collected by peristaltic pump at the precise depth of the conductivity sensor to validate sensor operation. Sample values are compared to the instrument record following instrument recovery. If differences greater than 5% exist between the collected samples, additional field samples are collected and analyzed. If the difference is found in the second set of samples the instrument record the data is invalidated until recalibration is performed.

Temperature: Quality control of temperature is performed at time of calibration. During calibration the sensor is placed in a mixed water bath with a certified thermometer. The sonde sensor must agree with the standard thermometer to within 0.2^{o}C before the sonde can be deployed to the field.

Chlorophyll: The *in situ* response of phytoplankton to excitation wavelengths varies according to many factors that cannot be accounted for individually. The data record will be corrected to a 2 hour (8 measurements) average and differences between discreet samples will be interpolated linearly. Post-hoc screening of the data will exclude any data that is more than $\pm$2 standard deviations from the mean of the previous 8 measurements. Analysis of water samples by acetone extraction and fluormetric analysis will be standardized using “pure” chlorophyll a (Sigma Scientific) and quantification using the trichromatic equations on a scanning spectrophotometer. Calibration follows the protocols for the Turner AU-10 fluorometer for chlorophyll analysis.

B.6.8 Instrument Calibration and Frequency Procedures

Macrophyte Survey
The GPS unit on the linked video system is checked using know reference points at the beginning and end of a day’s survey.

Benthic Infauna Community
Not instruments are used in this analysis.

Moored Instrumentation:
Instruments are deployed for 1 month between laboratory calibrations and downloads. If a 2 month deployment is desired, it will consist of back to back 1 month deployments.

Dissolved Oxygen: Two days before calibration of dissolved oxygen sensors the electrolyte solution and Teflon membrane are replaced according to the manufacturers

specifications. Sensors are examined to ensure that no air bubbles are trapped beneath the membrane and that the entire membrane surface is uniform, tight and smooth. With protective cap partially filled with distilled water and loosely affixed to the instrument the instrument is allowed to operate at a normal duty cycle (15 minutes) until the instrument record indicates the sensor is stable over several hours. Following this initial stabilization period, a single point calibration is performed at 100% oxygen saturation in water-saturated air (100% humidity in the protective cap) at the expected average deployment temperature. The calibration is verified before deployment at ambient room conditions. The procedure is repeated following deployment to determine sensor drift.

Conductivity:
After calibrating the oxygen electrode the conductivity cell is calibrated. Single point calibrations are performed prior to every deployment. The sensor is rinsed with deionized water and dried with compressed air. The sensor is lowered into a factory provided 50.0 mS KCl standard and allowed to remain for at least one minute to allow temperature equilibration. While in the "Specific Conductance" mode the sensor output is observed until the readings are stable and then accepting the displayed value finishes the calibration. The cell constant is then checked. The nominal cell constant for this type of sensor is 5.0. If the cell constant resulting from the calibration procedure differs by more than 0.2 the calibration is repeated following probe maintenance. The probe is replaced if the procedure fails twice.

Temperature:
Prior to deployment the temperature probe is compared to a certified thermometer at a temperature near the middle of the range of temperatures expected during deployment (typically 20 ^{o}C - 30 ^{o}C) . Any deviations from the certified thermometer are recorded to correct temperature data following deployment. The probe must agree within 0.2^{o}C before it can be deployed.

Chlorophyll:
Chlorophyll probes are routinely calibrated to 0% fluorescence by blocking the light path to the detector. Further calibration is performed using field samples, which have been filtered and extracted as described in section B.6.6.

B.6.9 Data Acquisition Requirements

Existing historic data required for the trend analysis of eelgrass, is held within the Project Technical Team. This eelgrass data is primarily held within the DEP eelgrass mapping program (C. Costello) and consists of mapping conducted state-wide since 1993.

Current benthic infaunal information will be collected by the Estuaries Project by direct sampling and analysis. Historic data will be used for comparison to present data to

determine trends. If the historic data was collected using different methods, then qualitative statements can still be made. For example, the shift from a filter feeding community to a deposit feeding community would be detected even if different methods were employed.

Regional light and rainfall data will be acquired by the Stream Technical Lead from: the Town of Falmouth (via the WHOI WEB site), OTIS Air Force Base, Massachusetts Cranberry Station in Wareham, City of New Bedford, and other sources as they are identified.

B.6.10 Data Management

Data from field observations will be recorded on field data sheets to be retained in embayment specific notebooks **(B-I).** Data is entered on the field data sheets while on-site at the time the measurements are taken and in laboratory notebooks at the Coastal Systems Analytical Facility (both data and chain of custody forms). The appropriate sub-task Technical Lead will be asked to check that all data is accurate and legible before making copies for Technical Coordinator and SMAST Project Library. All data is reviewed by the Technical Manager. The nutrient sampling portion of the program requires that Chain of Custody forms (COC) be filled out as the samples are delivered at SMAST. Each COC is checked as samples are received.

The indicator data sets will be presented both in maps and in spreadsheet formats. The GIS information, spreadsheets and any associated digital records will be held on CD-ROM with copies with the Habitat Assessment Technical Leaders , the Technical Coordinator (R. Samimy) and with the Technical Manager (B. Howes) in the SMAST Project Library.

The macrophyte survey data will follow the QAPP for DEP's on-going mapping program (which we have partnered with), C. Costello. Copies of maps and resultant spatial information will be held in the SMAST Project Library.

The benthic animal data will be held in spreadsheet format for each embayment on CD-ROM in the SMAST Project Library and with the Technical Coordinator.

Water column analytical data associated with the mooring program consists of raw data and synthesized results. Raw data is maintained in duplicate notebooks in the Analytical Facility. Data reduction involves the process of converting raw numbers into data that have direct chemical meaning or can be compared statistically. Calculation to concentration is done in an adjacent column for easy comparison. The calculation is based upon the regression equation calculated from the chemical standards. The results will be reported in terms of concentration, as means and standard errors. All data are subject to 100% check at all stages by everyone.

All data reported are reviewed to check for errors in transcription, calculation, or computer input. If data points are judged to be aberrant, the reserved sample will be reanalyzed. Data are also reviewed for adherence to analytical protocols and to pre-established criteria (e.g., holding times, surrogate recoveries, initial and continuing calibration, matrix spikes, laboratory duplicates, blank contamination). Students t-test for paired samples, analysis of variance, are used for interpretation. Data is transcribed only for the statistical analysis and each point is checked for accuracy. Sample logs associated with field and laboratory custody and tracking are maintained in the project files.

The synthesized mooring data is held in spreadsheet format for site within an embayment. The mooring time-series and check data will be held on CD-ROM and in paper copy at three locations: (a) mooring sub-task Technical Lead (D. Schlezinger, SMAST), (b) Technical Coordinator, SMAST, (c) Technical Manager in the SMAST Project Library.

B.6.11 Preventative Maintenance for Field Equipment

Macrophyte Survey
All appropriate equipment is rinsed with freshwater and stored dry. The survey system is shipped in proper cases. The equipment is the property of the DEP Eelgrass Mapping Program and is maintained at their facility.

Benthic Infauna Community
Not instruments are used in this analysis. Field equipment (Van Veen Grab, cores, sieves) are rinsed in freshwater and stored dry in non-temperature controlled storage.

Moored Instrumentation:
Moored instrumentation is typically laboratory calibrated and maintained at 30 day intervals. When not in use the instruments are held in dry heated storage at the SMAST Coastal Systems Laboratory.

Dissolved Oxygen:
Once a dissolved oxygen sensor has stabilized following a pre-deployment membrane and electrolyte change the “DO charge” value is read from the instrument menu. High charge indicates the presence of AgCl deposits on the silver anodes of the sensor, which compromise the probe response to changing oxygen concentrations. A DO charge greater than +60 is used as the criteria for maintenance. The membrane and electrolyte are removed and the sensor is dried. 15-micron sanding disks, provided by the manufacturer are used to remove the deposits. Following this reconditioning procedure the entire calibration procedure is repeated.

Conductivity:
A brush provided by the manufacturer is inserted into both sensor holes 10-15 times to remove any deposits.

Temperature:
There is no preventative maintenance for the temperature probe.

Chlorophyll:
Prior to deployment the wiper assembly is wiped clean with a soft cloth and proper function is ensured by initiating three wiping cycles. If the wiper assembly does not stop opposite the LED sensors the wiper is replaced. If the new wiper assembly does not stop opposite the LED sensors, then the entire sensor is replaced and the procedure is repeated.

B.7 Synthesis of Modeling and Habitat Assessments

This task collects no additional data but integrates the findings and data from tasks B.1 through B.6. The habitat assessments and thresholds development will follow the guidelines being prepared by the Technical Team for review by DEP before July 1, 2002. The basic concept will be to evaluate the present indicators of water quality and the results of the Linked Watershed-Embayment Model to:

- Determine the present habitat quality in different regions of each embayment
- Determine the temporal trend in habitat health
- Determine the primary causes for the present habitat quality
- Determine likely future habitat quality from the modeling scenarios
- Determine multiple thresholds for differing levels of habitat quality
- Evaluate habitat quality improvement from unrestricted tidal exchange
- Evaluate tidal restoration for identified tidally restricted wetlands
- Recommend restoration alternative which derive from the synthesis

The thresholds and assessment will link nitrogen loading rates to embayment nitrogen levels to habitat quality. Multiple thresholds are necessary, since it is not always possible to produce the highest level of habitat quality throughout every embayment. For example, some systems have naturally nutrient enriched conditions and naturally have not supported eelgrass beds.

B.7.1 Data Quality Objectives for Measurement Data

No data are collected under this task.

B.7.2 Documentation and Records

No data are collected under this task.

B.7.3 Sampling Process Design

No samples are collected under this task.

B.7.4 Sampling Methods Requirements

No samples are collected under this task.

B.7.5 Sample Handling and Custody Requirements

No samples are collected under this task.

B.7.6 Analytical Methods Requirements

No samples are collected under this task.

B.7.7 Quality Control Requirements

No samples are collected under this task.

B.7.8 Instrument Calibration and Frequency Procedures

No samples are collected under this task.

B.7.9 Data Acquisition Requirements

All data is acquired in earlier Project tasks.

B.7.10 Data Management

All synthesis and results will be presented in Estuaries Project Embayment Reports or in specific Technical Memoranda.

B.7.11 Preventative Maintenance for Field Equipment

No samples are collected under this task.

C. ASSESSMENT AND OVERSIGHT

C.1 Assessment and Response Actions

Review of the Estuaries Project field activities and data documentation is the responsibility of the Technical Manager. However, the Technical Manager will be assisted by the Project Technical Team in the review of all field and laboratory activities. The Technical Team will also serve as the evaluation body for the inclusion of previous data collection and water quality monitoring data for inclusion into the Estuaries Project database. The Technical Team, the QA/QC Officer, and the DEP Project Officer will conduct an annual review of the Project Approach, performance and objectives of the overall Project. The results of this review will be presented to the Planning and Steering Committees for discussion. Problems encountered which require modifications of approach will be part of this review and if the approach is altered the proper modifications to the Estuaries Project QAPP will be made.

C.2 Reports

Given the scope and long-term nature of the Estuaries Project, two types of reports are generated: (a) Technical Memoranda addressing specific issues raised by the various oversight committees or addressing the acceptability of data sets or setting technical guidelines, and (b) Embayment Specific Synthesis Reports which detail the field data collected by the Project: the embayment hydrodynamics, watershed loading and water quality modeling results; assessment of present embayment nutrient related health and identified bacterial contamination issues; the synthesis of the Linked Modeling results including the results of 4 scenario model runs; and site specific thresholds results. The Embayment Reports are produced in the second year of the 2-year cycle to complete an embayments analysis.

The Technical Memoranda are produced as issues arise and are distributed to the Technical, Planning and Steering Committees as appropriate. The Embayment Reports are distributed sequentially to these same committees for review and approval. The final version of each report will address comments which arise during review and will also indicate any issues relating to the modeling effort or parameterization data. In addition, any recommendations as to means for improving or streamlining the approach will be put forward.

In addition to reports, the Estuaries Project will also provide data for outreach effort (as funds allow) including for posters, fact-sheets and newsletters.

D. DATA VALIDATION AND USABILITY

D.1 Data Review, Validation / Usage

As part of the data review and validation, all field and lab data will be reviewed and discussed by the Program Coordinator and Science advisors from SMAST to determine if the data meets the QAPP objectives (**see B-II** for additional detail on data acceptance criteria). Historical data or data collected by the Estuaries Project will be screened for "flaws" based on (a) its quality relative to criteria established in the Project QAPP, (b) comparison of data to associated parameters that are known with "certainty", and (c) biogeochemical cross-checks (for example a PC/PN ratio of >25 is suspect). When a potential problem datum is identified, a secondary procedure of checking the field and laboratory notebooks, calculations, and data entry is performed. Errors in data entry will be corrected, and any outliers will be flagged for further review or discarded. Data which remain "at issue" will be maintained in the database, and will be discarded only if they fall more than 2 standard deviations away from the mean of the other appropriate data points. Discarded data will be documented. Upon completion of data entry and data checks, the data will be summarized with the intent to develop findings, conclusions and recommendations.

The Massachusetts Estuaries Project Technical Team will review all project data prior to its use in water quality modeling, system synthesis or thresholds development. The team will render an opinion and judgment regarding data acceptability, generally using the criteria in the 4 data classes, described below: (1) collected under a QAPP meeting the requirements of the Estuaries Project QAPP, (2) collected under a QAPP but not meeting the requirements of the Estuaries Project, (3) collected without an approved QAPP, but data is traceable and methodologies documented and meet requirements of Estuaries Project QAPP, and (4) collected without an approved QAPP and data is not traceable or methods are undocumented. Data will be deemed to be:

- Fully useable, to be fully incorporated into the Project database;
- Useable only as supporting data, additional Project data collection is required;
- Useable only as qualitative supporting information (anecdotal);
- Not useable in any fashion for this Project.

Verification of monitoring data sets can occur in several different ways. Ideally, the data set being considered for inclusion into the Massachusetts Estuaries Project will have been collected under an approved Quality Assurance Project Plan (QAPP), with limits meeting the requirements of the Estuaries Project QAPP. Approval of QAPPs would typically be rendered by the Massachusetts Department of Environmental Protection (DEP) or the U.S. Environmental Protection Agency (EPA). Attempts will be made by the Estuaries Project to collect QAPPs for each data set which could provide useable

data to the Project. These QAPPs will be kept in the Estuaries Project library for future reference should the need arise. Should this scenario be the case, it will be recommended to the Technical Team that the data set be included into the Estuaries Project. If it is determined that the data was collected with an approved QAPP but detection limits do not meet the requirements of the Estuaries Project QAPP, data will be considered unacceptable unless further review by Technical Team deems any special considerations to allow use.

In the absence of a DEP or EPA approved QAPP, the person or organization responsible for collecting the data and the lab that was responsible for analysis of samples will be sought out for specific information regarding data collection practice and analysis. Collection of samples or measurement data, in addition to the analysis of samples by a lab, at a minimum must have been performed in accordance to a set of standard operating procedures specific to the parameter measurement or sample type being collected.

Should a data set under consideration be collected in the absence of a DEP or EPA approved QAPP and the data is not traceable back to the person or organization responsible for the collection of the data, data almost certainly will be unacceptable after review by Technical Team. These data will be treated as anecdotal information.

Having a QAPP does not necessarily ensure that data will be used by the Estuaries Project. The documentation that the QAPP was followed and the QC checks performed will also be evaluated by the Technical Team as part of the data review process.

Ultimately, all data being considered for use in the Massachusetts Estuaries Project will be judged worthy relative to quality control criteria set forth in the present Project QAPP. Criteria for acceptance of data in each of the Estuaries Project elements (hydrodynamic modeling, watershed nitrogen loading, nitrogen regeneration, linked watershed embayment nitrogen model, habitat assessment, synthesis of modeling and habitat assessments) are presented in respective sections. Additionally, data being considered for inclusion in the estuaries project must meet the criteria for precision, accuracy, and sensitivity (including instrument detection limits) as defined in the overall project QAPP.

To Reiterate, the Massachusetts Estuaries Project Technical Team will review all project data prior to its use in water quality modeling, system synthesis or thresholds development. The team will render an opinion and judgment regarding data acceptability, generally using the criteria in the 4 data classes given above, data will be deemed to be:

- Fully useable, to be fully incorporated into the Project database;
- Useable only as supporting data, requiring Project data collection;
- Useable only as qualitative supporting information (anecdotal);
- Not useable in any fashion for this Project.

D.2 Data Review, Validation

Data entry is checked by the Program Coordinator and two laboratory personnel and the QA/QC checks are performed by the Project QA Officer. Data will be reviewed by the Project Technical Coordinator before being entered into the Project database and Library. Data sheets will be checked against the spreadsheet on a regular basis and against a final print out. Linked spreadsheet programs have been developed to facilitate the data synthesis and display aspects of the Estuaries Project. Automatic calculations have been integrated into the linked spreadsheets as appropriate to minimize the possibility of human error. However, test data is checked to confirm that the equations are functioning properly. If an unusual or unbelievable recording is noted, the laboratory or field personnel responsible for collecting the data or entering the data will be called to discuss the data. Technical staff collecting samples or measurements in the field are also instructed to take replicate samples if an unusual reading is recorded in the field.

Upon completion of data entry and data checks, the following will be calculated for each parameter: averages, minimum value, maximum value, standard deviation, and any other required calculation.

D.3 Reconciliation with Data Quality Objectives

If data requirements and quality indicators are not being met in accordance to the specifications presented in the QAPP, equipment and techniques will be reassessed and improved, sampling personnel retrained and related specifications may be revised for the next sampling season. Any changes will be brought forward in the annual Project review and annual QAPP updates. Limitations due to equipment failure, sampling performance, or techniques will be explained in final reports and other summary reports as needed.

All of the methods to be used by the Estuaries Project have been employed in similar studies of southeastern Massachusetts embayments over the past decade. The QAPP criteria are based upon these applications of portions of or the full Linked Watershed-Embayment Nitrogen Management Approach. However, it is likely that as the Project progresses that it will be possible to stream-line data collection approaches. This will require a through Technical Review by the Technical Team and DEP and a revision of the QAPP. Changes will only be considered if they maintain the consistency of approach for all 89 embayment systems.

The Technical Manager with assistance from the Project Technical Team will be responsible for review of existing monitoring data and estuarine process data to determine suitability for inclusion into the water quality modeling, synthesis and development of site specific thresholds. Decisions regarding data incorporation will be made by the Estuaries Project Technical Team (which includes DEP Project Officer).

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The Massachusetts Estuaries Project

Quality Assurance Project Plan

MA Estuaries Project QAPP Appendices A.I-XXIII
Embayment Specific Sampling

MASSACHUSETTS ESTUARIES PROJECT

LISTING OF APPENDIX QAPPs A.I - XX

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Appendix A-XIX	BB/New Bedford: Acushnet River, New Bedford Inner Harbor
Appendix A-XX	BB/Bourne: Eel Pond, Back River

Watershed Code:

CC – Cape Cod
BB – Buzzards Bay
MV – Martha's Vineyard
N – Nantucket

MA Estuaries Project QAPP Appendices A.I-XX
Embayment Specific Sampling

Introduction

Phase III of the Estuaries Project is the implementation of the Linked Watershed-Embayment Model which was selected after evaluation under Phase I. The Estuaries Project will implement this Linked Approach in each of the 89 embayments throughout Southeastern Massachusetts over six years or as funding allows. Embayments will be addressed generally following a 2 year cycle, where year 1 is primarily data collection and year 2 is primarily modeling and synthesis. However, the cycle will be flexible to meet the needs of the municipalities and DEP.

The initial 20 embayments for which the approach is to be implemented were selected based upon prioritization by the DEP/SMAST in Phase II. Prioritization will occur on an annual basis. Embayments 1-20 differ from the general 2 year cycle, in that embayments 1-10 had most of the field data collected prior to the Estuaries Project initiation of Phase III. Therefore, embayments 1-10 enter the cycle in a quasi-year 2, since some minor field data collection is required to complete some of them but most just require the modeling and synthesis elements of the Approach. Embayments 11-20 generally require significant field data collection and full modeling and synthesis. Embayments 1-10 are currently scheduled for completion by June 2003 and embayments 11-20 by June 2004, although specific embayments will be completed prior to these dates.

All data not collected under the Estuaries Project has been reviewed for consistency to Estuaries Project Protocols following the guidelines in B-II. All accepted data used to parameterize the water quality model has been collected since 1990 and all chemical and biological data since 1997. The basic guideline is that all data, historic or new, must conform to the Estuaries Project QAPP for quality and completeness. In addition, relative to estuaries whose baseline water quality monitoring data was collected by municipalities or non-governmental monitoring programs, the Estuaries Project Staff will collect limited water quality samples during summer. These samples will be assayed for the suite of nutrient, plant pigment and associated parameters to parallel the baseline data series. Project water quality sampling will generally be performed at 3-4 sites within each embayment on 1-2 occasions during July/August. Additional samples for oxygen and plant pigments will be performed at 2-5 locations. Comparison of these “check” samples to the long-term baseline and on-going monitoring program data series will provide an additional level of QA.

MA Estuaries Project QAPP
Appendix A-I Popponesset Bay
Towns of Mashpee and Barnstable
Prioritization Rank: Round 1 - #1

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

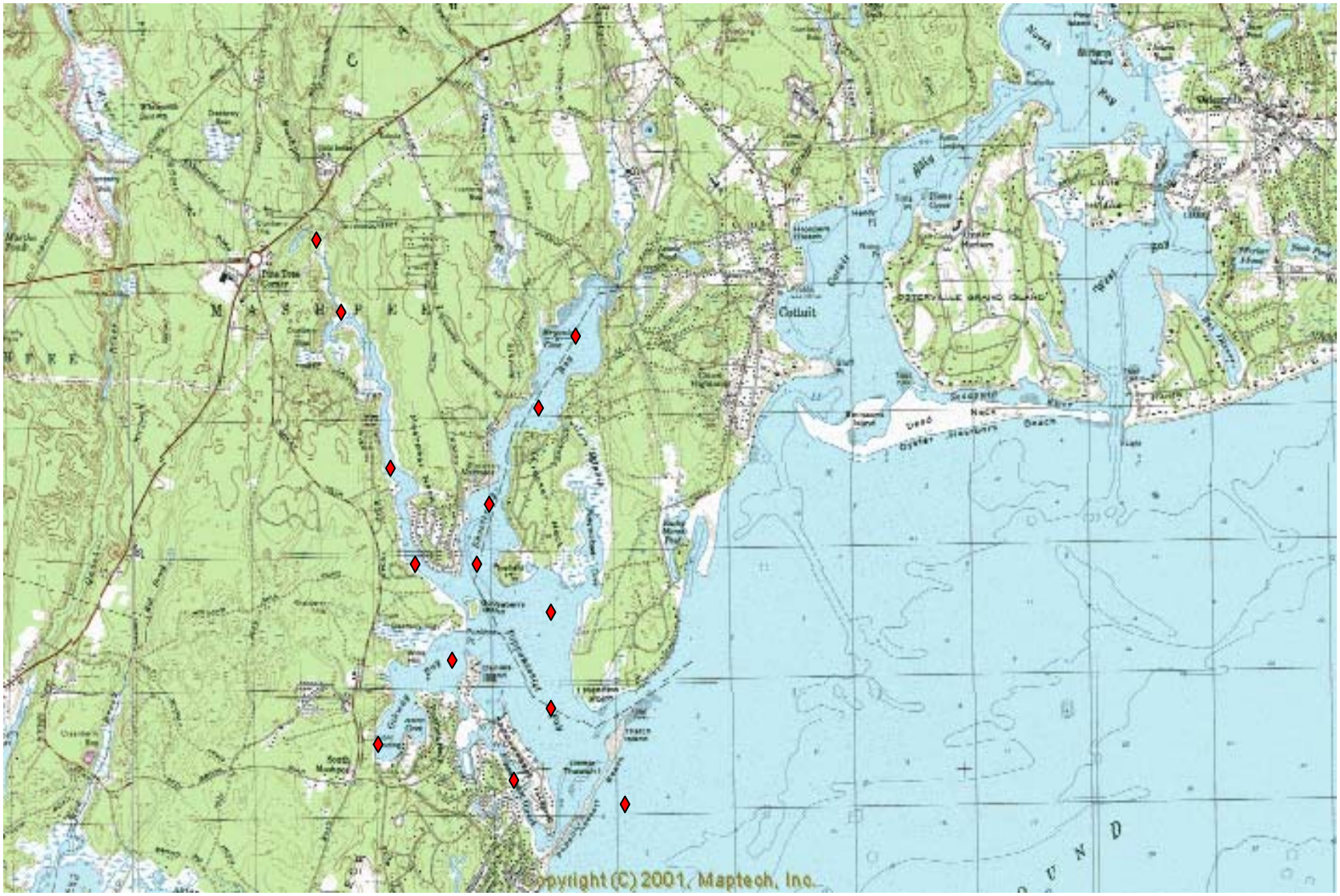
Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Popponessett Bay, Mashpee & Barnstable: All field data collection is complete. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay's QAPP (Williams and Howes, 2001). All technical design and analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Estuary Project required field data is complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. Water quality modeling is will include additional scenario runs over the Estuaries Project Standard protocol, due to funding from the Town of Mashpee. There is one minor adjustments from the Estuary Project approach to field data collection in that the benthic regeneration samples were collected several times throughout the embayment, but in clusters. Regarding dissolved oxygen measurements in this system, a maximum of 6 dissolved oxygen meters were deployed in the upper half of the estuary for continuous measurements during the months of July and August.

Massachusetts Estuaries Project Round 1 Prioritization

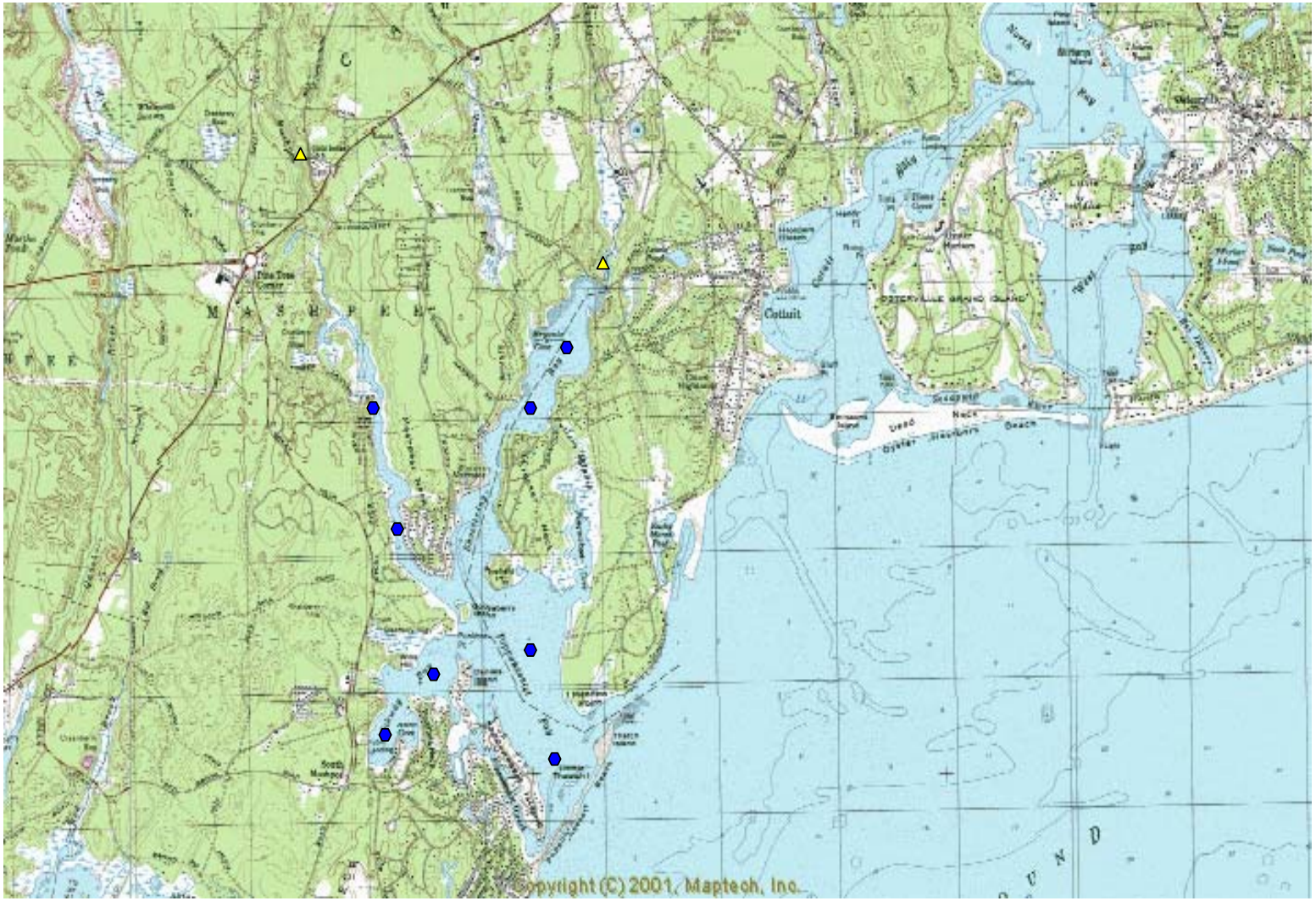


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3

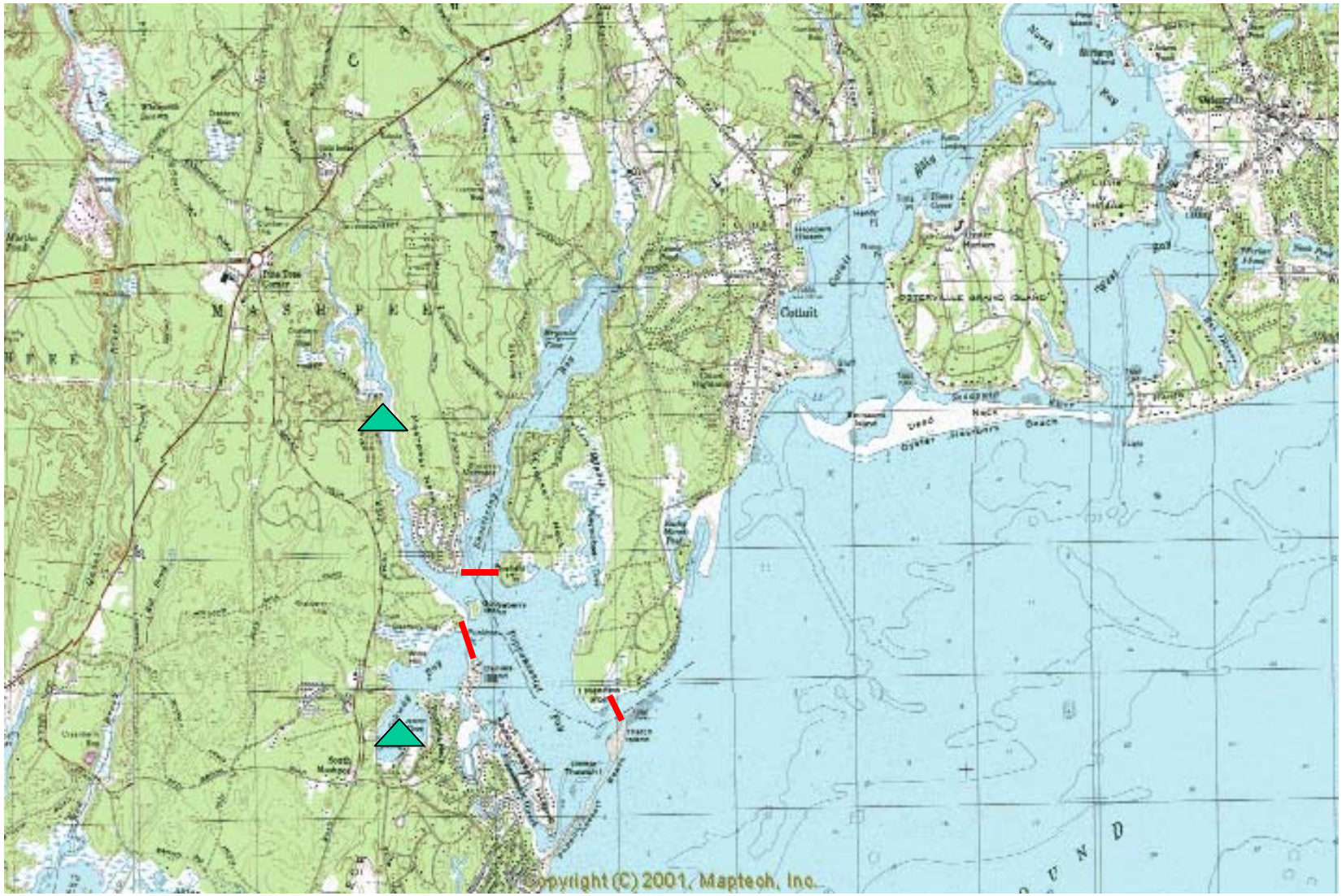

Tide Gauge Location
ADCP Transects
Copyright (C) 2001, Maptech, Inc.

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Popponesset Bay (1)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	2	Weekly	100	10	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	8	Once/Embayment	16	16	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	5 **	60 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	8	Once/Embayment	8	16	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-II Sulfur Springs/Bucks Creek
Town of Chatham
Prioritization Rank: Round 1 - #2

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Sulfur Springs, Chatham*:* All field data collection is complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Pleasant Bay Alliance QAPP. All technical design are acceptable and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Estuary Project required field data is complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated) due to the embayment's basic configuration and the lack of suitable channel cross section needed for accurate ADCP application. DO records will not be collected on this shallow intertidal system.

Regarding dissolved oxygen measurements in this system, 1 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization



Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Sulfur Springs / Bucks Creek (2)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	7	Once/Embayment	7	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	1 **	12 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	0	Once/Embayment	0	0	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-III Muddy Creek
Town of Chatham
Prioritization Rank: Round 1 - #3

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Muddy Creek. Chatham & Harwich*:* All field data collection is complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Pleasant Bay Alliance QAPP. All technical design are acceptable and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Estuary Project required field data is complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated) due to the embayment's basic configuration and the lack of suitable channel cross section needed for accurate ADCP application. An additional analysis will be included as to the management alternatives of (a) opening the culvert between Muddy Creek and Pleasant Bay and (b) repairing the dike at mid-

system to improve flushing of the lower system and restore the freshwater habitat of the upper system. A D.O. mooring will be placed in the lower portion of this system to help refine the thresholds analysis.

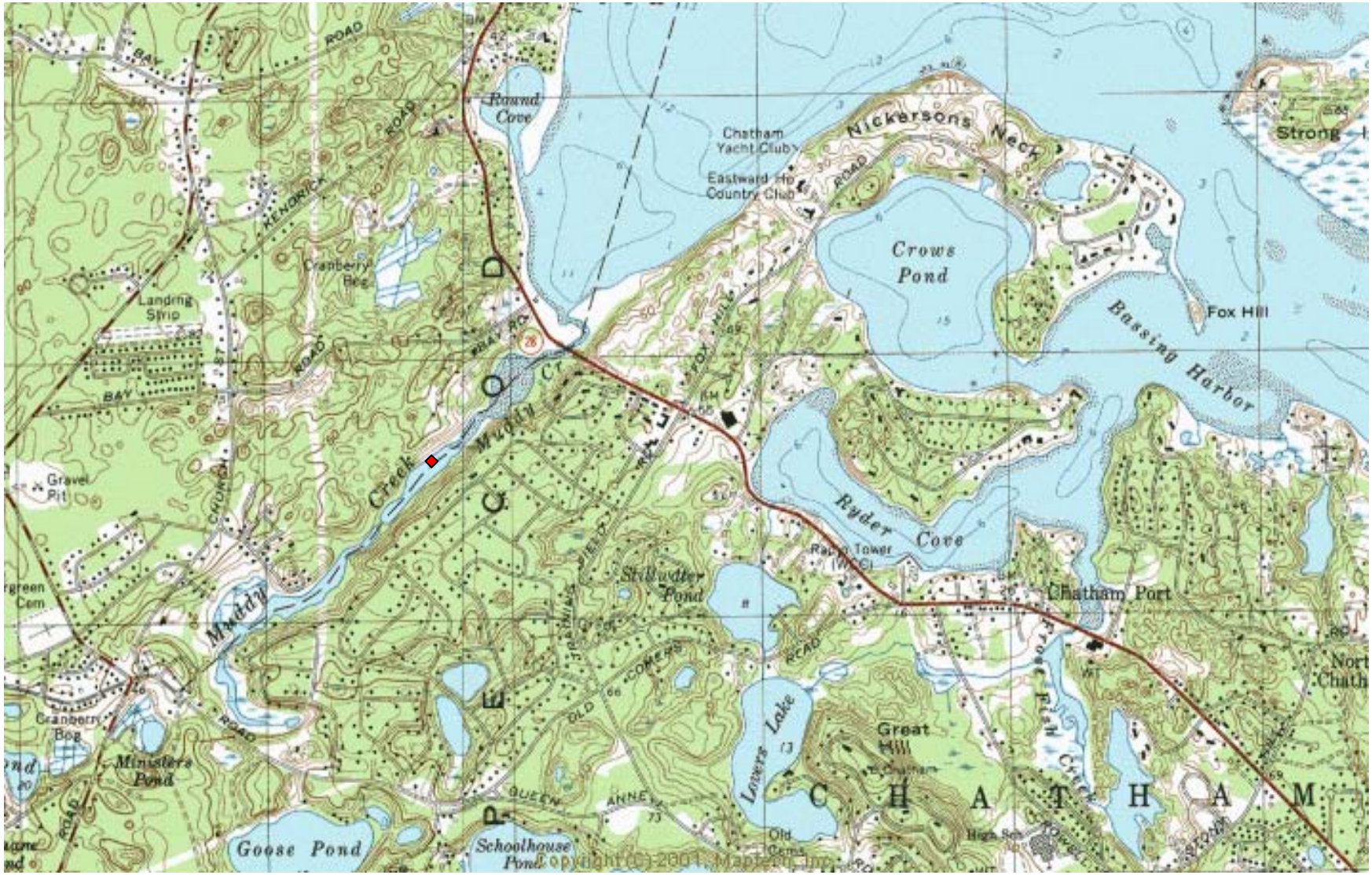
Since Muddy Creek has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Muddy Creek System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This “paired” sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization

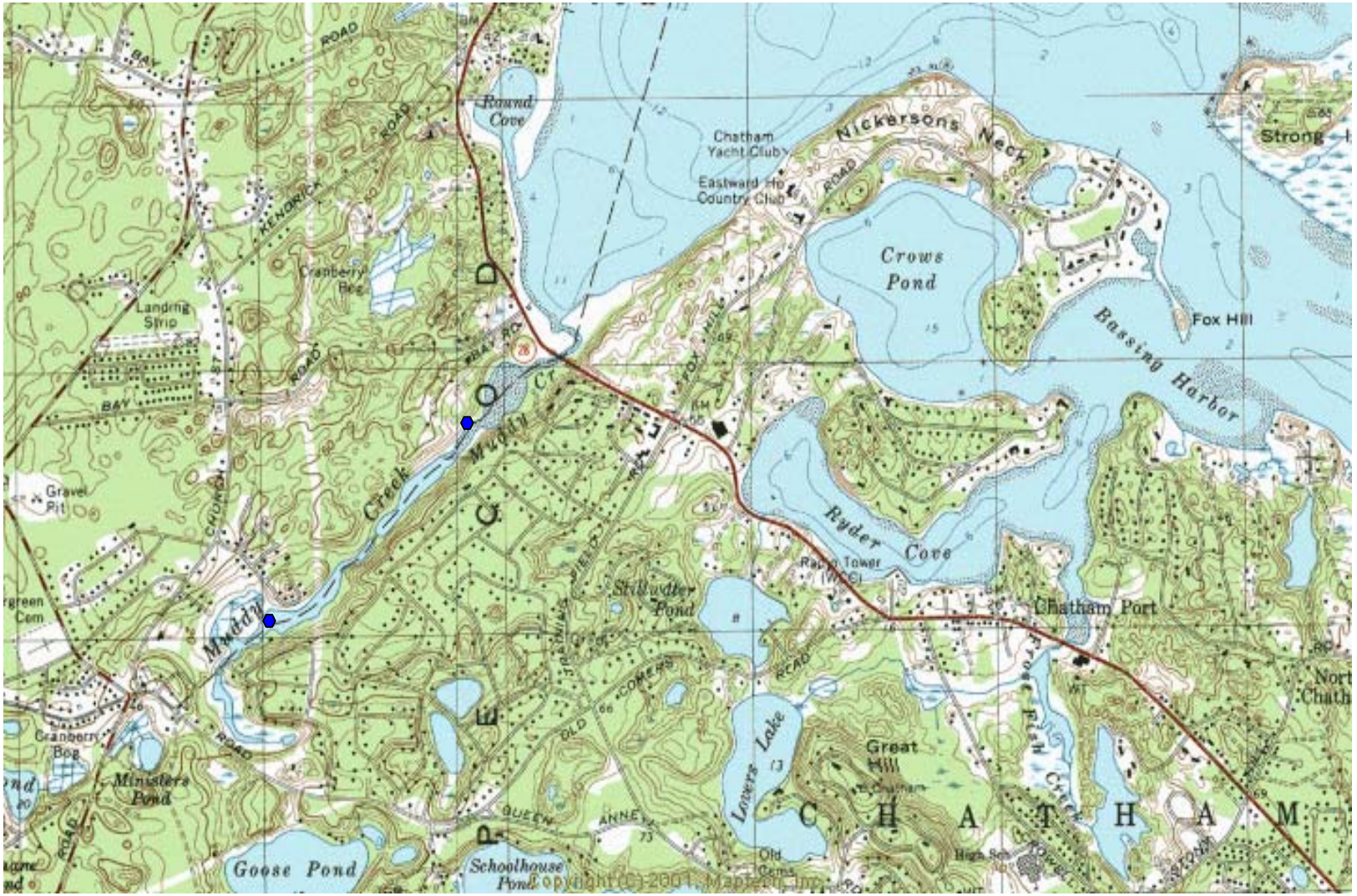


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Muddy Creek (3)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	2	Once/Embayment	2	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	2	Once/Embayment	2	2	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-IV The Bassing Harbor System
Bassing Harbor/Ryders Cove/Frost Fish Creek
Town of Chatham
Prioritization Rank: Round 1 - #4

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Bassing Harbor System, Chatham*:* Almost all field data collection is complete to allow modeling and synthesis, except for a nitrogen attenuation study of Frost Fish Creek. Water quality monitoring data was collected and analyzed following the Pleasant Bay Alliance QAPP. All technical design details are acceptable and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. All of the standard Estuary Project required field data is complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary

Project Technical Team members. This work has been conducted as part of Chatham's Comprehensive Wastewater Planning effort.

The Estuaries Project will continuing sampling of stream discharge and nitrogen loading from Lovers Lake/Stillwater Pond into Ryders Cove through the summer of 2002 in collaboration with the Chatham Water Quality Laboratory (R. Duncanson). An additional eelgrass survey will be conducted in 2002 (previous was 2000), due to the projected rate of decline in this system and 4 DO records will be collected, to refine the site specific thresholds analysis.

Additions to the Estuaries Project Standard Approach are as follows:

(1) This system requires a nitrogen attenuation study of the Frost Fish Creek System. This is a tidal creek-salt marsh and will require measurements of net nitrogen discharge to Ryders Cove. The protocol will be the same as employed in the DEP/SMAST study of Mashapaquit Creek in West Falmouth Harbor.
(2) The benthic regeneration survey of the Bassing Harbor System was conducted in both summers of 2000 and 2001.
(3) An analysis of well withdrawals on watershed nitrogen loading will be performed based upon the modeling study of Earth Tech (currently under review).

Regarding dissolved oxygen measurements in this system, a maximum of 5 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

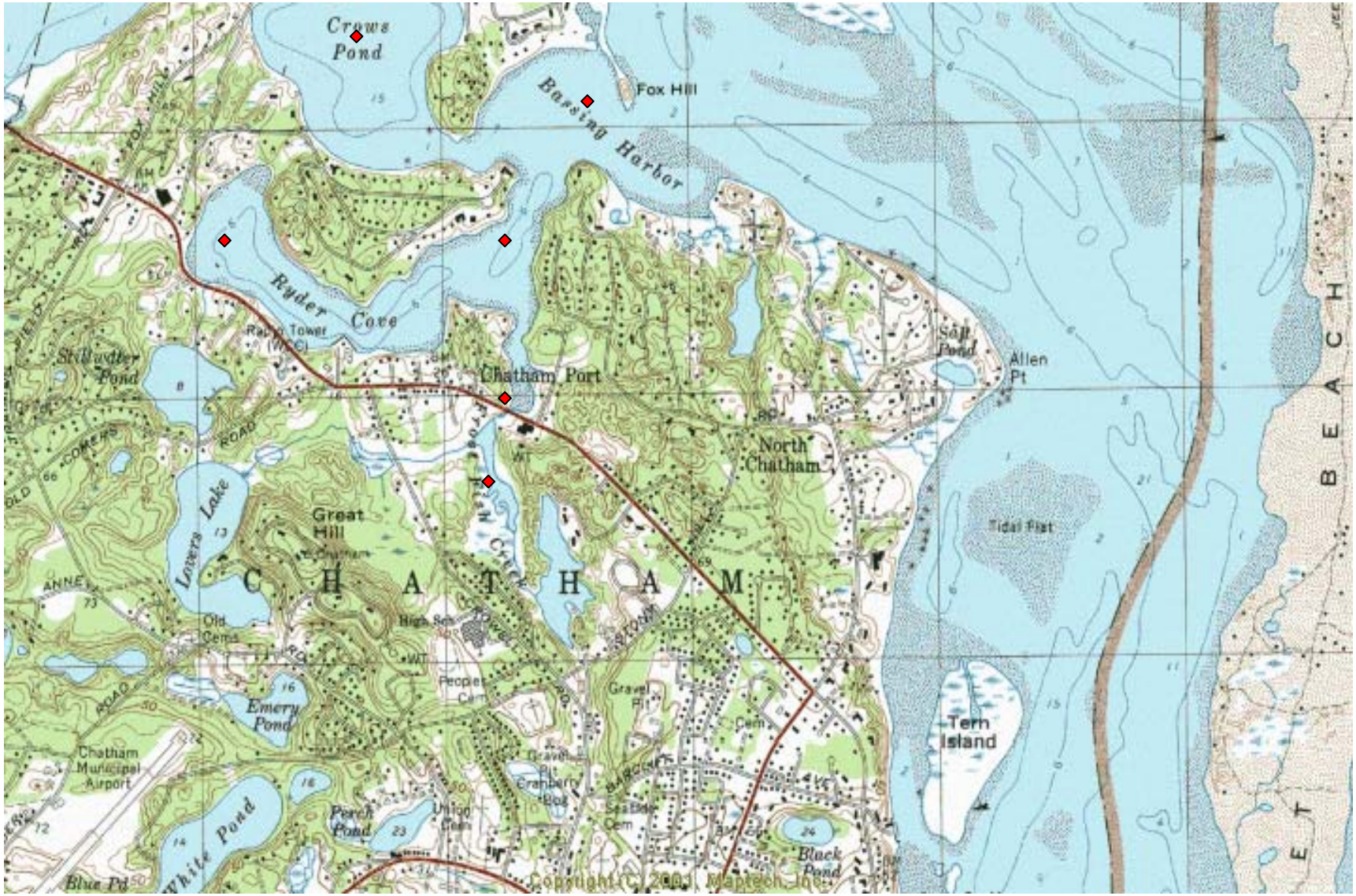
Since Bassing Harbor / Ryders Cove / Frost Fish Creek has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Bassing Harbor System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This "paired" sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization



Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location — ADCP Transects

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Bassing Harbor / Ryders Cove / Frost Fish Creek (4)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	2	Weekly	100	10	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	26	Once/Embayment	26	3	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	4 **	48 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	4	Once/Embayment	4	6	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-V Stage Harbor System
Town of Chatham
Prioritization Rank: Round 1 - #5

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Stage Harbor, Chatham*:* All field data collection is complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Pleasant Bay Alliance QAPP. All technical design details are acceptable and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Estuary Project required field data is complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. An additional eelgrass survey and 4 D.O. records will be conducted in 2002 to support the thresholds analysis.

Regarding dissolved oxygen measurements in this system, a maximum of 5 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization



Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3


Blue Pd
Bear Pond
West Chatham
Oyster Pond
Long Pt
Stetson Cove
Oyster Pond River
The Neck
Chatham
Aunt Lydias Cove
Little Mill Pond
Mill Pond
Chatham Lighthouse
Toms Neck
Mitchell River
Stage Harbor
Sears Pt
Stage Island
Morris Island
Tidal Flat
Harding Beach Pt
Quitnesset
CHATHAM HARBOR
NAUSET
COD
CAPE
Tide Gauge Location
ADCP Transects

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Stage Harbor (5)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	15	Once/Embayment	15	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	3 **	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	5	Once/Embayment	5	10	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-VI Taylor's Pond
Town of Chatham
Prioritization Rank: Round 1 - #6

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Taylors Pond, Chatham*:* Data is mostly complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Pleasant Bay Alliance QAPP. All technical design details are acceptable and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Initial water quality modeling discovered that previously determined watershed nitrogen loads during summer were greatly overestimated due to a failure to account for water withdrawal from the Town well field. An analysis of well withdrawals on watershed nitrogen loading will be performed based upon the groundwater modeling study of Earth Tech (currently under review). The Project will then re-parameterization the Taylors Pond water quality model to account for summer water withdrawals. The land-use analysis will have to be conducted and the modeling performed, prior to synthesis and reporting.

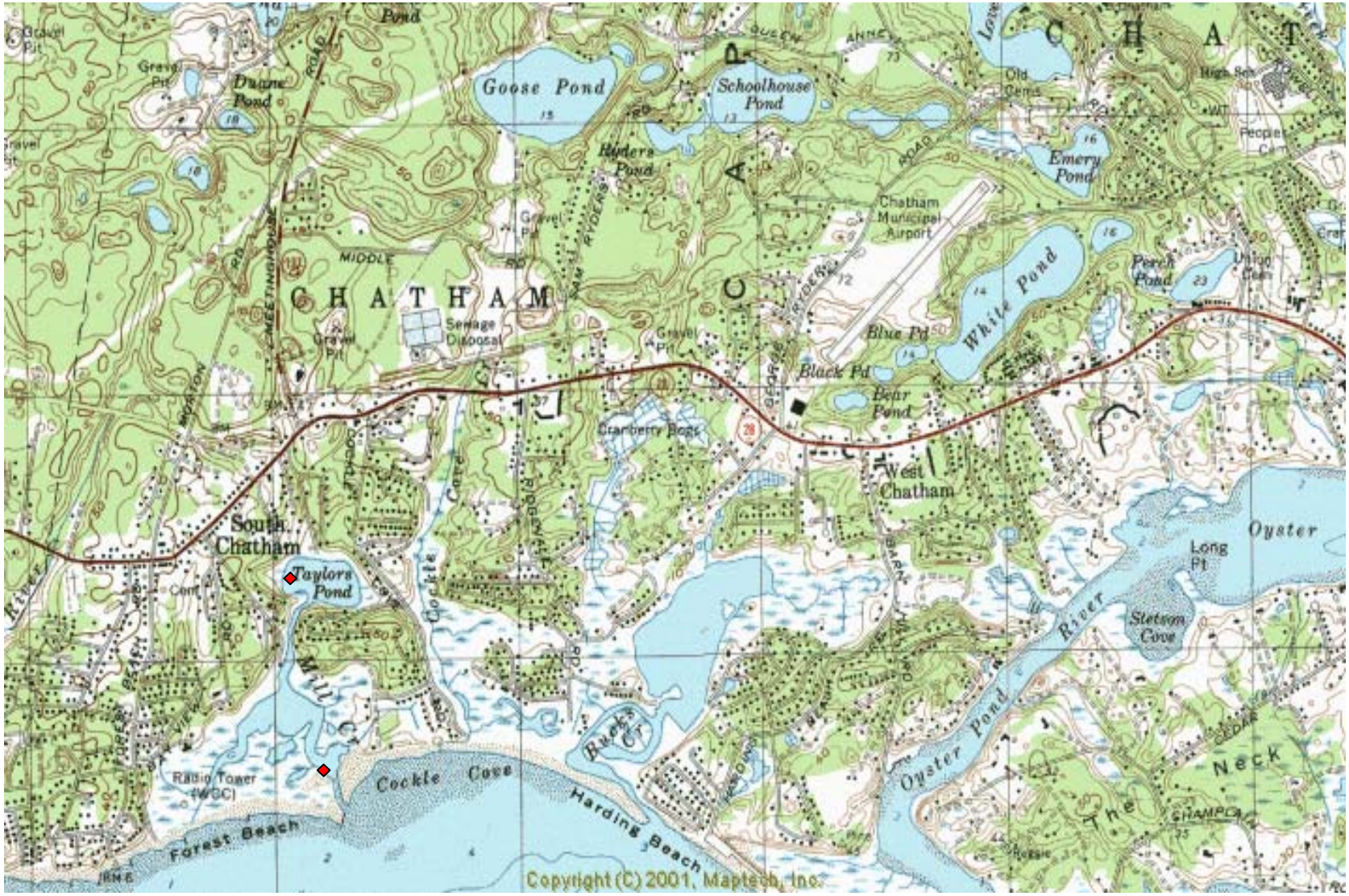
Acoustic Doppler Current Profiling (ADCP) will not be performed, due to the embayment's basic configuration and the lack of suitable channel cross section needed for accurate ADCP measurements.

Regarding dissolved oxygen measurements in this system, a maximum of 1 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization

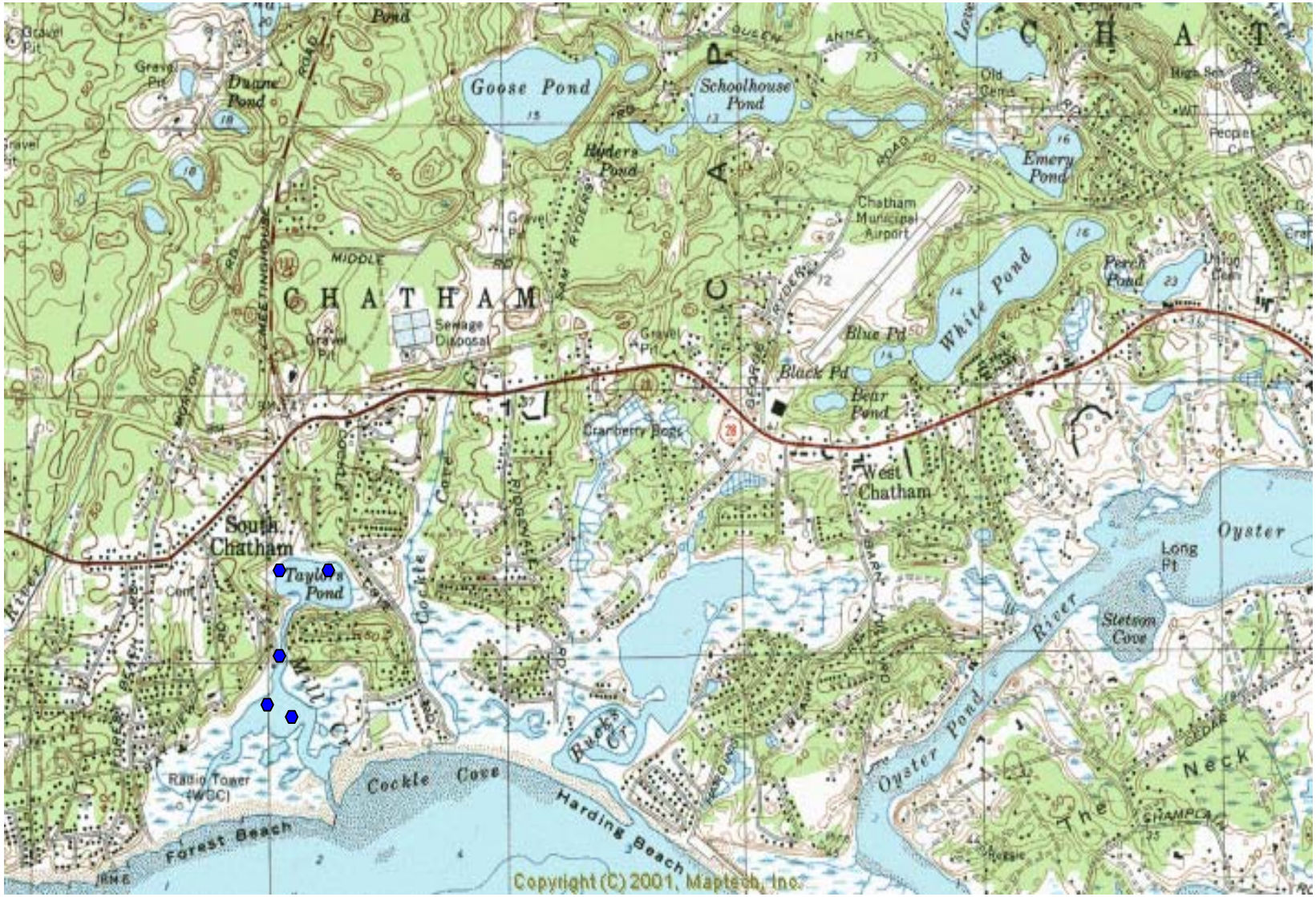


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Taylors Pond (6)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	5	Once/Embayment	5	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	1 **	12 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	1	Once/Embayment	1	2	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-VII Bournes Pond
Town of Falmouth
Prioritization Rank: Round 1 - #7

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Bournes Pond, Falmouth*:* Data is mostly complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Falmouth PondWatch Program. Estuary Project required field data is nearly complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. An additional eelgrass survey and oxygen records will be conducted in 2002 to support the thresholds analysis.

While benthic regeneration rates have been determined for this system, the spatial distribution is not as extensive as appropriate for the Estuaries Project Approach. Therefore, additional benthic regeneration sampling will be conducted in 2002. These data enhance the water quality model and update the previous synthesis to be consistent with the Estuaries Project. An additional eelgrass survey and 2-3 D.O. recordings will be conducted in 2002 to support the thresholds analysis. Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated by field observations), due to the

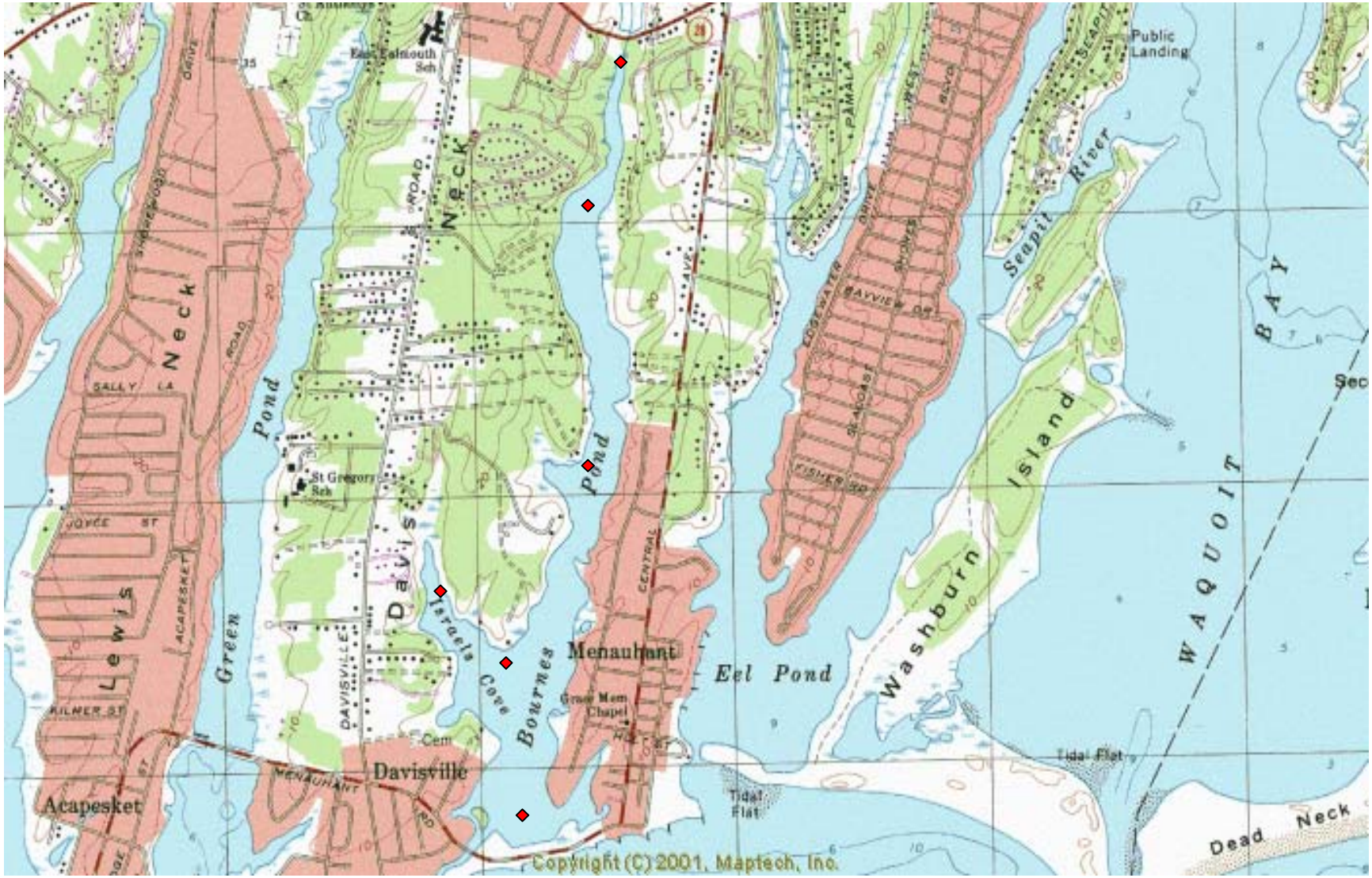
embayment's basic configuration and the lack of suitable channel cross section needed for accurate ADCP measurements.

Regarding dissolved oxygen measurements in this system, a maximum of 2 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization

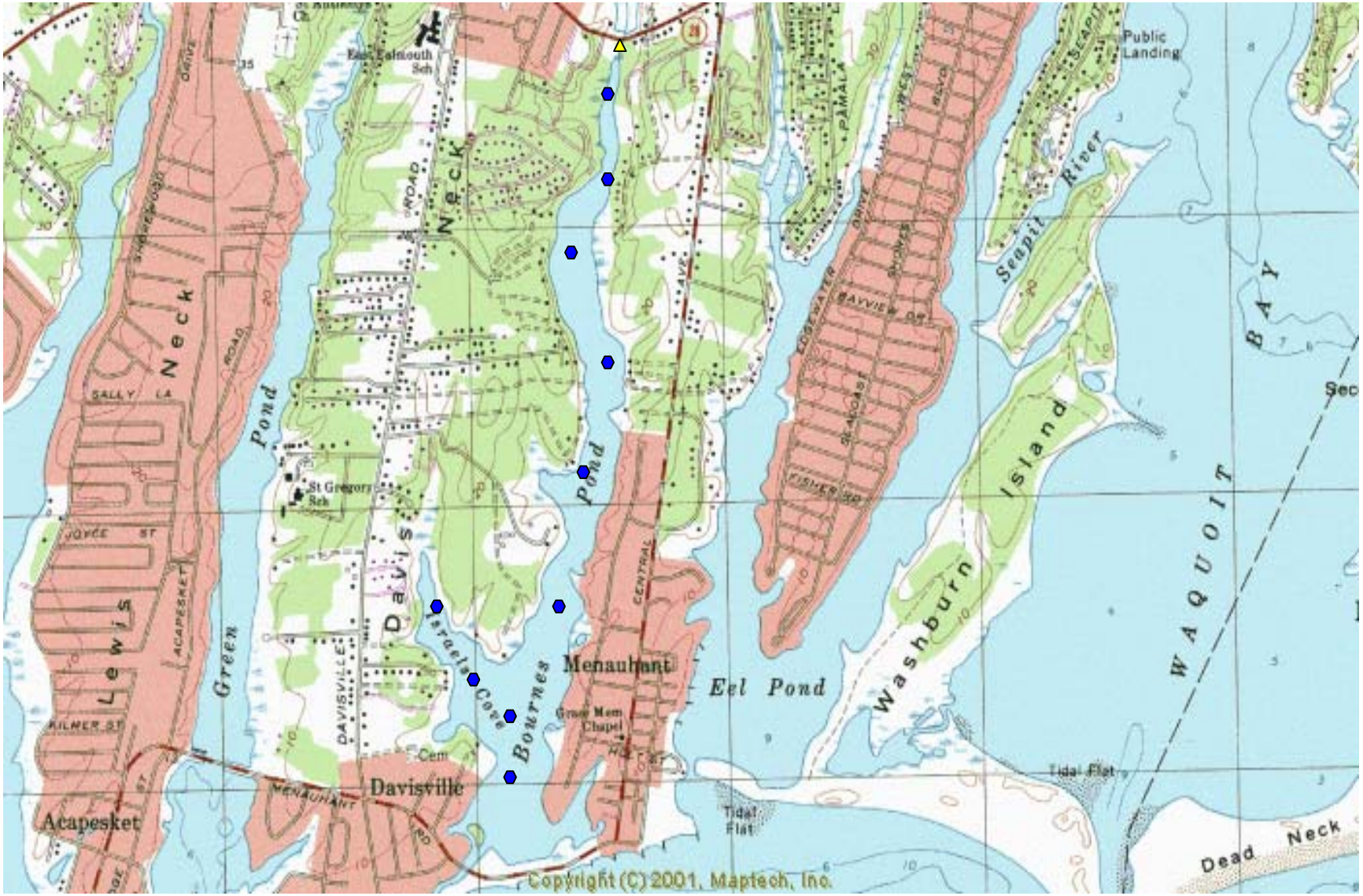


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Bournes Pond (7)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	10	Once/Embayment	10	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	7	Once/Embayment	7	7	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-VIII Hamblin/Jehu Ponds
Including Quashnet River
Towns of Falmouth and Mashpee
Prioritization Rank: Round 1 - #8

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Quashnet-Hamblin Pond-Jehu Pond, Mashpee & Falmouth*:* Data is mainly complete to allow modeling and synthesis. Two summers of water quality monitoring data will be included as collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST. All technical design details and the analytical aspects of the monitoring were conducted by the Coastal Systems Program at SMAST. Additional water quality data is anticipated to be provided by WBNERR through its association with the five year NSF-LMER (National

Science Foundation's Land Margin Ecological Research) program. Existing Estuary Project required field data was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members.

Field data will be collected during 2002 on (1) stream flow and nitrogen load, (2) benthic animals, (3) additional D.O. records (in addition to the WBNERR data, and (4) an eelgrass survey will be conducted to support the thresholds analysis.

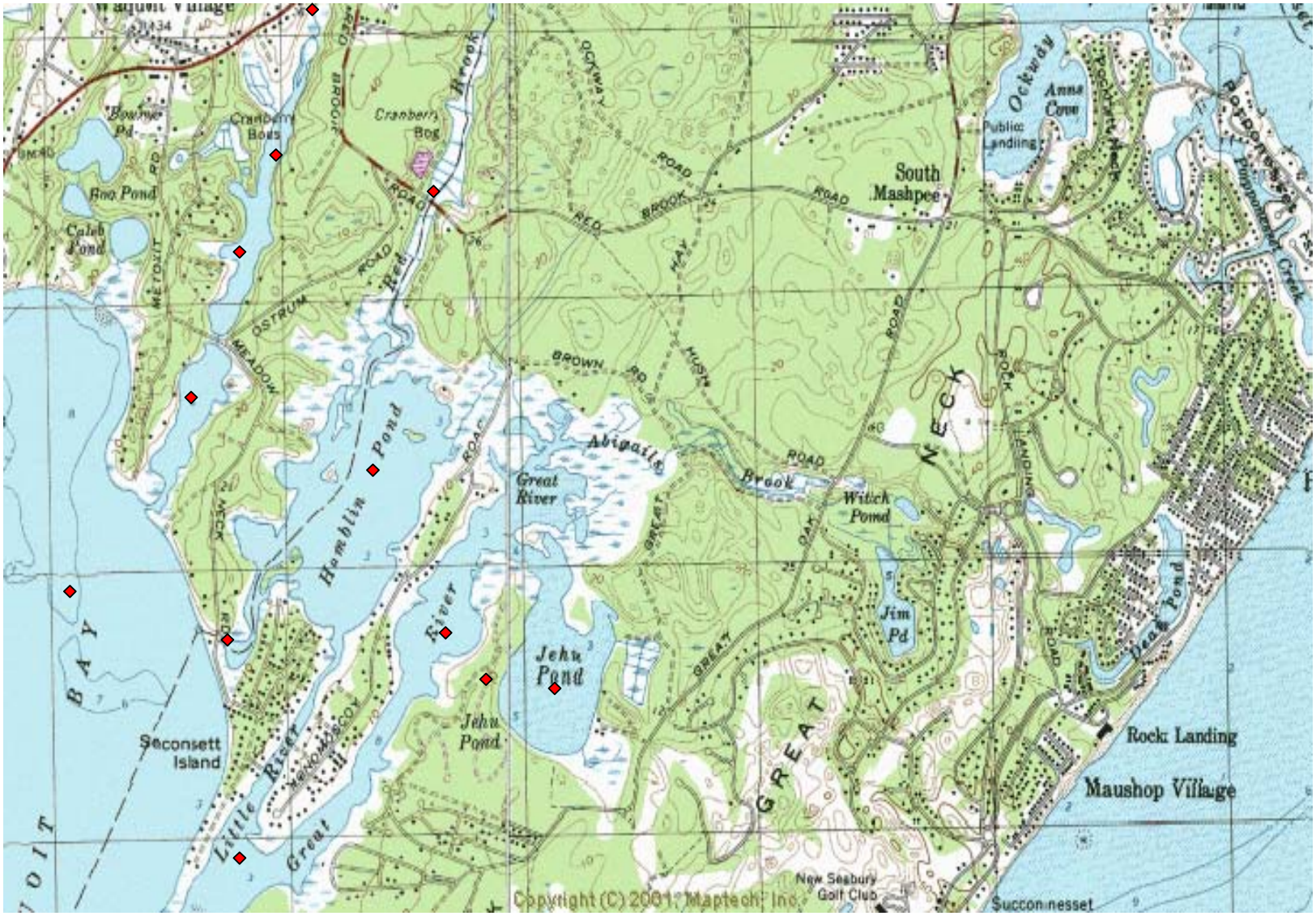
Regarding dissolved oxygen measurements in this system, a maximum of 2 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated by direct field observations) due to the embayment's basic configuration and the lack of suitable channel cross section needed for accurate ADCP measurements.

Massachusetts Estuaries Project Round 1 Prioritization

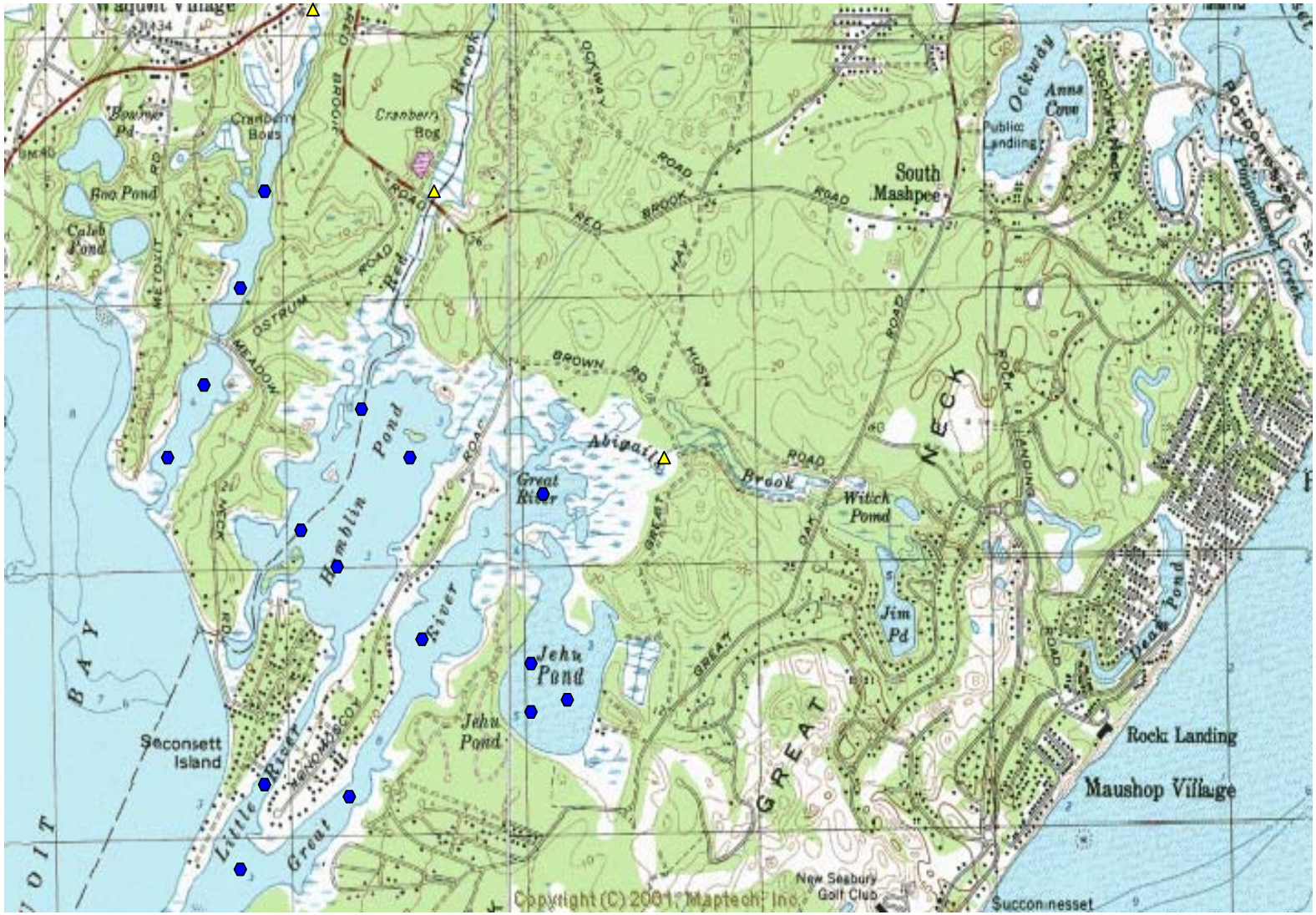


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Hamblin / Jehu Ponds / Quashnet River (8)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	14	Once/Embayment	14	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	10	Once/Embayment	10	10	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-IX Great/Perch Ponds
Town of Falmouth
Prioritization Rank: Round 1 - #9

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Great/Perch Pond, Falmouth: Data is mostly complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Falmouth PondWatch Program. Estuary Project required field data is nearly complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. An additional eelgrass survey and 2-3 D.O. recordings will be conducted in 2002 to support the thresholds analysis.

While benthic regeneration rates have been determined for this system, the spatial distribution is not as extensive as appropriate for the Estuaries Project Approach. Therefore, additional benthic regeneration sampling will be conducted in 2002. These data enhance the water quality model and update the previous synthesis to be consistent with the Estuaries Project. An additional eelgrass survey will be conducted in 2002 to support the thresholds analysis.

Regarding dissolved oxygen measurements in this system, a maximum of 2 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization

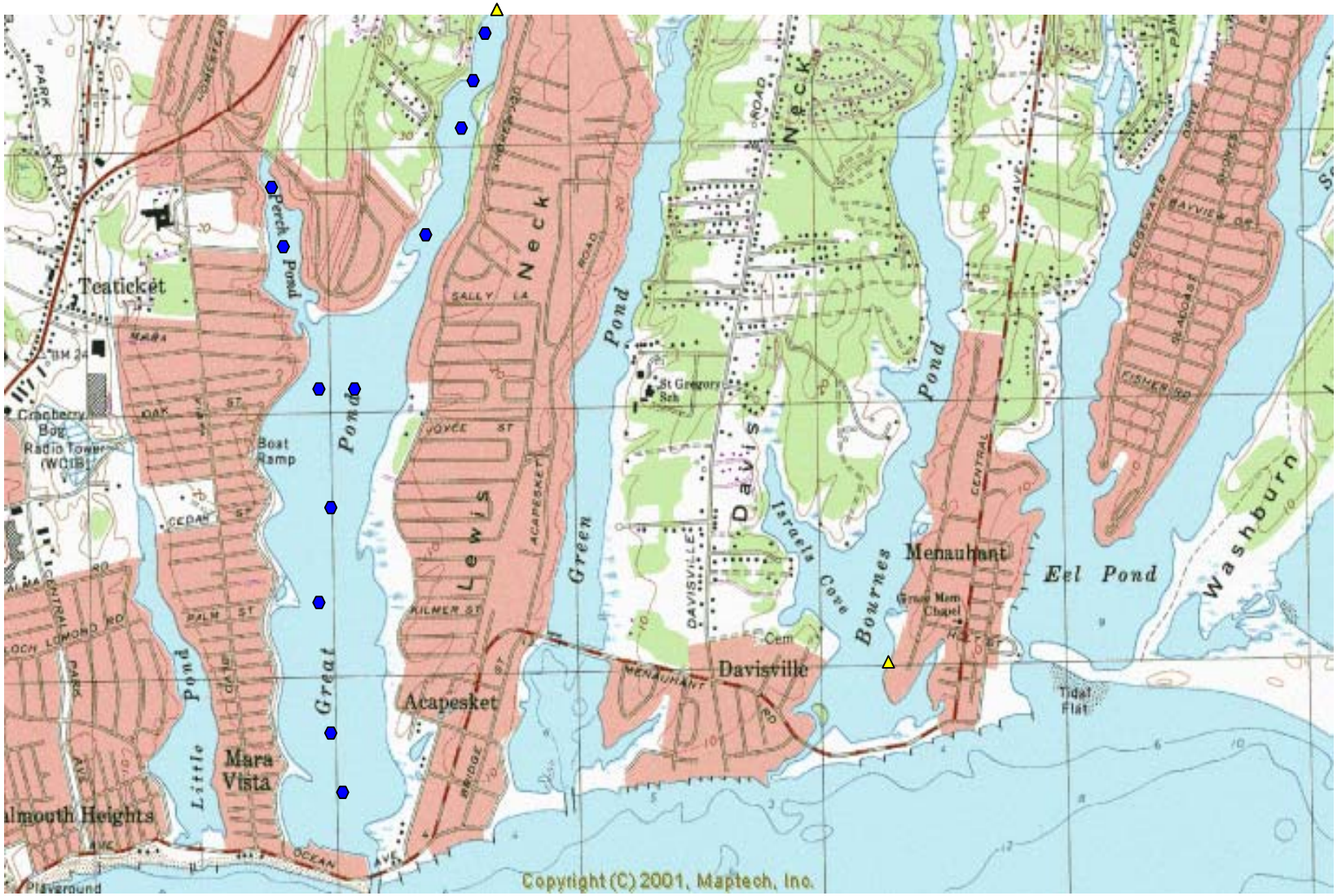


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location — ADCP Transects

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Great / Perch Ponds (9)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	12	Once/Embayment	12	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	7	Once/Embayment	7	7	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-X Green Pond
Town of Falmouth
Prioritization Rank: Round 1 - #10

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Green Pond, Falmouth*:* Data is mostly complete to allow modeling and synthesis. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Falmouth PondWatch Program. Estuary Project required field data is nearly complete and was collected following the procedures of this Estuaries Project QAPP and was performed by Estuary Project Technical Team members. An additional eelgrass survey and 2-3 D.O. recordings will be conducted in 2002 to support the thresholds analysis.

While benthic regeneration rates have been determined for this system, the spatial distribution is not as extensive as appropriate for the Estuaries Project Approach. Therefore, additional benthic regeneration sampling will be conducted in 2002. These data enhance the water quality model and update the previous synthesis to be consistent with the Estuaries Project. An additional eelgrass survey will be conducted in 2002 to support the thresholds analysis. Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated by field observations), due to the embayment's basic

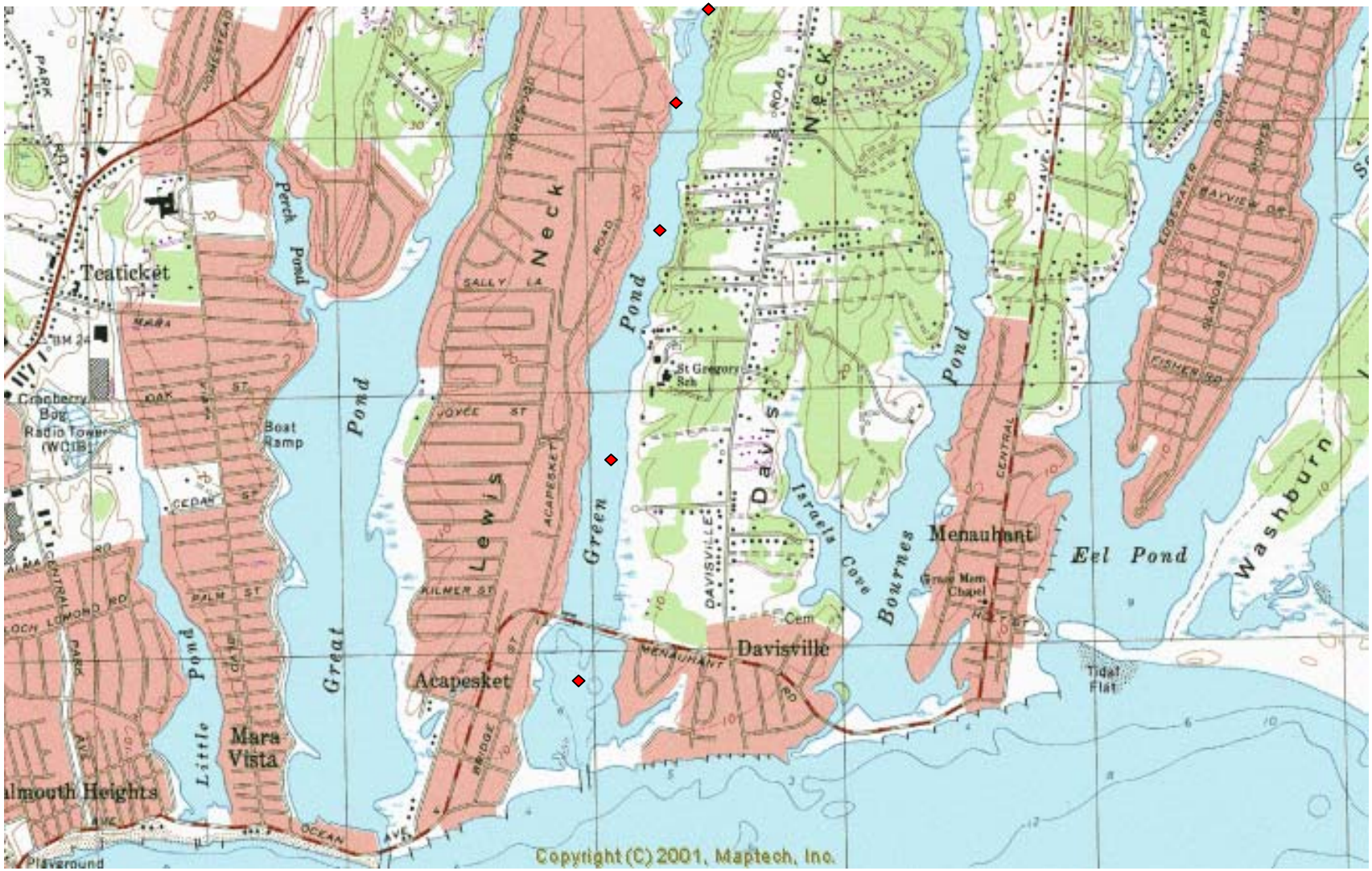
configuration and the lack of suitable channel cross section needed for accurate ADCP measurements.

Regarding dissolved oxygen measurements in this system, a maximum of 3 dissolved oxygen meter will be deployed in the upper half of the estuary for continuous measurements during the months of July and August. Specific deployment site is to be determined.

Massachusetts Estuaries Project Round 1 Prioritization



Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Green Pond (10)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	9	Once/Embayment	9	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	3 **	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	6	Once/Embayment	6	6	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XI Acushnet River/New Bedford Inner Harbor
City of New Bedford
Prioritization Rank: Round 1 - #11

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

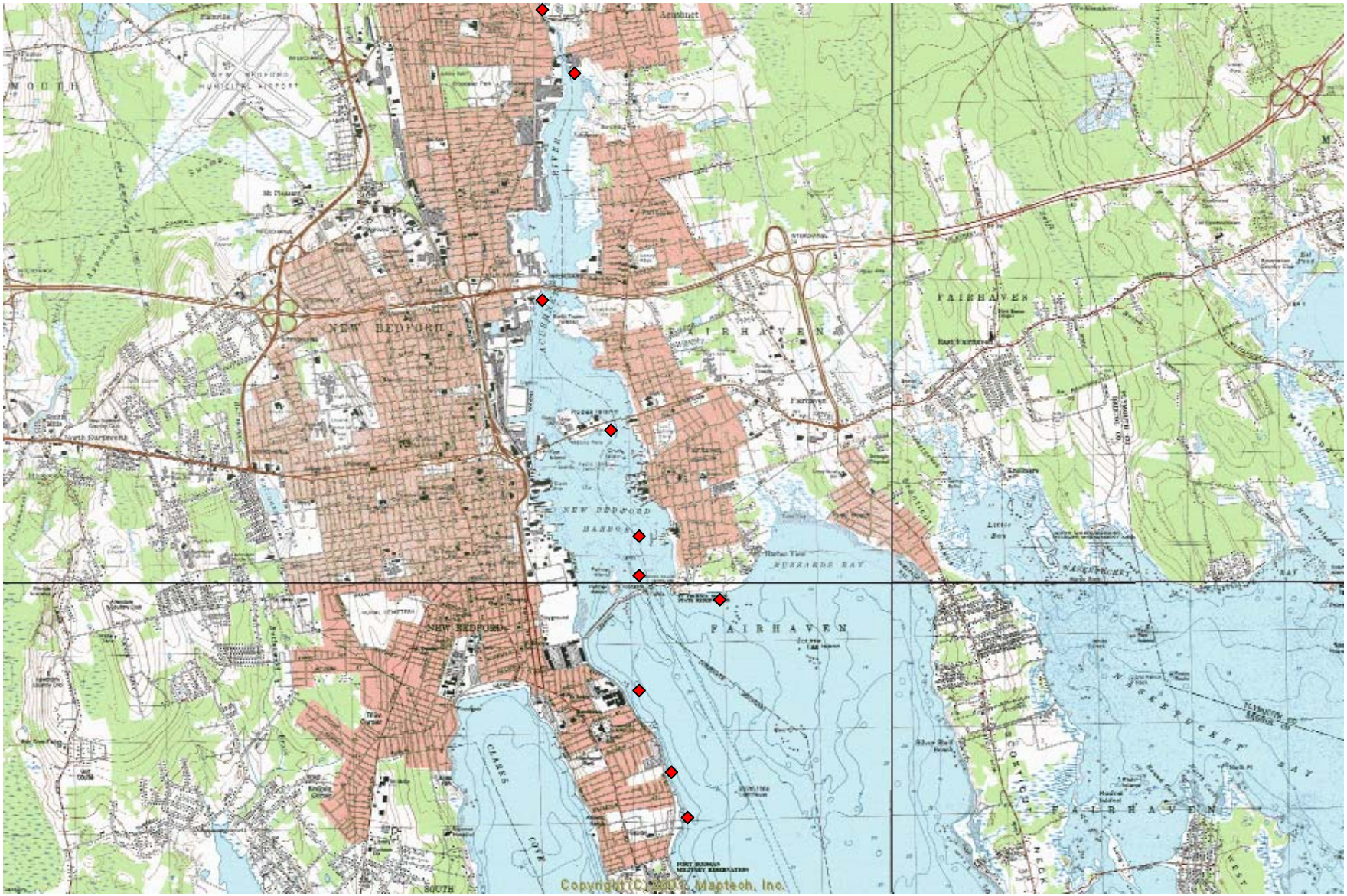
Acushnet River-Inner New Bedford Harbor (on 303d list-pathogens), New Bedford-Fairhaven & Acushnet*:* Some Estuaries Project Approach data is available for this system and there is a 10 year record of nutrient related water quality data. Extensive studies have been conducted on this system relating to the PCB clean-up and the CSO discharges. In addition, recent work by Applied Science Associates Inc (ASA) under EPA contract will provide some useful hydrodynamic data (Kim et al., 2001). These studies will provide the habitat assessment data required for the Estuaries Project (eelgrass, macroalgae, benthic animals). These data were all collected under approved QAPP's. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP (Howes and Williams 2001). All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program. Dissolved oxygen moorings to complete the habitat assessment will be placed at 2-3 locations (1-2 in the upper and 1 in the lower basin, during summer 2002). Specific deployment sites are to be determined.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model (with ADCP validation, ASA did not collect ADCP data) which will require placement of tide gauges (ASA study had only 1 gauge), (2) conduct a benthic regeneration survey, (3) update and make consistent with the Project Approach the land-use and watershed nitrogen loading model (we incorporate the data in the Buzzards Bay Project study), (4) expand the Acushnet River discharge data on flow and nitrogen load to allow determination of nitrogen attenuation within the upper watershed, and (5) conduct the water quality modeling, thresholds analysis and synthesis. Confirmation of previous eelgrass mapping will be conducted during 2002.

Massachusetts Estuaries Project Round 1 Prioritization

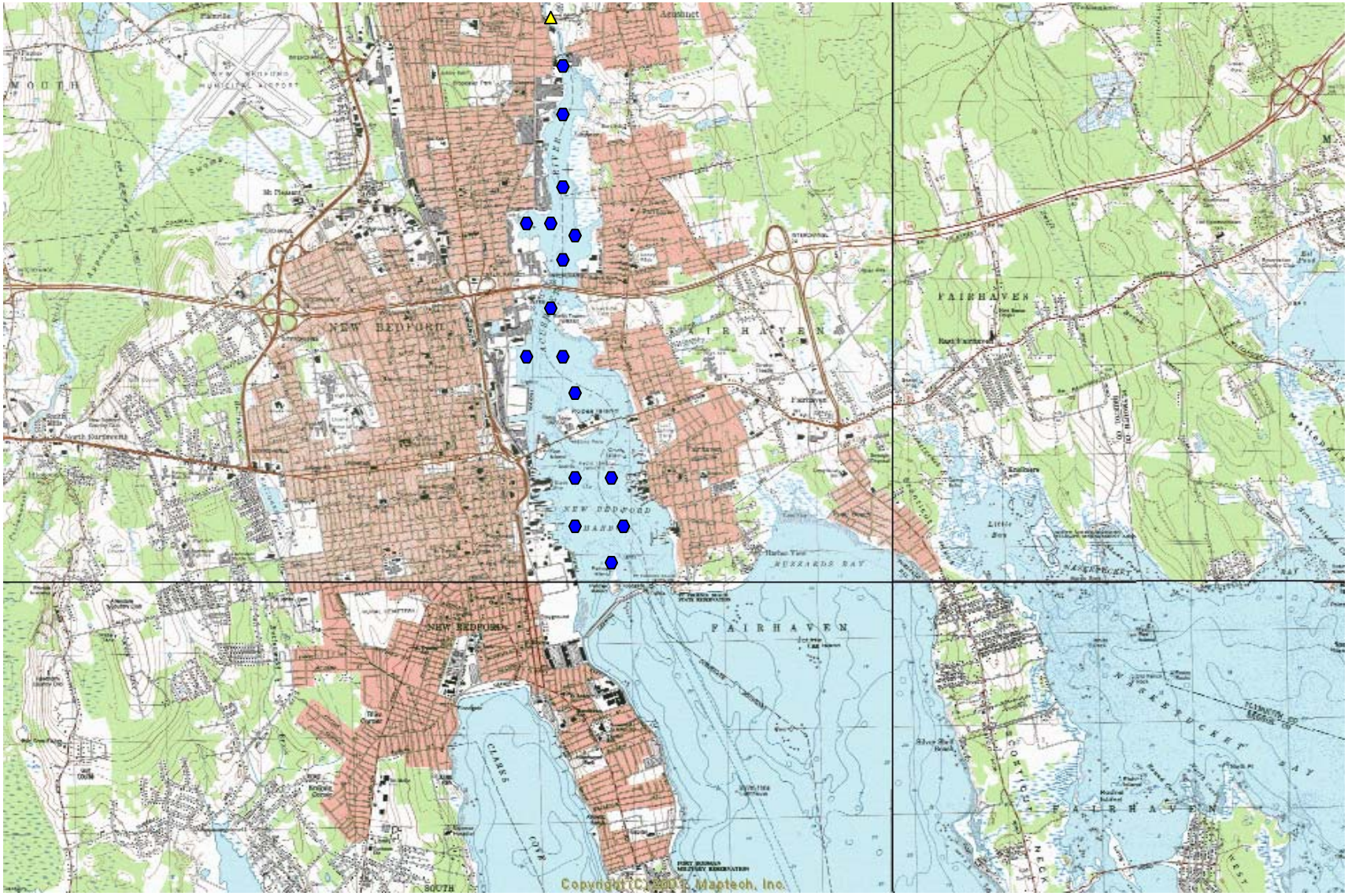


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

ADCP Transect

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Acushnet River / New Bedford Inner Harbor (11)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	14	Once/Embayment	14	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	4 **	48 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	3	Once/Embayment	3	6	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XII Little Pond
Town of Falmouth
Prioritization Rank: Round 1 - #12

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Little Pond, Falmouth: There is an extensive historical data set on the nitrogen cycling in Little Pond (1985-1995). Much of the data to support modeling and synthesis needs to be updated and will require field data collection by the
Estuaries Project. The previous data collection on benthic regeneration and stream discharge was not collected under a QAPP, but was collected by Estuaries Project staff and is fully consistent with Estuary Project protocols as specified in the present QAPP. Water quality monitoring data (1987-2001) has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP (Howes and Williams 2001). All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Falmouth PondWatch Program.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model which will require placement of tide gauges (previous data is prior to the new inlet); (2) conduct a benthic regeneration survey; (3) update the existing land-use and watershed nitrogen loading model; (4) collect benthic infaunal data within the upper, mid and lower basins to

compare to historic data; (5) two dissolved oxygen meters will be deployed in the mid and lower basins of the estuary for continuous measurements, specific deployment sites are to be determined; and (6) conduct the water quality modeling, thresholds analysis and synthesis. Confirmation of previous eelgrass mapping will be conducted during 2002.

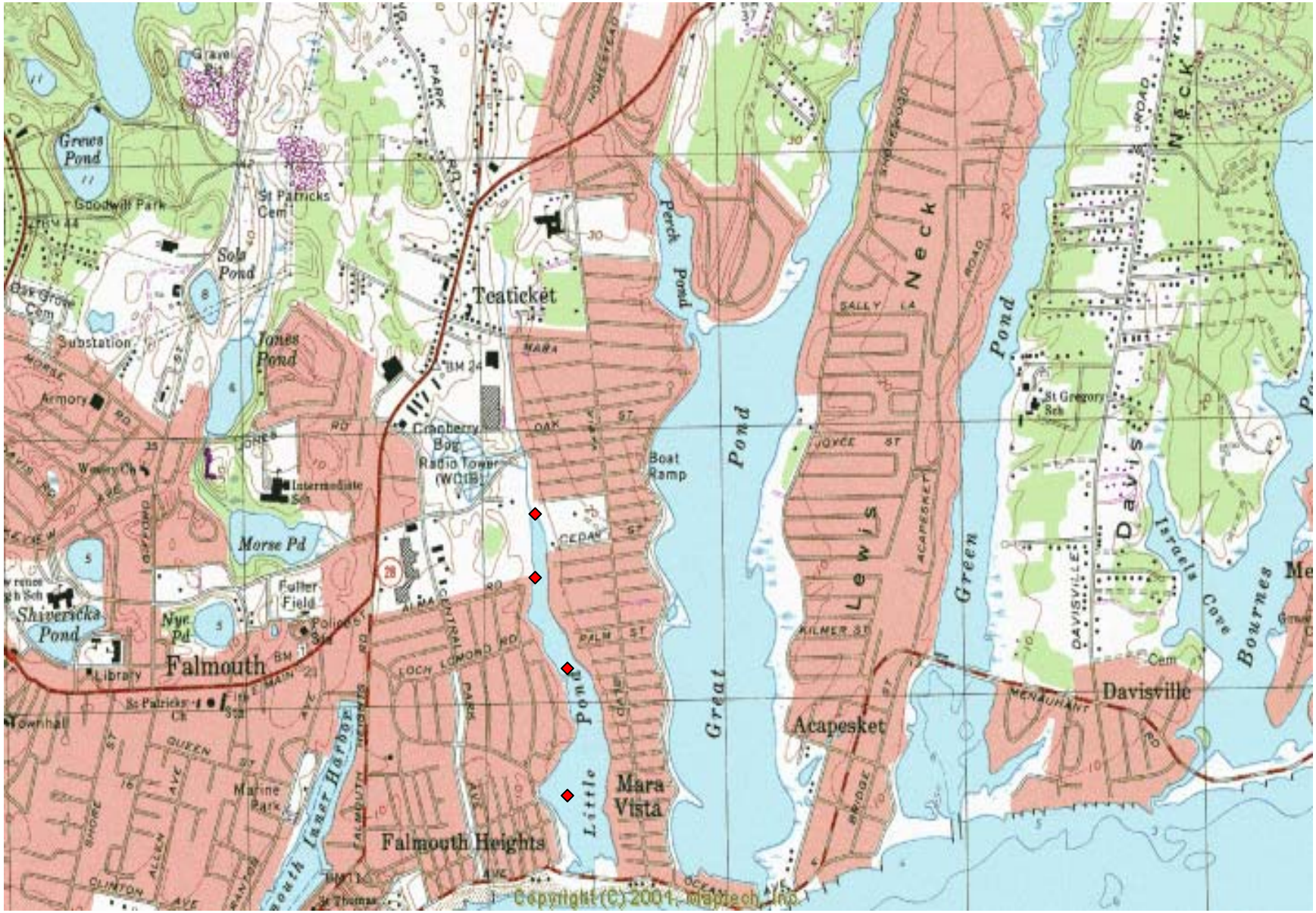
Acoustic Doppler Current Profiling (ADCP) will not be performed, due to the embayment's basic configuration and the lack of suitable channel cross section.

Note: This system is being evaluated, as part of the Falmouth Comprehensive Wastewater Planning effort. The focus is to consider installing sewers throughout much of the eastern and northern watershed.

Massachusetts Estuaries Project Round 1 Prioritization



Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Little Pond (12)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	7	Once/Embayment	7	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	6	Once/Embayment	6	3	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XIII Nantucket Harbor
Island of Nantucket
Prioritization Rank: Round 1 - #13

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Nantucket Harbor (on 303d list-pathogens), Nantucket*:* Nantucket Harbor was the site of a precursor study to the Estuaries Project (WHOI Nantucket Harbor Study 1990-1995). This included each aspect of the Estuaries Project data collection, including DEP's eelgrass mapping program (it was one of the first reference sites). While there was not a QAPP, the work is fully compliant with this QAPP. However, the water quality modeling and thresholds analysis was not conducted.

The existing data includes eelgrass mapping, macroalgal surveys, infaunal analysis, benthic regeneration, multiple tide gauges, bathymetry, D.O. records (4 sites, within each of the main basins), current records, validated land-use analysis, stream flow and nitrogen loads.

Estuaries Project sampling will include (1) deployment of tide gauges and (2) ADCP transects.
Water quality monitoring data has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST.

Since Nantucket Harbor has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Nantucket Harbor System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This "paired" sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization

SMAST
University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

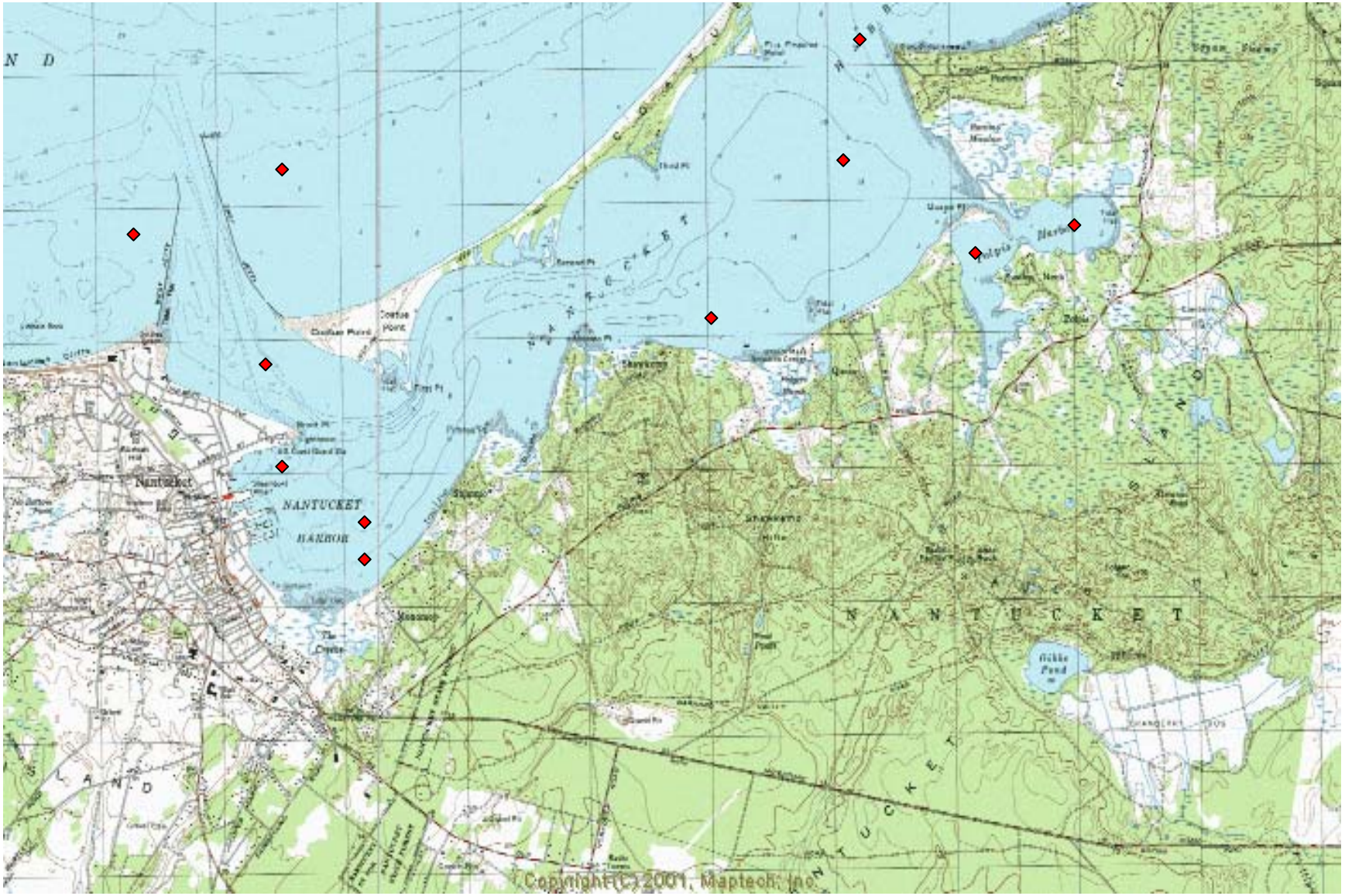


Figure 1



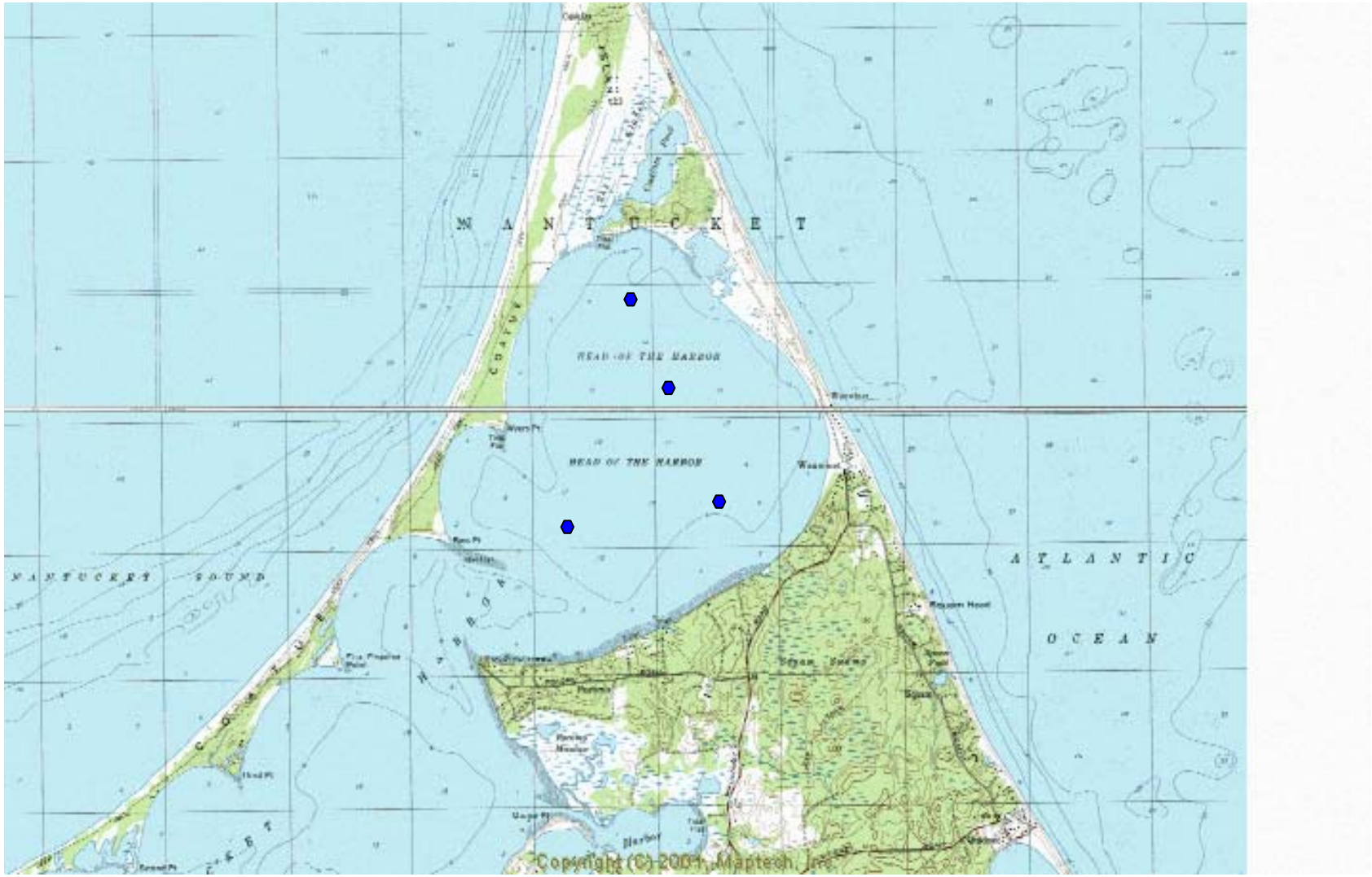
◆ Nutrient Sampling Locations

Figure 2



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4



Tide Gauge Location ADCP Transect

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Nantucket Harbor (13)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	8 (isco)	1	daily	100	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	24	Once/Embayment	24	6	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	4 **	48 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab		Once/Embayment	4	8	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XIV West Falmouth Harbor
Town of Falmouth
Prioritization Rank: Round 1 - #14

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

West Falmouth Harbor, Falmouth*:* This system has seen intense activity as part of the Falmouth WWTF permit renewal and system upgrade. Several of the key elements of the Linked Approach have been collected in this effort by DEP/SMAST. However, the full Linked Watershed-Embayment Management Model has not been applied to date.

Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring and Falmouth PondWatch Programs.

The existing data which will be used is fully compliant with this QAPP and was collected and analyzed by present Estuaries Project Technical Team members (and are included in DEP's West Falmouth Harbor Report). These data sets include: (1) benthic infaunal surveys, (2) eelgrass (and macroalgae) mapping and historical reconstruction, and (3) stream nitrogen loading and wetlands attenuation.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based upon existing data and conduct ADCP measurements at the inlet; (2) update the existing

land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect dissolved oxygen records to complete the habitat assessment (1 in Snug Harbor and 1 in the outer Harbor), (4) re-map eelgrass distribution to enhance thresholds analysis; and (5) conduct the water quality modeling, thresholds analysis and synthesis.

Note: West Falmouth Harbor represents a critical site for evaluating nitrogen thresholds. We have a continuous record of nitrogen levels as the Falmouth WWTF plume has been discharging to the Harbor and causing accelerated eutrophication. Eelgrass distribution is changing rapidly and the last mapping was conducted in 1999.

Massachusetts Estuaries Project Round 1 Prioritization

SMAST
University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

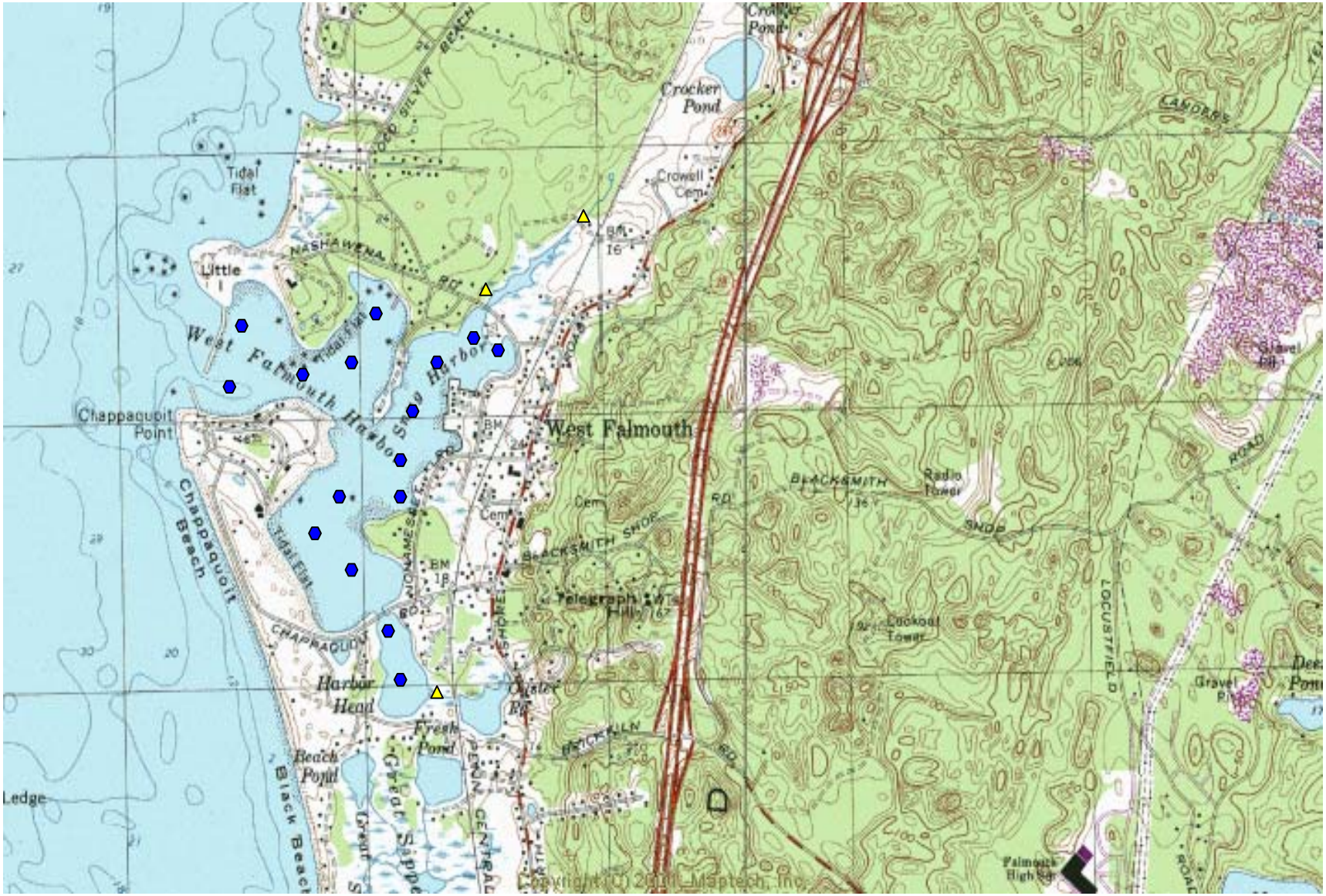


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location ADCP Transect

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
West Falmouth Harbor (14)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	15	Once/Embayment	15	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	0	0	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	6	Once/Embayment	6	2	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XV Three Bays System
Town of Barnstable
Prioritization Rank: Round 1 - #15

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Three Bays (on 303d list-pathogens), Barnstable*:* Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Three Bays Preservation Monitoring Program. This program has technical staff (including SMAST staff) performing the sampling.

The existing data for the Linked Approach which will be used is fully compliant with this QAPP and was collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) stream flow and nitrogen loading from the Marstons Mills and Little Rivers, (2) dissolved oxygen records from 4 sites (2 in Princes Cove, upper and mid North Bay, (3) nutrient sampling of major lakes and ponds, (4) some bathymetric and tidal data, including 2 permanent tide gauges.

Since Three Bays has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Three Bays System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This "paired" sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III.

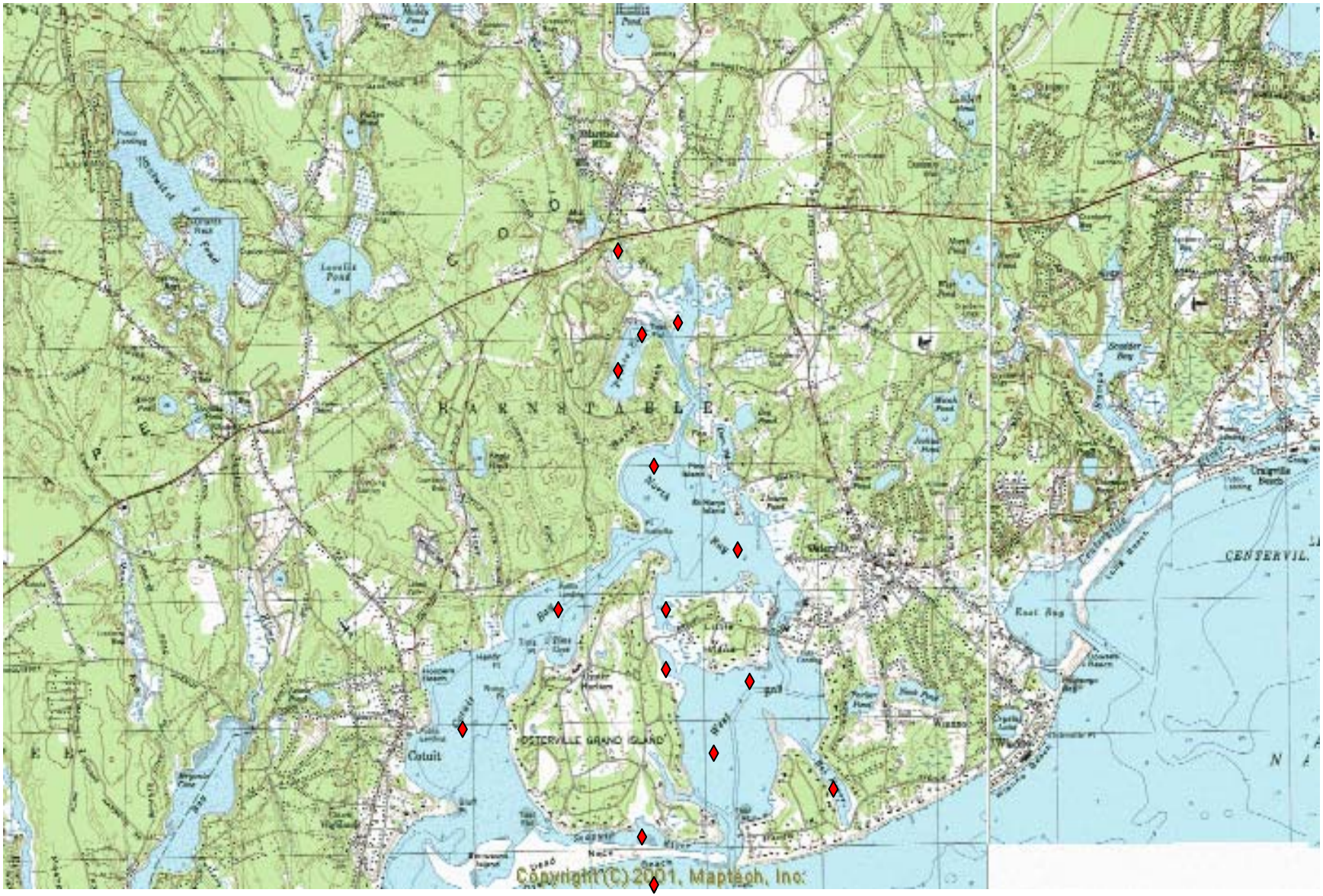
The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based which will require placement of tide gauges and conducting ADCP measurements; (2) update the existing land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect 2 additional dissolved oxygen records to complete the habitat assessment (1 lower North Bay and 1 in upper West Bay), (4) map eelgrass distribution and create historic record; (5) conduct the water quality modeling, thresholds analysis and synthesis and (6) conduct wet versus dry weather bacterial surveys within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization

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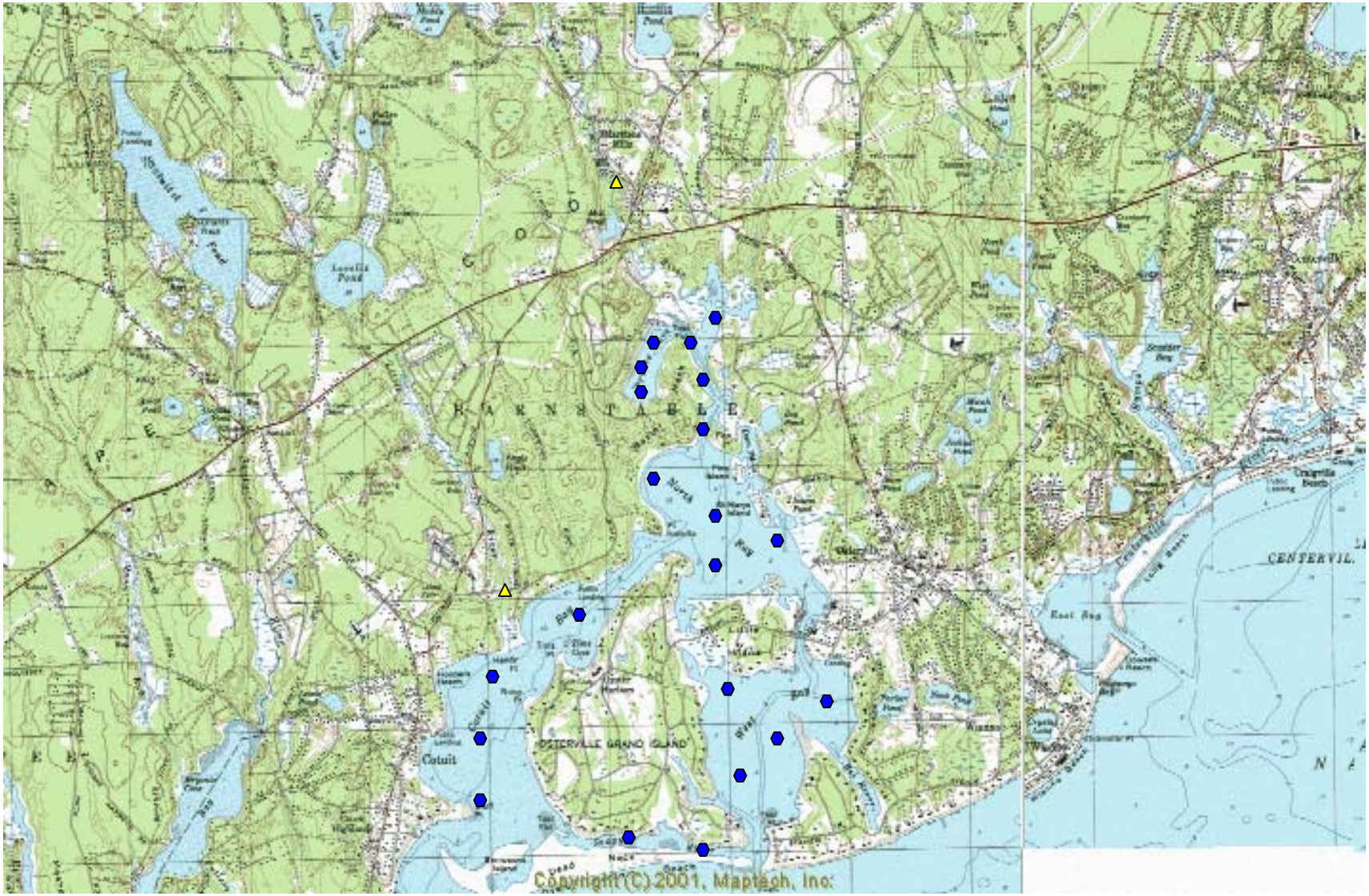
Massachusetts Department of Environmental Protection





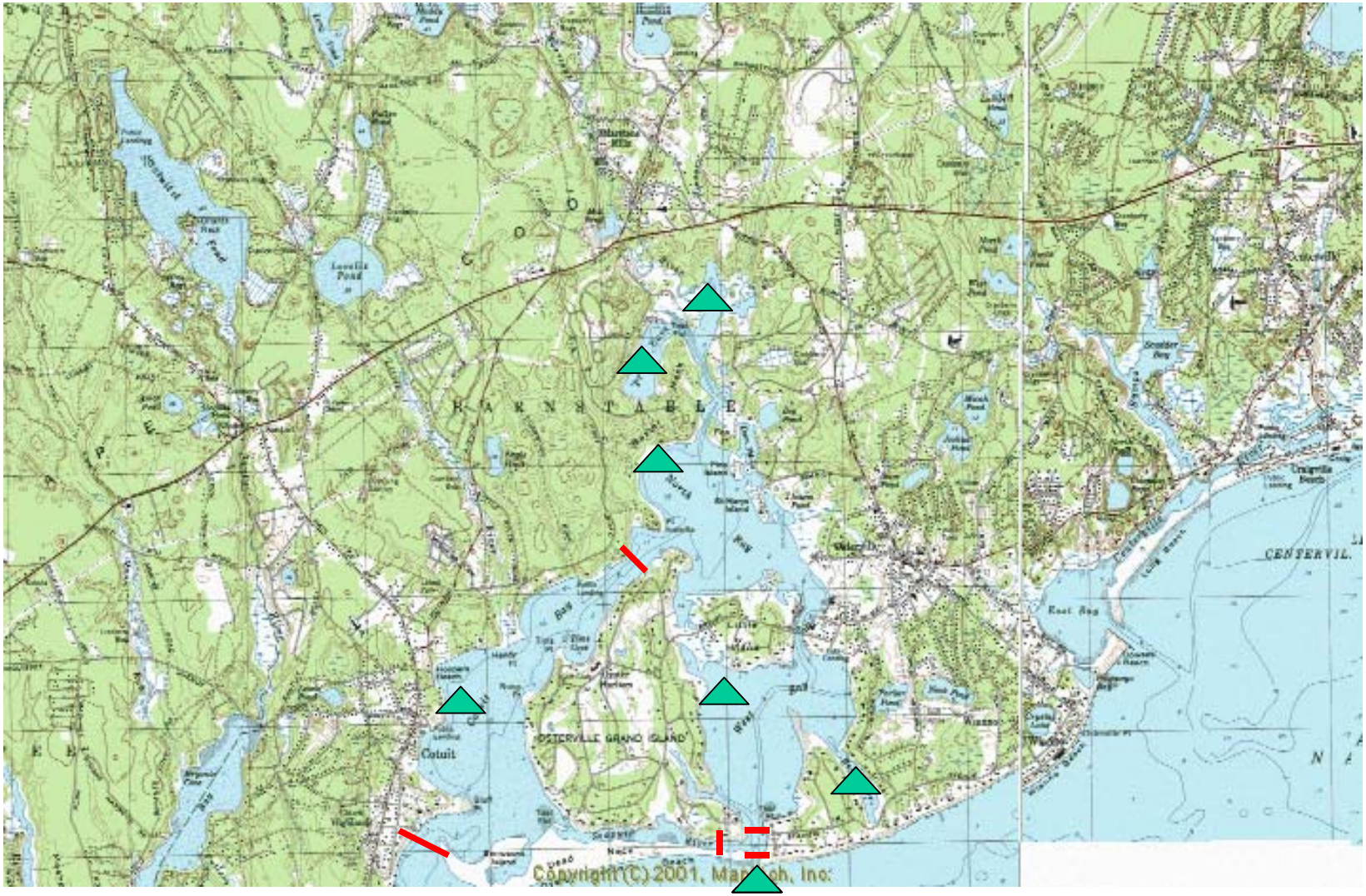
◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

ADCP Transect

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Three Bays System (15)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	2	Weekly	100	10	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	19	Once/Embayment	19	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	4 **	48 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	10	Once/Embayment	10	20	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XVI Edgartown Great Pond
Island of Martha's Vineyard
Prioritization Rank: Round 1 - #16

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Edgartown Great Pond, Edgartown*:* This salt pond is closed to tidal exchange by a barrier beach. It has a "managed tidal exchange" through periodic opening by the Town of Edgartown. This system has seen intense activity as part of the Edgartown WWTF upgrade. Some useful data has been collected on key elements of the Linked Approach as part of this effort. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP (Williams and Howes, 2001, and has had its own independent QAPP, as well). All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Martha's Vineyard Commission. Monitoring is conducted by technical personnel, no volunteers are used.

The data which has been previously collected and may be used to parameterize the Estuaries Project Approach does not appear to be fully compliant with this QAPP. Therefore field data collection by Estuaries Project Technical Team members is required before inclusion into the analysis. Given the differences in protocols, the previous data will

only be used to supplement Estuaries Project data. These data sets include: (1) benthic infaunal surveys, (2) eelgrass (and macroalgae) mapping (by Gaines, WHOI) and (3) D.O. records. Note there have been 2 sets of D.O. records collected for the system, the first is unacceptable as the meter was placed too close to the surface and the second data set is not yet available.

A major existing data set which is compliant with the Project QAPP and which will be incorporated fully is the MVC's land-use and watershed delineation (Martha's Vineyard Commission, 1999). This data will allow implementation of the Project's watershed nitrogen loading model.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model which accounts for the dispersion and mixing within the estuary during openings (includes tide gauges and bathymetric survey); (2) collect dissolved oxygen records (1 each in upper and lower pond) with specific sites to be determined, (3) map eelgrass distribution; (4) confirm previous infaunal community analysis; (5) conduct a benthic nitrogen regeneration survey; (6) gauge the stream into the upper pond which likely receives discharge from the WWTF plume (if possible based upon site inspection), and (7) conduct the water quality modeling, thresholds analysis and synthesis. This work will be conducted in collaboration with the Martha's Vineyard Commission through their coastal scientist, William Wilcox.

Hydrodynamic instrumentation will be deployed before, during, and after seasonal breach. Acoustic Doppler Current Profiling (ADCP) will not be performed due to the closure of the pond.

Massachusetts Estuaries Project Round 1 Prioritization

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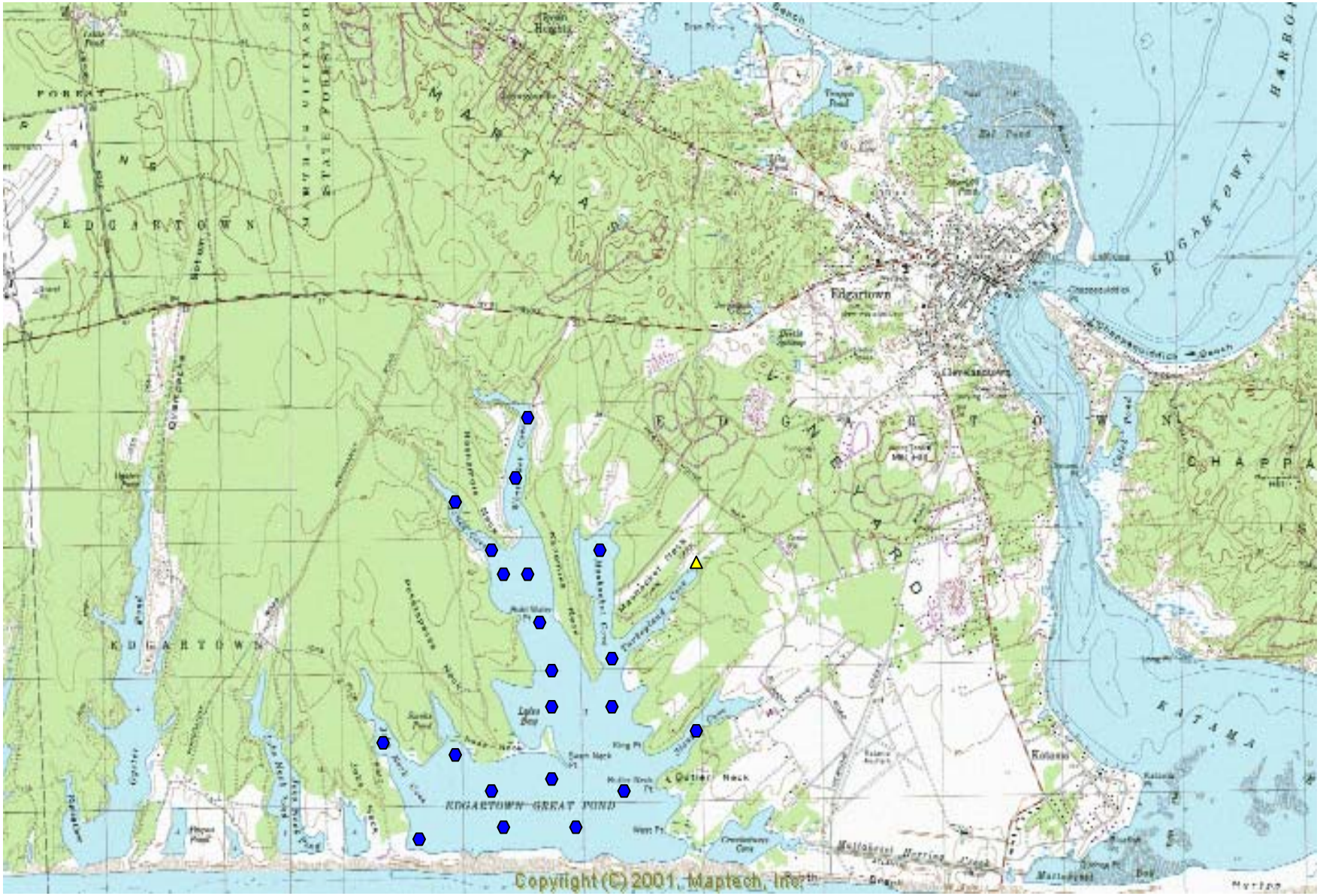


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Edgartown Great Pond (16)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	19	Once/Embayment	19	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	3 **	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	10	Once/Embayment	10	20	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XVII Oyster Pond
Town of Falmouth
Prioritization Rank: Round 1 - #17

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Oyster Pond, Falmouth*:* Some useful data exist on hydrodynamics, watershed delineation and habitat parameters. However, none of these data sets is complete and each component of the Linked Approach will require some additional data collection or modeling.

This salt pond is closed to tidal exchange by a barrier beach. It has a “managed tidal exchange” through a control weir at the pond outlet. This pond has significant historical data collected by WHOI scientists that will help in assessment and management. Some data has been collected on key elements of the Linked Approach by members of the Estuaries Project Technical Team under the protocols of this QAPP.

Water quality monitoring data (1987-2001) has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Falmouth PondWatch Program.

The data which has been previously collected and will be used to parameterize the Estuaries Project Approach includes: (1) tide gauges, (2) freshwater inflow and nitrogen levels in stream flow, and (3) temporal and spatial distribution of stratification.

Supporting data on stratification of the central basin, historical records of salinity and nitrogen levels, fish populations, herring populations and basic structure are also available.

The main Estuaries Project efforts will be to (1) update the hydrodynamic model (including a bathymetric survey), (2) collect dissolved oxygen records (2 depth profile at the upper basin), (3) infaunal community analysis; (4) conduct a benthic nitrogen regeneration survey; (5) determine stream flow and nitrogen discharge to the upper pond, (6) conduct land-use analysis based upon new USGS watershed delineation, and (7) conduct the water quality modeling, thresholds analysis and synthesis.

Acoustic Doppler Current Profiling (ADCP) will not be performed, due to the embayment's basic configuration and the lack of suitable channel cross section (water is only 20-50 cm depth).

Since Oyster Pond has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Oyster Pond System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This "paired" sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

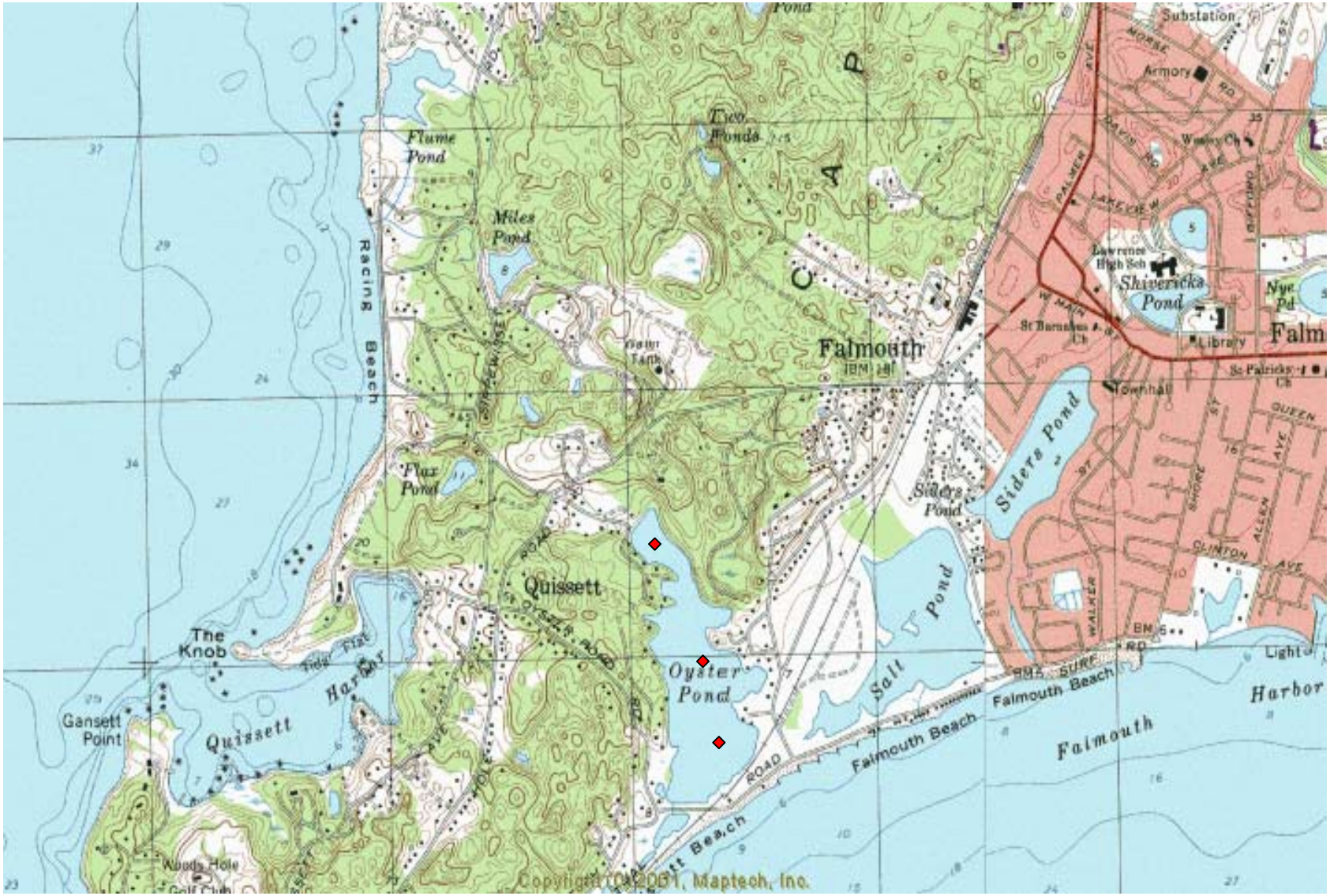
Massachusetts Estuaries Project Round 1 Prioritization

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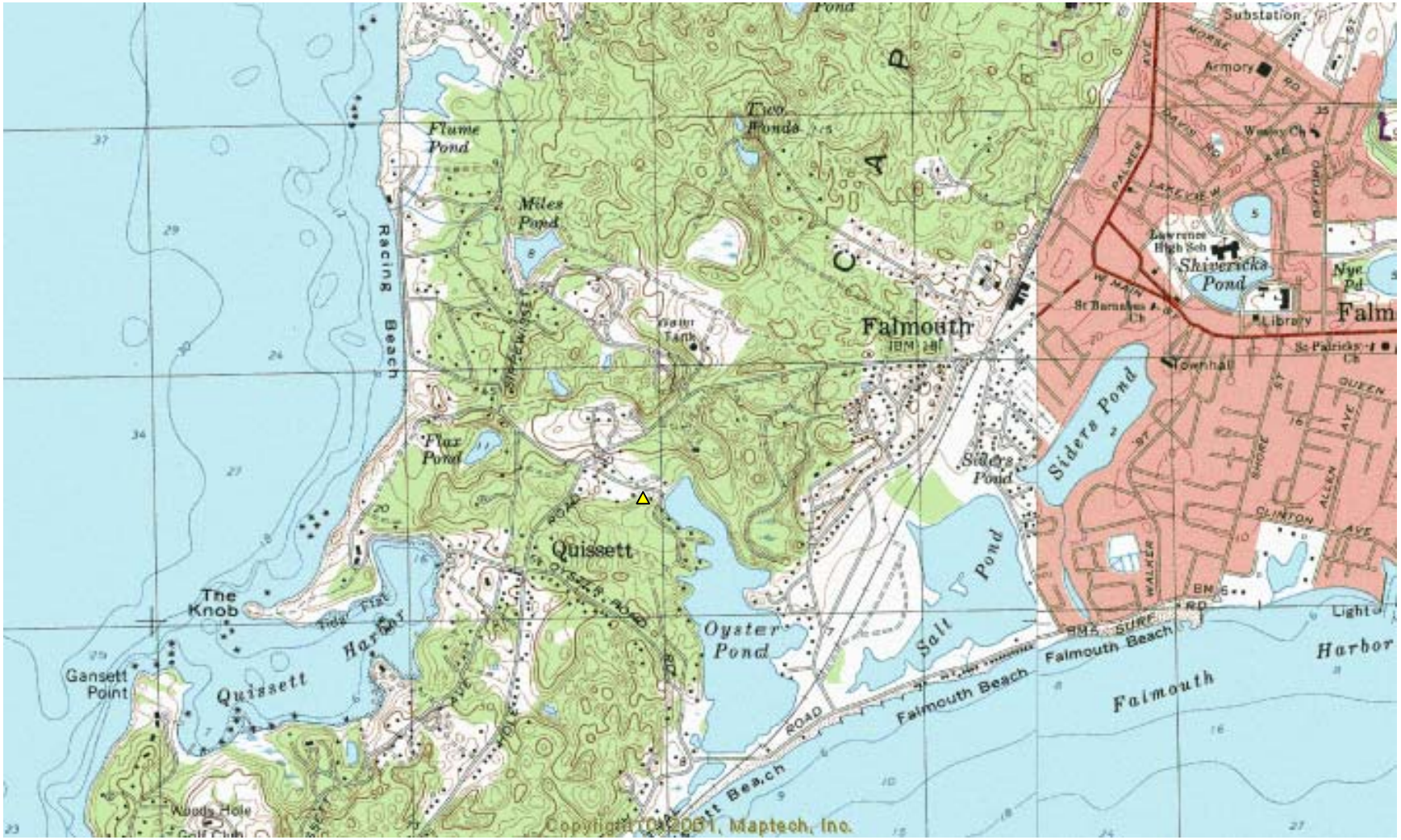


Figure 1



◆ Nutrient Sampling Locations

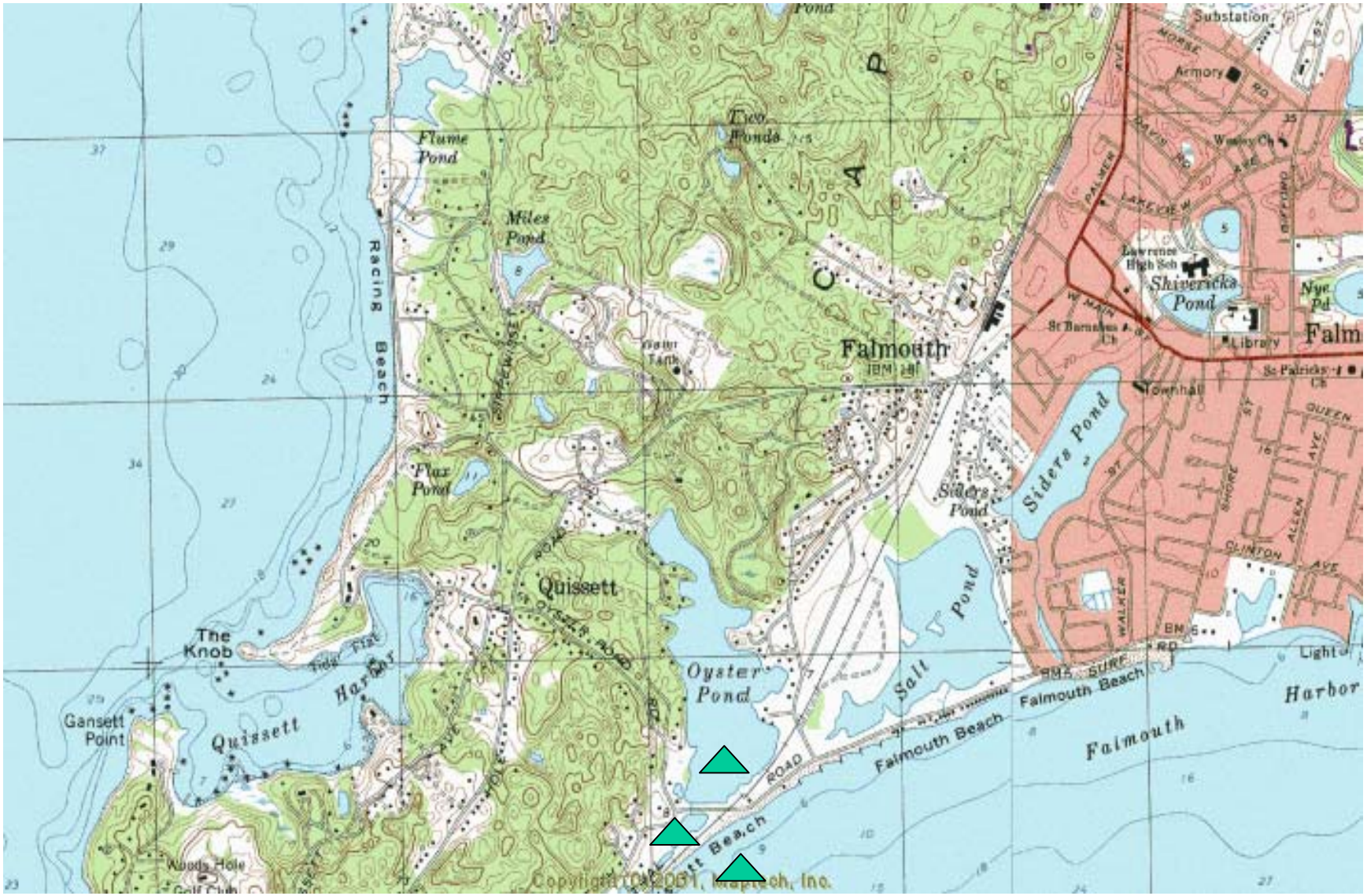
Figure 2



Benthic nutrient flux is inferred from changes in hypolimnion concentrations. Coring will be performed along the edge of the pond just below water surface at this site.

● Benthic Coring Locations △ Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Oyster Pond (17)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	3	Once/Embayment	4	4	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	0	0	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	5	Once/Embayment	5	10	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XVIII Sesachacha Pond
Nantucket Island
Prioritization Rank: Round 1 - #18

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Sesechacha Pond (on 303d list-pathogens), Nantucket*:* This salt pond is closed to tidal exchange by a barrier beach. It has a “managed tidal exchange” through periodic opening by the Town of Nantucket. This system has seen periods of regular opening and intervals of years with no-openings. Some useful data has been collected on key elements of the Linked Approach as part of the pond management planning. Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP by Estuaries Project Technical Team members with analysis by the Coastal Systems Program at SMAST. Over the past 5 years monitoring data has been sparse and these data have not yet been evaluated for inclusion into the Estuaries Project.

Data is available on the exchange characteristics and nutrient conditions (associated with openings), watershed delineation, and habitat assessment parameters (infaunal and eelgrass). However, none of these data sets is complete and each component of the Linked Approach will require some additional data collection or modeling.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model which accounts for the dispersion and mixing within the estuary during openings (includes tide gauges and bathymetric survey); (2) collect dissolved oxygen records (in the central basin)

with specific sites to be determined, (3) map eelgrass distribution; (4) conduct infaunal community analysis; (5) conduct a benthic nitrogen regeneration survey; (6) conduct land-use analysis; and (7) conduct the water quality modeling, thresholds analysis and synthesis. This work will be conducted in collaboration with the Nantucket Marine Department.

If pond is breached during the field season for management purposes, hydrodynamic instrumentation will be deployed, before, during, and after to prescribed breach.

Acoustic Doppler Current Profiling (ADCP) will not be performed due to the closure of the pond. Stream gauging will not be performed due to the lack of stream discharges.

Since Sesachacha Pond has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Sesachacha Pond System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This “paired” sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization

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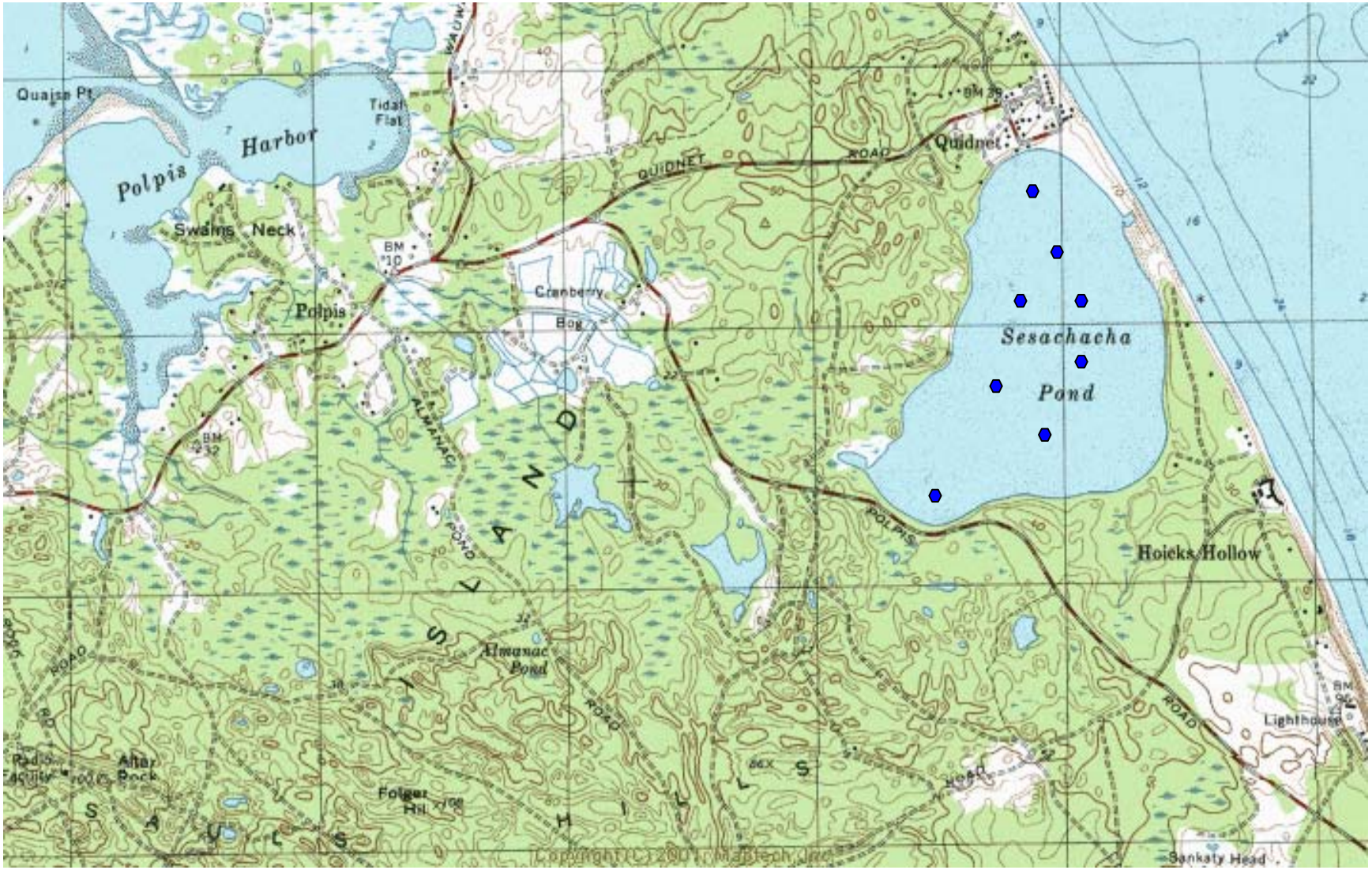


Figure 1



◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Sesachacha Pond (18)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	NA	NA	NA	NA	0	0	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	7	Once/Embayment	7	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	1 **	12 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	5	Once/Embayment	5	10	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XIX Agawam/Wareham/Broad Marsh Rivers Including Mark's Cove
Town of Wareham
Prioritization Rank: Round 1 - #19

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Wareham River System (Agawam and Wankinco Rivers, Broad Marsh, Marks Cove and Central Estuary), Wareham*:* This system has seen intense activity as part of the Town of Wareham's WWTF permit renewal and system upgrade. Several of the key elements of the Linked Approach have been collected in this effort by Camp, Dresser and McKee and SMAST. However, there was not a system hydrodynamic model or water quality model run as part of this process.

Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP, 1992-2001 (Howes and Williams 2001). All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program. Additional, water quality data was collected by SMAST in 2000 for the Town of Wareham.

The existing data which will be used is fully compliant with this QAPP and was collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) stream nitrogen loading and wetlands attenuation in both the Agawam and Wankinco Rivers, (2) some tide gauge records (need to be supplemented due to failure of the offshore gauge), and (3) land-use analysis (including a study of nitrogen discharge from the existing WWTF).

Some supporting data is also available: (1) a study of nutrient limitation in the Agawam River, and (2) surveys of stratification, estuarine circulation and nutrient structure of the estuary.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based in part on existing tidal data and new gauge records with ADCP measurements of currents; (2) update the existing land-use and watershed nitrogen loading model to conform with Project protocols; (3) collect dissolved oxygen records at 5 locations from the Wankinco/Agawam confluence, equidistant to the mouth of the estuary; (4) map eelgrass and macroalgal distribution; (5) conduct benthic regeneration survey; (6) conduct infaunal community survey and (7) conduct the water quality modeling, thresholds analysis and synthesis.

An additional effort (outside of Estuary Project standard protocols) may be made to use a moored acoustic current meter at the railroad bridge in the upper estuary. This decision will be made based upon a site visit (to see if a mooring is feasible) and further analysis of the extant tide records. The current meter is part of the SMAST Coastal Systems Program instrumentation inventory and will be at no cost to the Project.

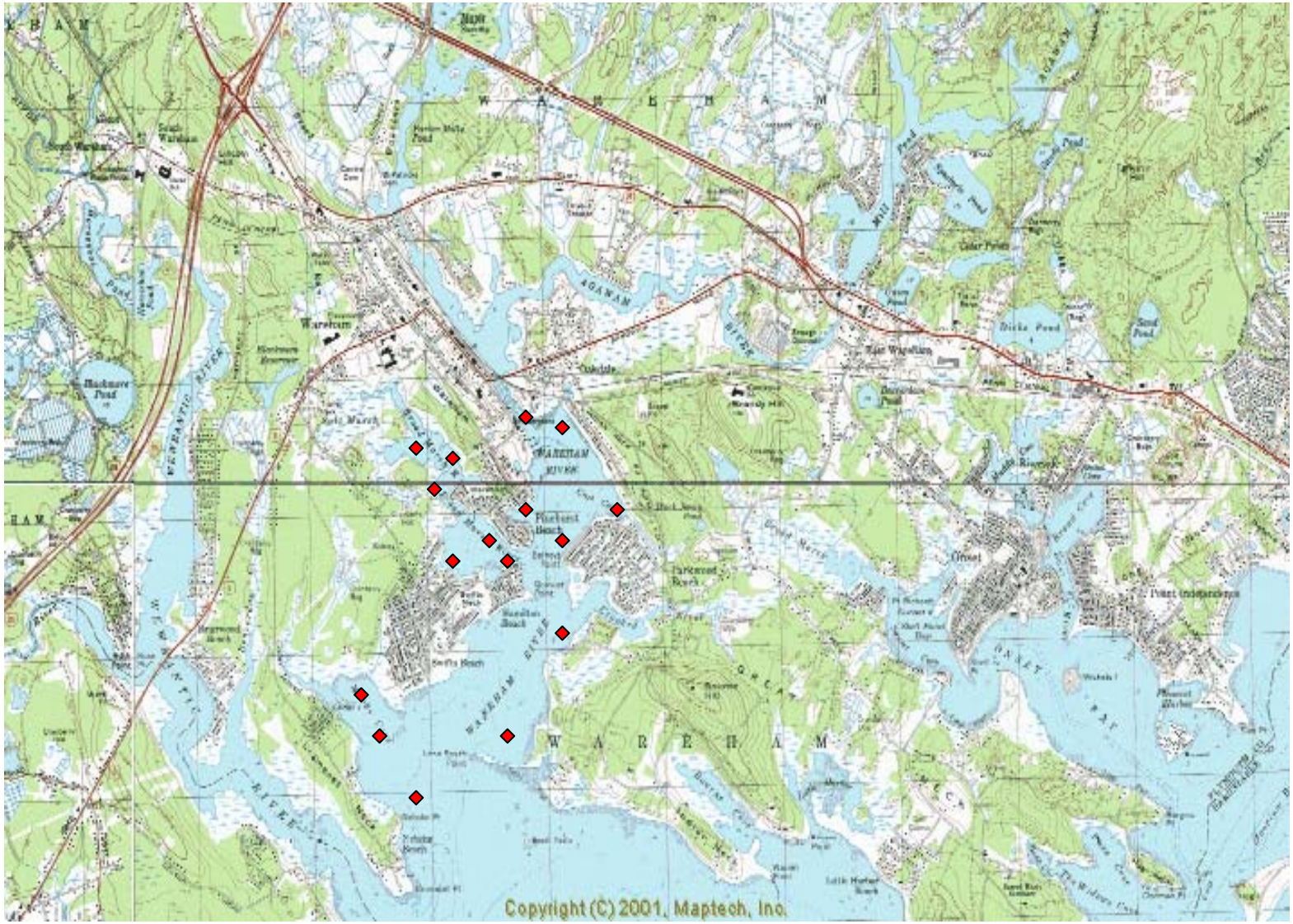
Since the Acushnet River / New Bedford Inner Harbor has documented fecal coliform problems, there is data on fecal coliform distribution collected by DMF and SMAST. In addition, there has been a study using a DNA methodology to identify sources.

Based upon review of existing DMF bacterial data (Howes and Samimy 2002) bacterial assessment will be performed on the Acushnet River / New Bedford Inner Harbor System. Surface water (0.15 cm depth) will be collected at each of the benthic flux sites and stream gauge sites (Figure 3), during both wet weather and dry weather. This “paired” sampling will be conducted on 3-5 occasions, focusing on periods of warmer water temperatures. The sampling will follow that outlined in B-III. Wet versus dry weather bacterial surveys will be conducted within the embayment.

Massachusetts Estuaries Project Round 1 Prioritization

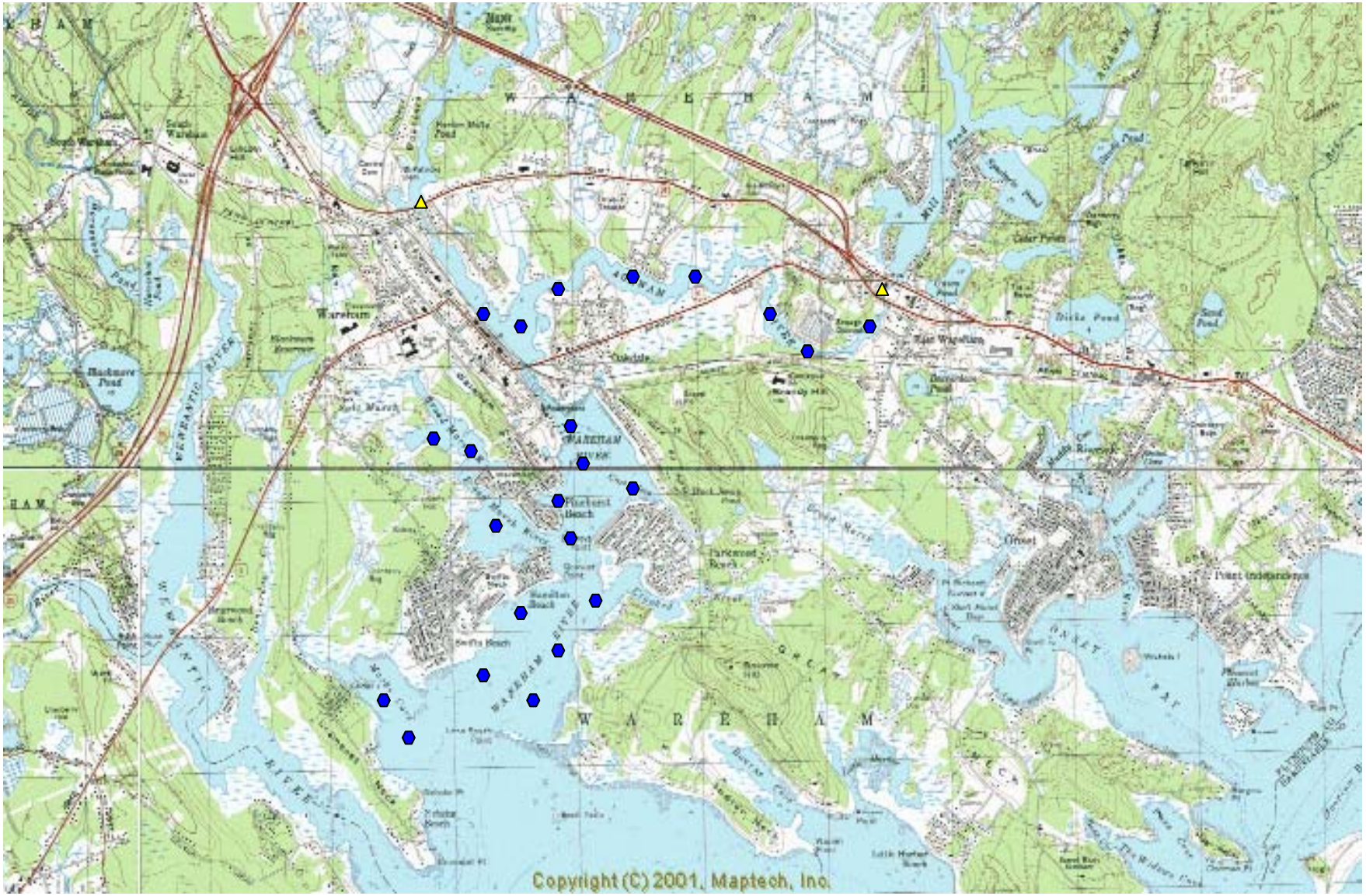


Figure 1



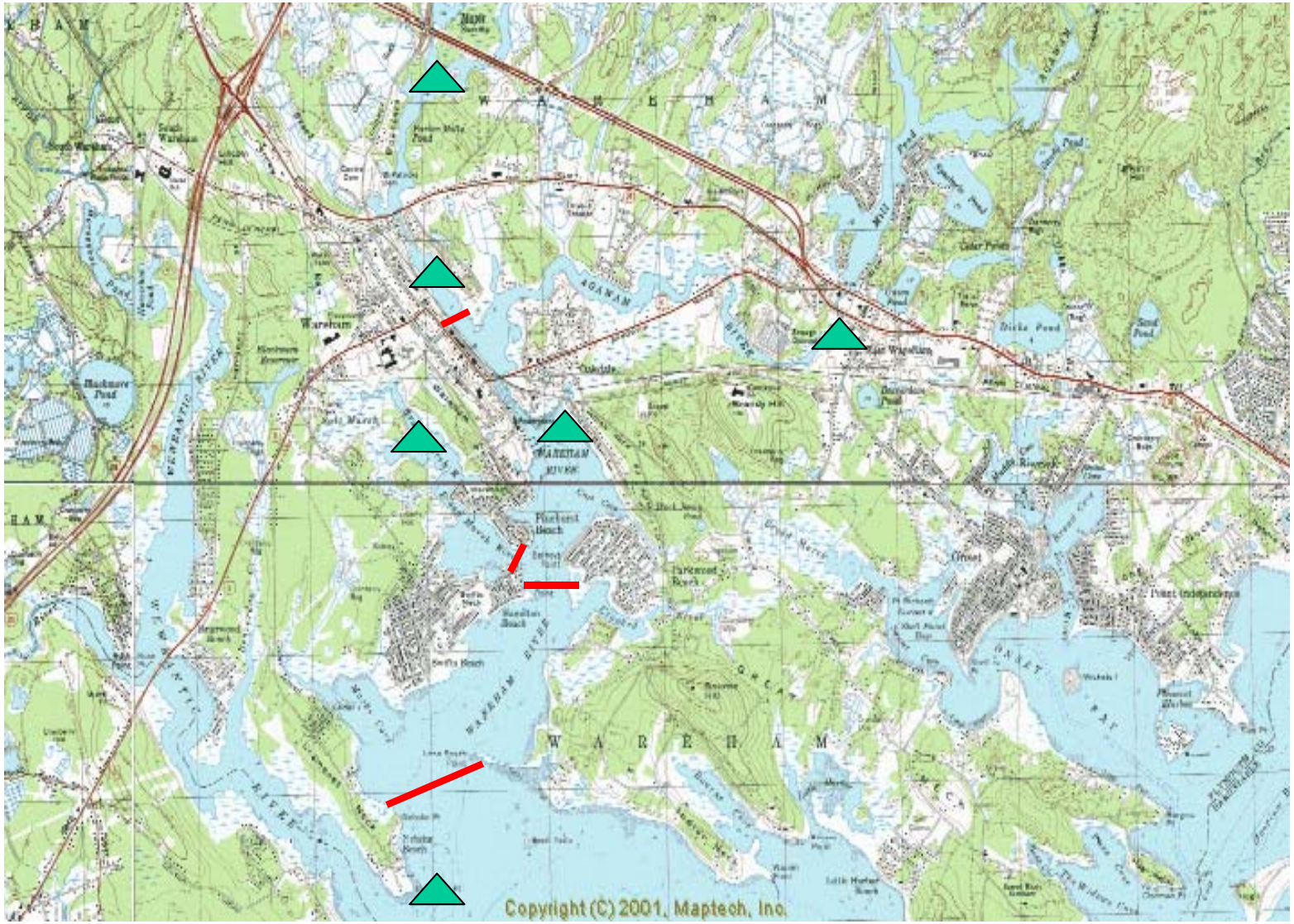
◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location — ADCP Transect

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Agawam River / Wareham River / Broad Marsh / Marks Cove (19)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	2	daily to every 5 days	200	20	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	23	Once/Embayment	23	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	4 **	48 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	10	Once/Embayment	10	20	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XX Eel Pond Back River
Town of Bourne
Prioritization Rank: Round 1 - #20

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Back River/Eel Pond, Bourne*:* This system has seen significant activity as part of the Town of Bourne Landfill upgrade. Several of the key elements of the Linked Approach have been collected in this effort by the Estuaries Project Technical Team in 2001. However, the full Linked Watershed-Embayment Management Model has not been applied to date.

Water quality monitoring data was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program. An additional spatial survey of oxygen was conducted by SMAST in 2001.

The existing key data which will be used is fully compliant with this QAPP and was collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) limited stream nitrogen loading and wetlands attenuation; (2) complete benthic regeneration survey; (3) tide gauges, bathymetry and hydrodynamic

model and (4) some landfill nitrogen loading measurements to support the watershed nitrogen modeling.

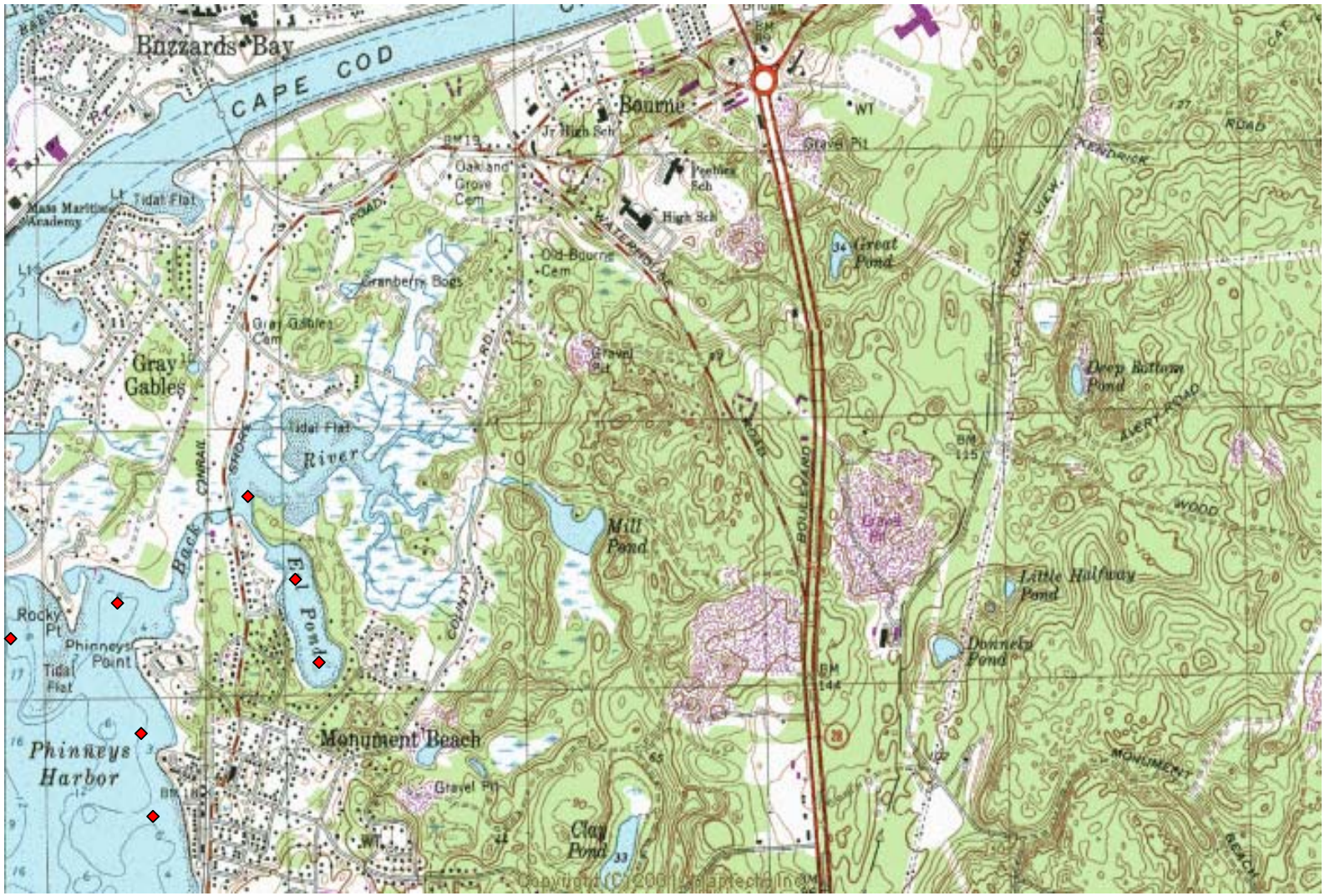
The main Estuaries Project efforts will be to (1) update the existing land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (2) enhance the stream flow and nitrogen loading database to bring in to QAPP compliance; (3) conduct benthic infaunal survey; (4) collect dissolved oxygen records (1 mid marsh and 1 in Eel Pond), (5) re-map eelgrass distribution; and (5) conduct the water quality modeling, thresholds analysis and synthesis.

Acoustic Doppler Current Profiling (ADCP) will not be performed (unless otherwise indicated) due to the embayment's basic configuration and the lack of suitable channel cross section.

Massachusetts Estuaries Project Round 1 Prioritization

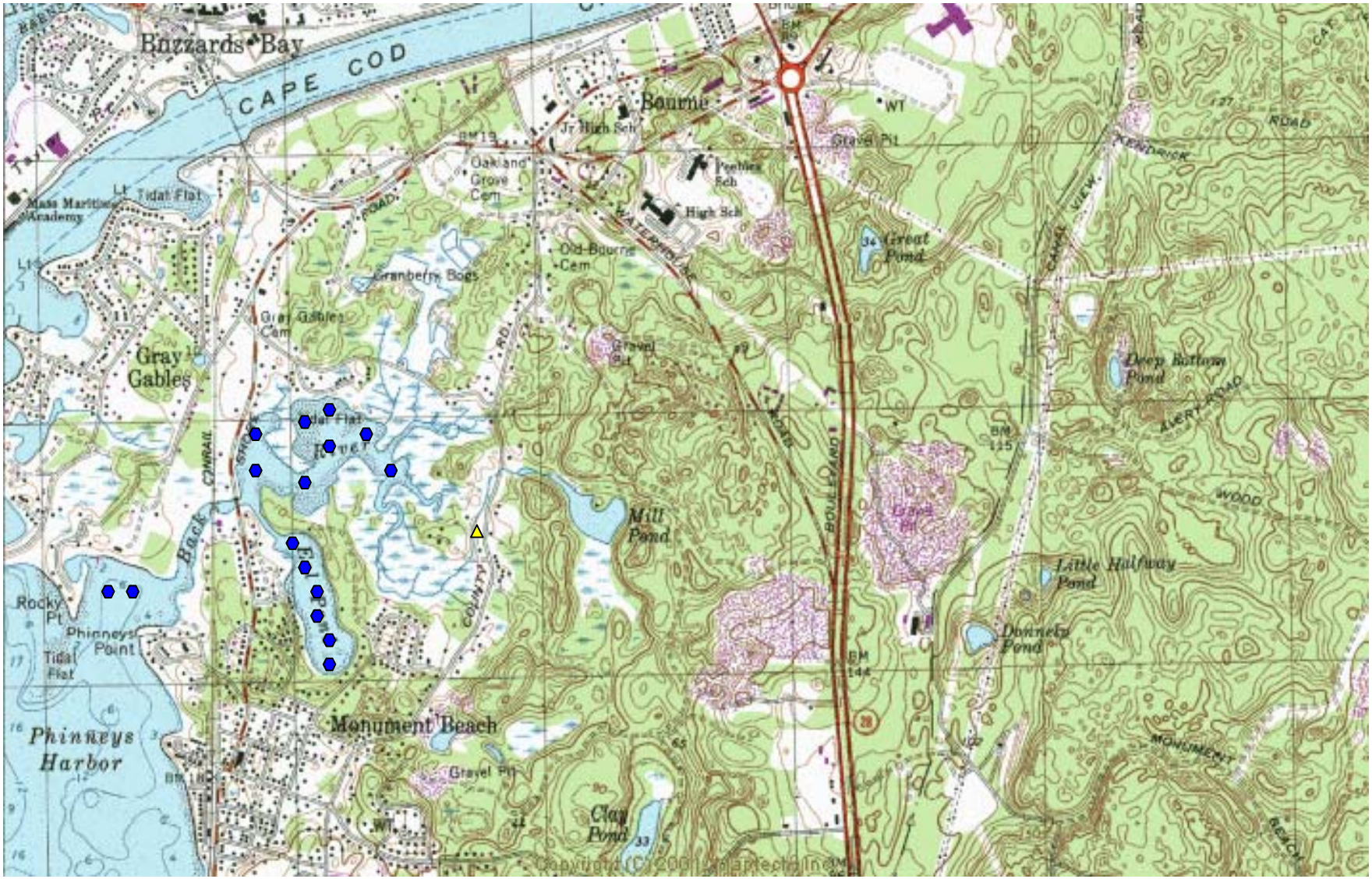


Figure 1



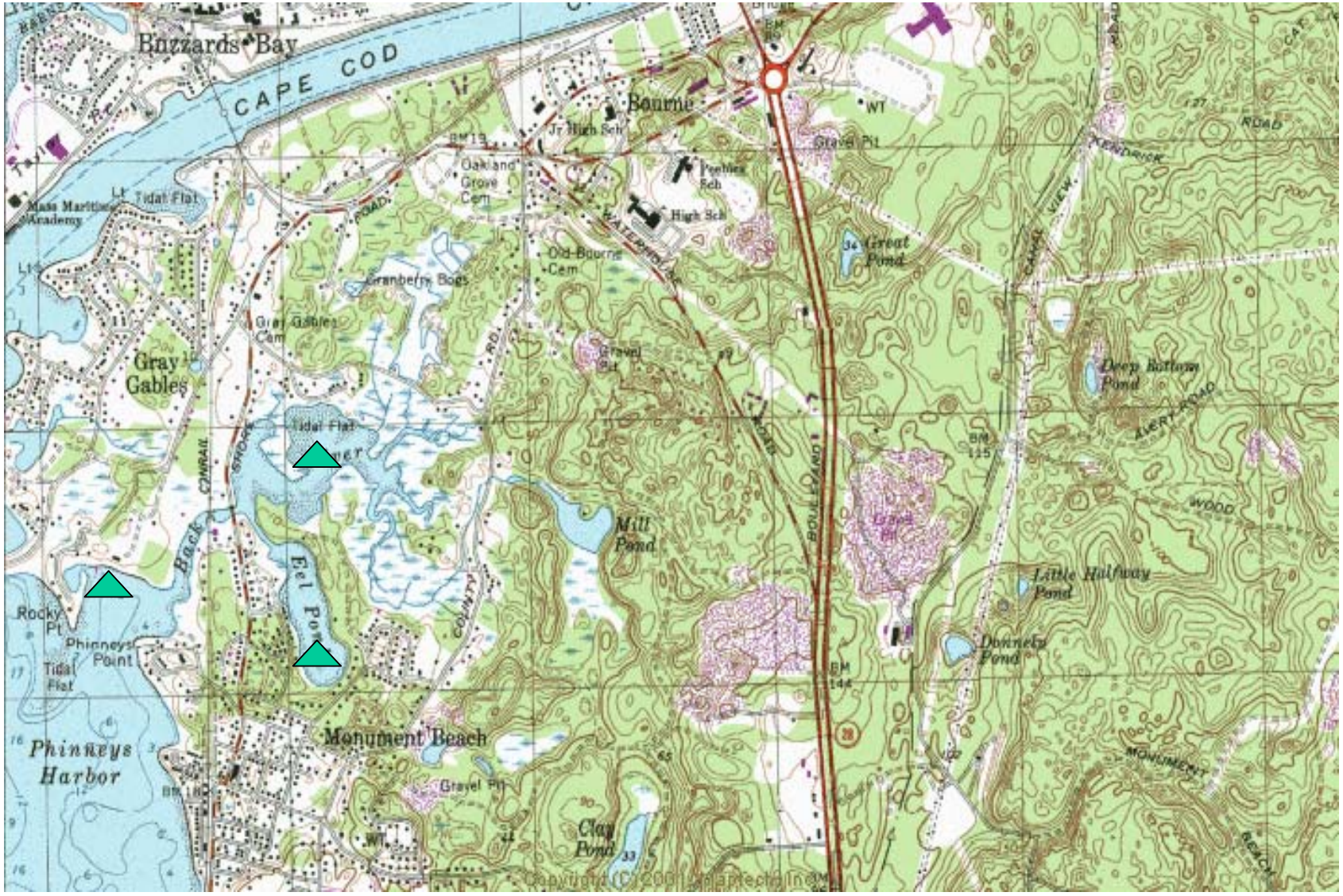
◆ Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage Locations

Figure 3



Tide Gauge Location

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Eel Pond / Back River (20)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	50	5	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	13	Once/Embayment	13	3	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,l,m	NA	NA	15 minutes ****	2 **	24 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	5	Once/Embayment	5	10	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXI Namskaket Marsh
Town of Orleans
Prioritization Rank: Round 2 - #21

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Namskaket Marsh, Orleans: This estuary consists primarily of a salt marsh system exchanging water with Cape Cod Bay through a single main tidal channel. This system will likely receive some discharge of nutrient enriched groundwater originating from the Tri-Town Septage Treatment Facility. The existing plume is being tracked by USGS.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Town of Orleans Water Quality Monitoring Program. This program uses both technical staff and volunteers to perform the sampling. There are also water quality data collected by the Town of Orleans from lakes which may be in the watershed (awaiting USGS completion of delineations). These data were collected under an approved QAPP with chemical assays primarily by the NPS Laboratory, with some checks by the SMAST Analytical Facility. Additional, nitrogen process-level data exist for this system which will provide supporting information for the Estuaries Project. These data were collected by the

USGS Study of the upper marsh related to the Tri-Town Septage Treatment Plume for DEP. The data which will be incorporated includes: (1) magnitude of the nitrogen load from the Treatment Facility reaching the marsh now and projected future discharge; (2) rates of denitrification within the upper marsh creek bottoms; (3) likely responses of the vegetated marsh and creek bottoms to increased nitrogen loading.

There are additional existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and an ADCP validated hydrodynamic model of this system, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream site.

The main Estuaries Project efforts will be to (1) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (2) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (3) collect benthic cores and determine summer nitrogen regeneration rates; (4) collect a dissolved oxygen record to support the habitat assessment; (5) map eelgrass distribution and create historic record; (6) collect benthic infaunal distribution and indicator data; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

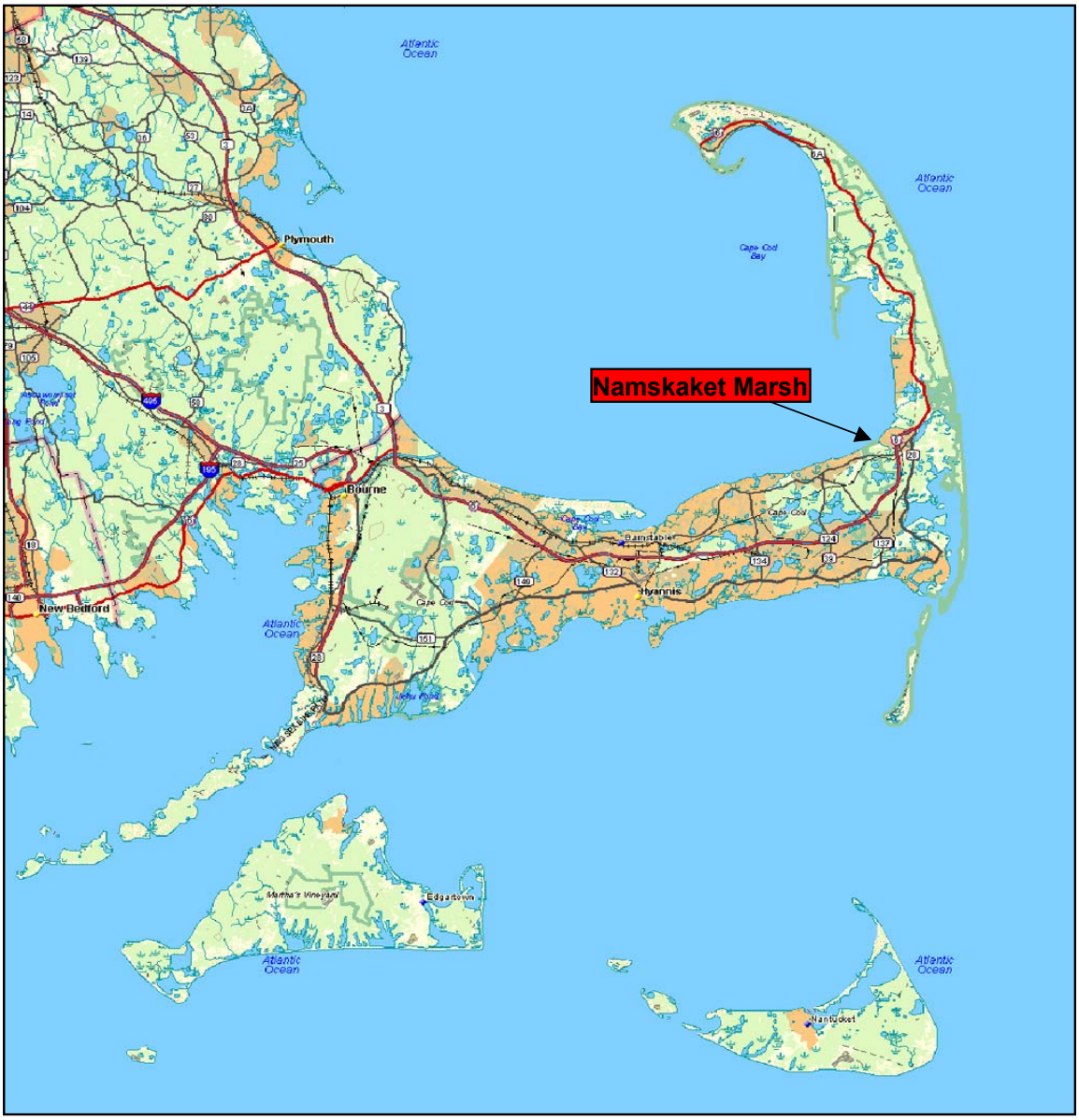
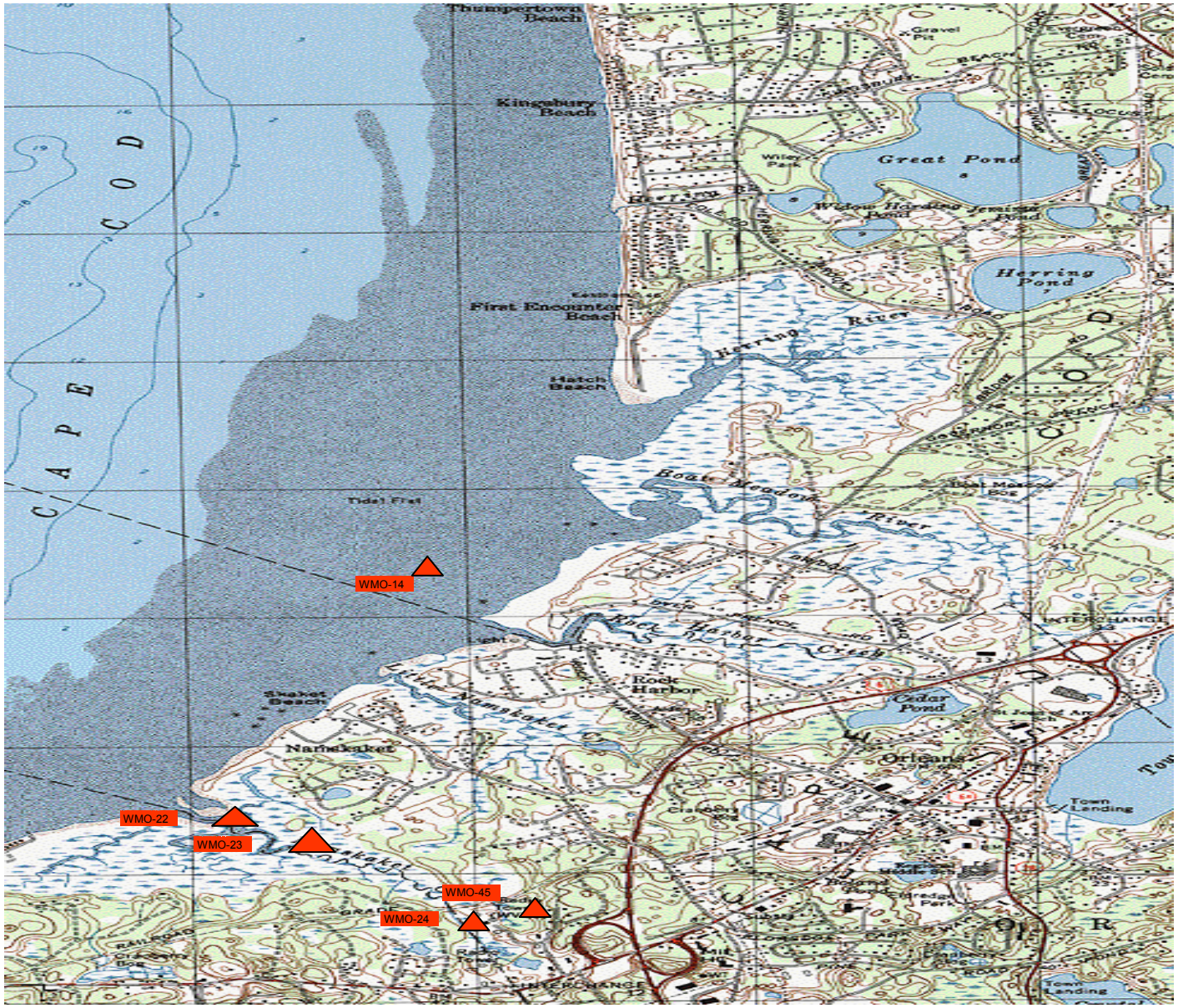
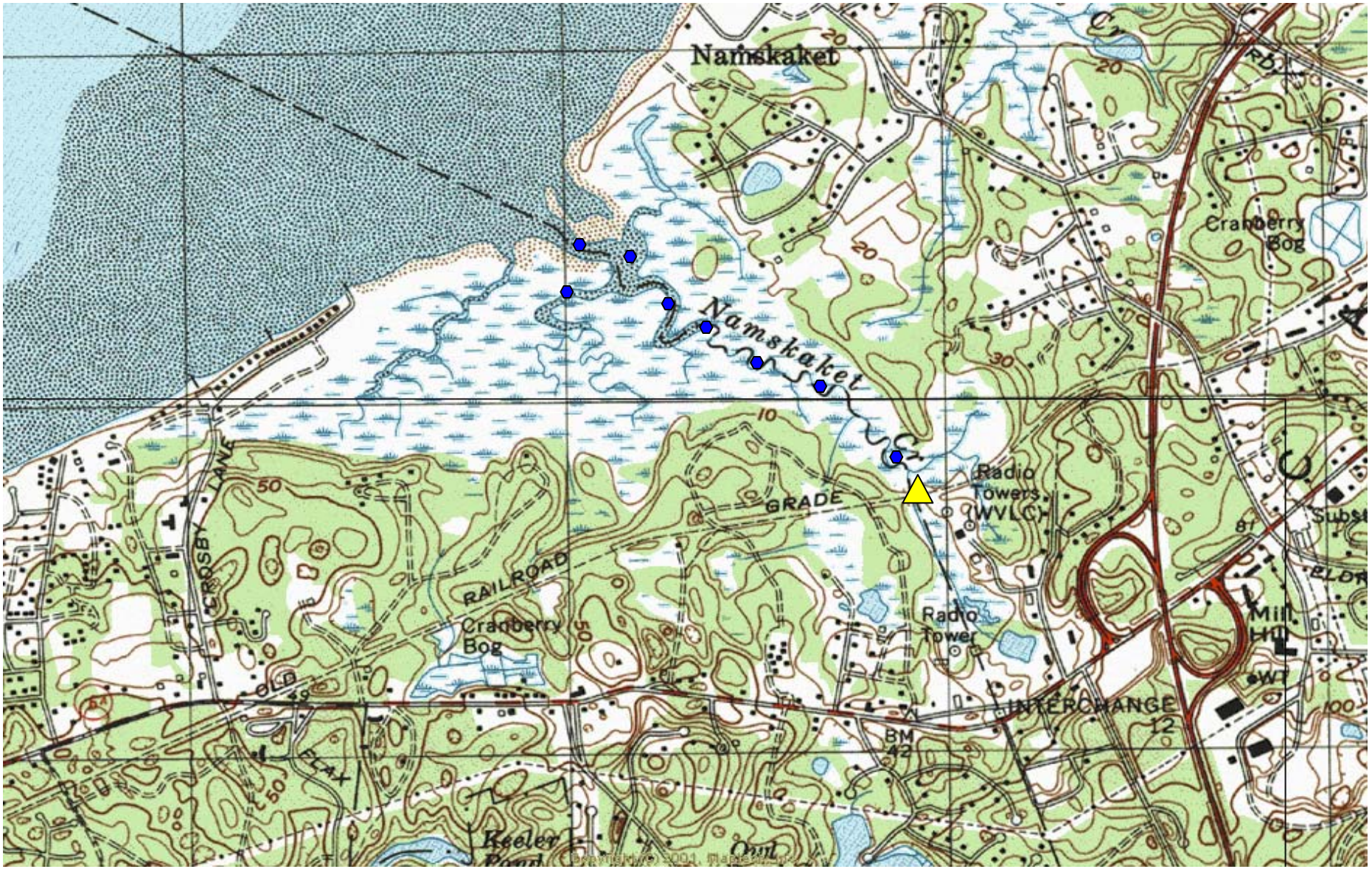

Namskaket Marsh
Atlantic Ocean
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Cape Cod Bay
Martha's Vineyard
Edgartown
Nantucket

Figure 1



▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3

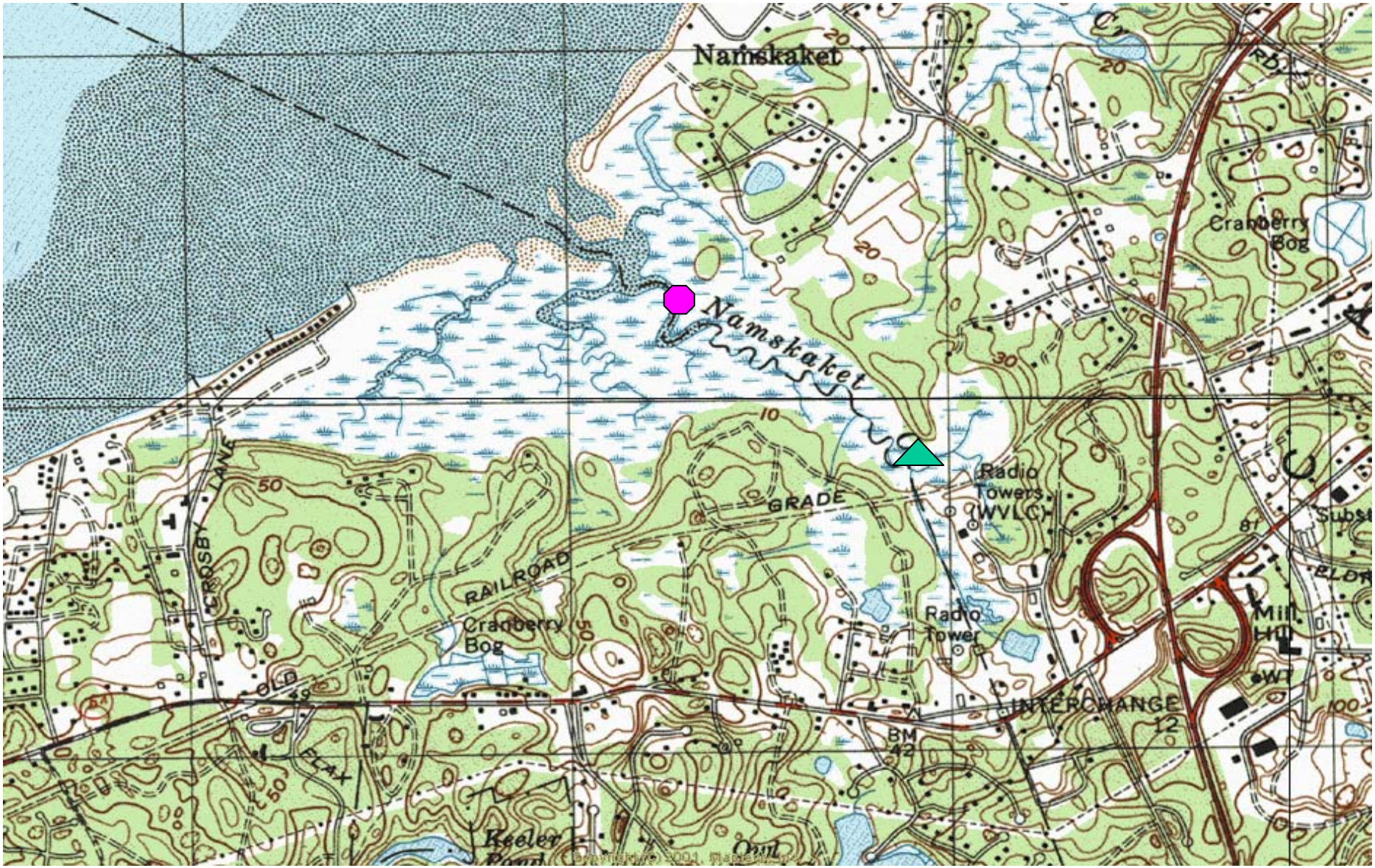

Namskaket
Namskaket
Cranberry Bog
Radio Towers WVLCH
GRADE
RAILROAD
CROSBY LANE
Cranberry Bog
Radio Tower
Mill Hill
INTERCHANGE 12
BM 42
OLD
Keeler Pond
Tide Gauge Location
ADCP
Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Namskaket Marsh (21)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	8	Once/Embayment	8	0 *****	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	1**	15 minutes ****	> 2880	9 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	4	Once/Embayment	4	8	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
***** Cores will be collected in both Namskaket and Little Namskaket Systems on same day therefore QC sample listed in table for Little Namskaket Marsh
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXII Little Namskaket Marsh
Town of Orleans
Prioritization Rank: Round 2 - #22

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Little Namskaket Marsh, Orleans:
This estuary consists primarily of a salt marsh system exchanging water with Cape Cod Bay through a single main tidal channel. This system may potentially receive nutrient enriched groundwater discharges originating from the Tri-Town Septage Treatment Facility. The existing plume is being tracked by USGS.

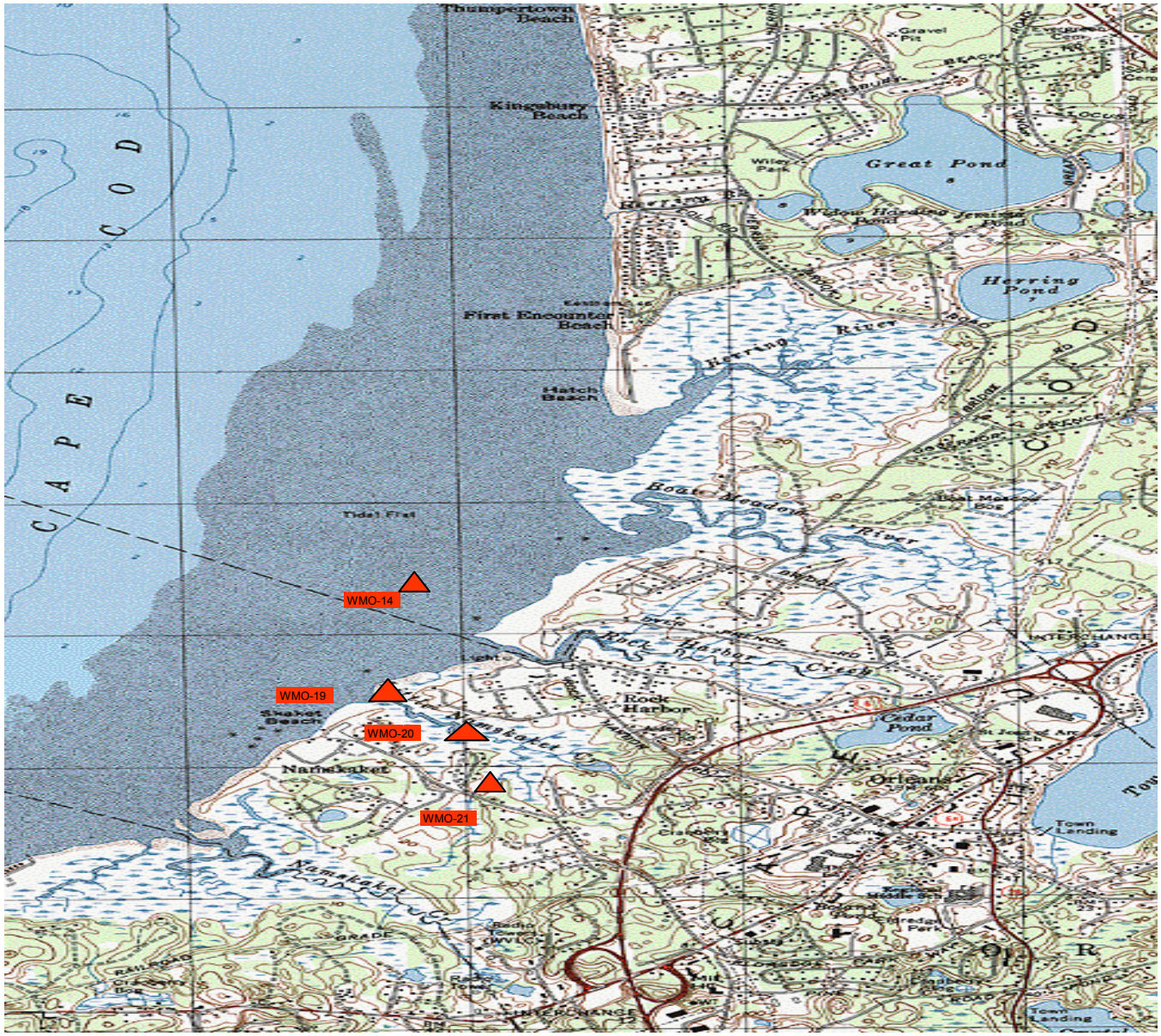
Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Town of Orleans Water Quality Monitoring Program. This program uses both technical staff and volunteers to perform the sampling. There are also water quality data collected by the Town of Orleans from lakes which may be in the watershed (awaiting USGS completion of delineations). These data were collected under an approved QAPP with chemical assays primarily by the NPS Laboratory, with some checks by the SMAST Analytical Facility.

There are some existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and an ADCP validated hydrodynamic model of this system, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream site.

The main Estuaries Project efforts will be to (1) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (2) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (3) collect benthic cores and determine summer nitrogen regeneration rates; (4) collect a dissolved oxygen record to support the habitat assessment; (5) map eelgrass distribution and create historic record; (6) collect benthic infaunal distribution and indicator data; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

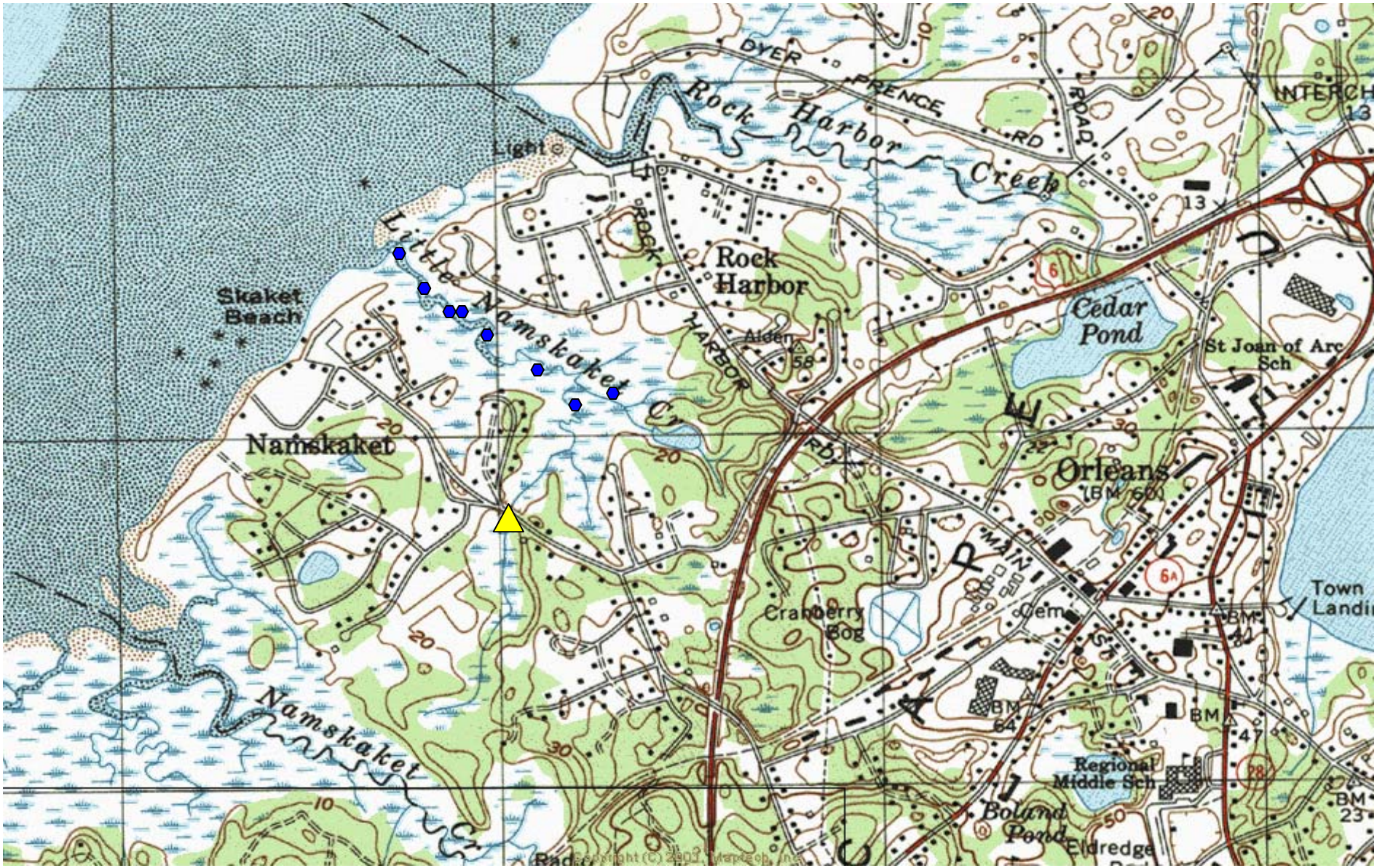

Little Namskaket Marsh
Atlantic Ocean
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Edgartown
Nantucket

Figure 1



Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling Location

Figure 3

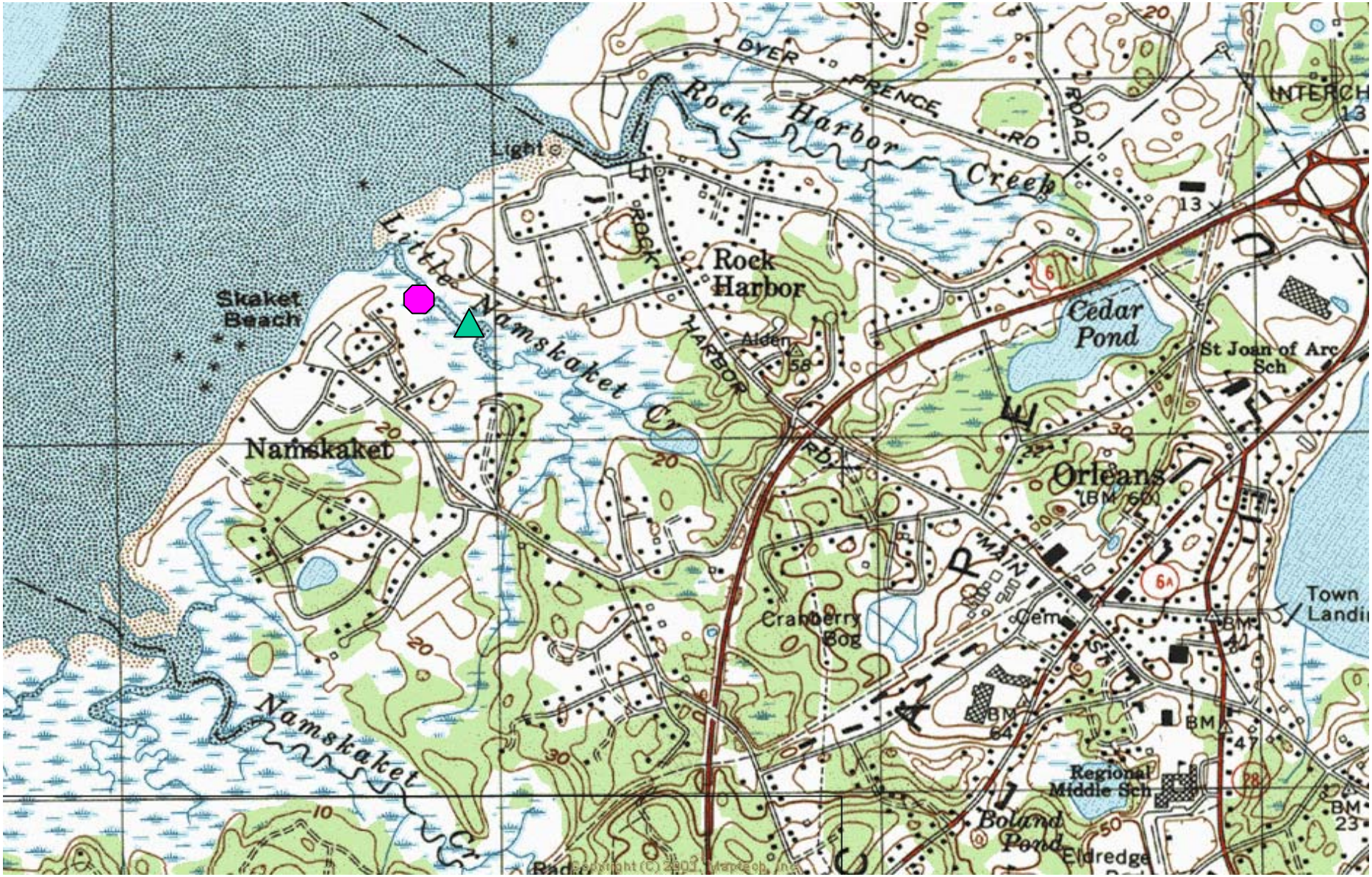

Rock Harbor Creek
Rock Harbor
Little Namskaket Cr
Namskaket
Namskaket Cr
Skaket Beach
Cedar Pond
Orleans
Cranberry Bog
Bound Pond
Eldredge
St Joan of Arc Sch
Regional Middle Sch
Town Landi
DYER
PRENCE
RD
ROAD
MAIN
ROCK
HARBOR
Light
Alden
58
13
6
6A
28
BM
64
47
23
Cem
Tide Gauge
ADCP
Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Little Namskaket Marsh (22)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	7	Once/Embayment	7	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	1**	15 minutes ****	> 2880	9 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	4	Once/Embayment	4	4	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXIII Rock Harbor
Town of Orleans
Prioritization Rank: Round 2 - #23

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Rock Harbor, Orleans: This estuary consists primarily of a salt marsh system, with a man-made harbor in its lower reach, exchanging water with Cape Cod Bay through a single main tidal channel. The Harbor is fully populated with boat slips and moorings.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Town of Orleans Water Quality Monitoring Program. This program uses both technical staff and volunteers to perform the sampling. There are also water quality data collected by the Town of Orleans from lakes within the watershed. These data were collected under an approved QAPP with chemical assays primarily by the NPS Laboratory, with some checks by the SMAST Analytical Facility.

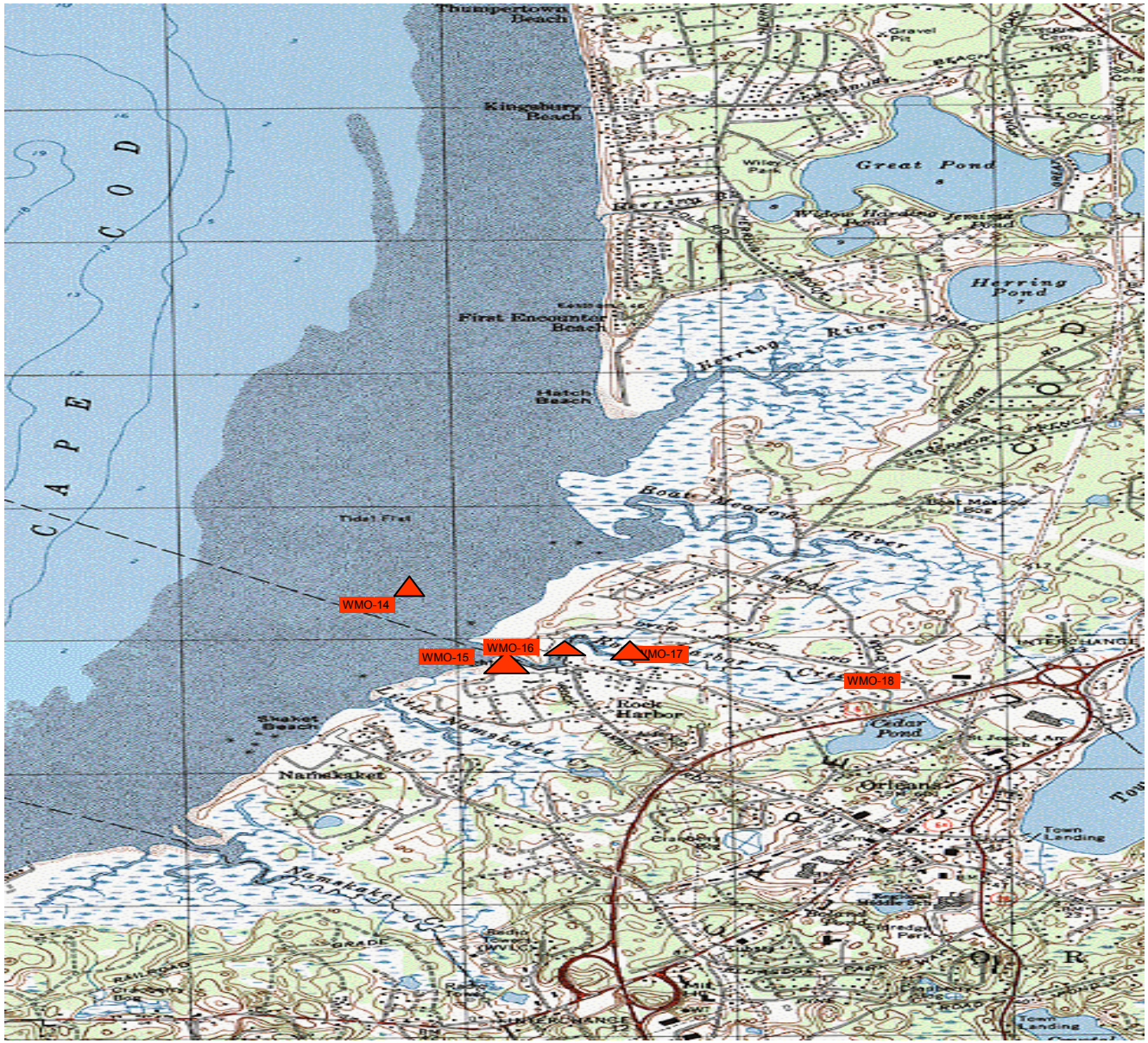
There are some existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed

by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and an ADCP validated hydrodynamic model of this system, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream site.

The main Estuaries Project efforts will be to (1) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (2) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (3) collect benthic cores and determine summer nitrogen regeneration rates; (4) collect a dissolved oxygen record to support the habitat assessment; (5) map eelgrass distribution and create historic record; (6) collect benthic infaunal distribution and indicator data; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

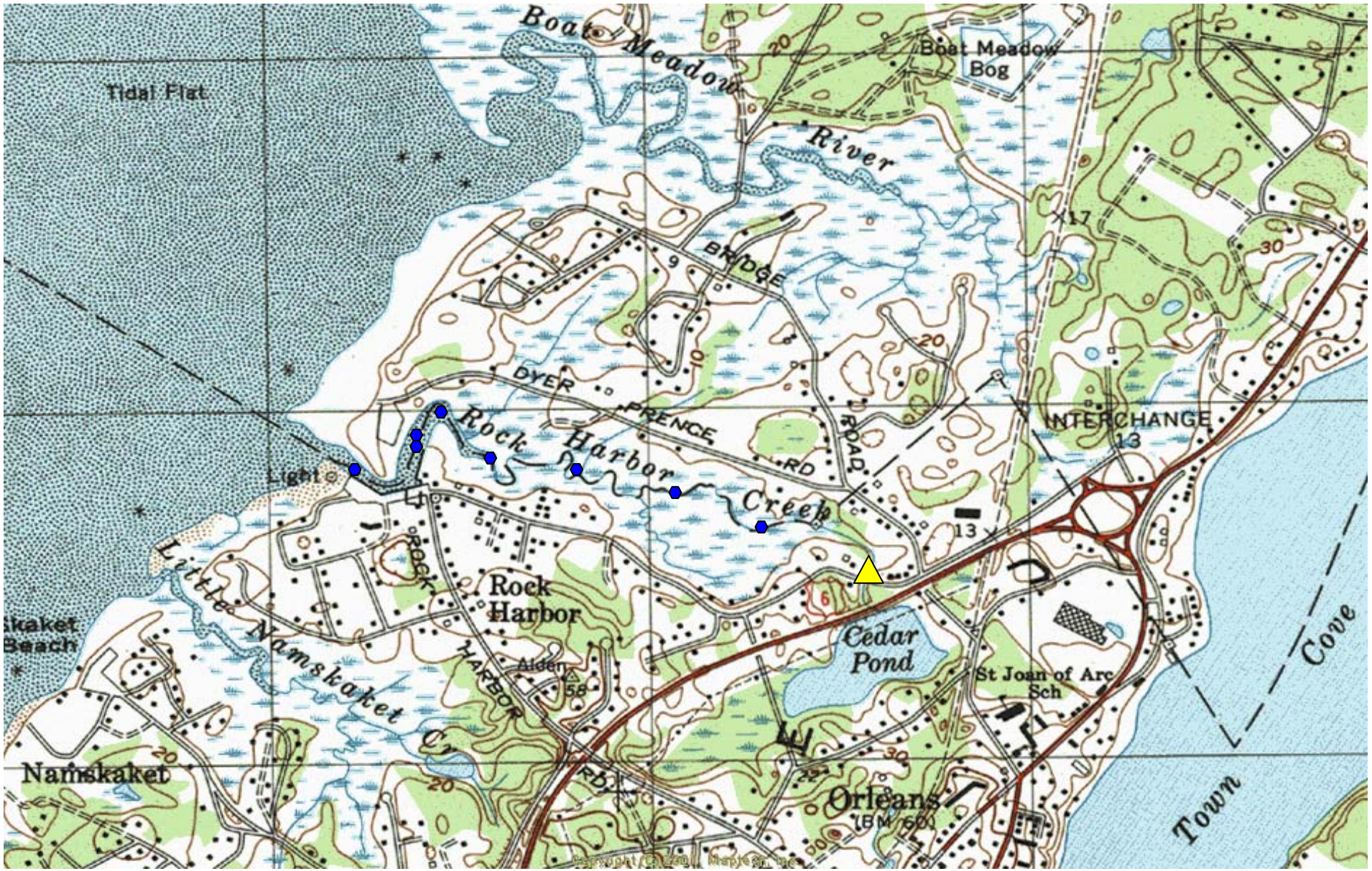

Rock Harbor
Plymouth
Bourne
Hyannis
New Bedford
Atlantic Ocean

Figure 1



▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge Location — ADCP Transects — Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Rock Harbor (23)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	7	Once/Embayment	7	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	1**	15 minutes ****	> 2880	9 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	4	Once/Embayment	4	4	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXIV Nauset Marsh
Town of Orleans
Prioritization Rank: Round 2 - #24

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Nauset Marsh, Orleans: This estuary consists primarily of a salt marsh system (upper half) coupled to a large lagoon, Town Cove (lower half). Both sub-systems exchange tidal waters with the Atlantic Ocean through a single inlet, Nauset Inlet. This system supports significant shellfish resources. The Nauset System experienced a large red-tide bloom during the summer of 2002. The Estuaries Project is collaborating with a group from WHOI who are planning a system-wide assessment of red-tide during the project period.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Town of Orleans Water Quality Monitoring Program. This program uses both technical staff and volunteers to perform the sampling. There are also water quality data collected by the Town of Orleans from lakes potentially within the watershed (awaiting USGS delineations). These data were collected under an approved QAPP with chemical assays primarily by the NPS Laboratory, with some checks by the SMAST Analytical Facility.

There are historical data which have been assembled by the Estuaries Project which directly relate to the Linked Modeling effort: (1) Town Cove Study (Teal et al. 1983), (2) preliminary land-use analysis by the Cape Cod Commission (2000), (3) tidal circulation modeling by WHOI, 1997 (data not usable due to lack of offshore system driving gauge), (4) denitrification measurements in nearshore of upper system (Nowicki et al.).

There are some existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and an ADCP validated hydrodynamic model of this system, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream site.

The main Estuaries Project efforts will be to (1) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (2) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (3) collect benthic cores and determine summer nitrogen regeneration rates; (4) collect a dissolved oxygen record to support the habitat assessment; (5) map eelgrass distribution and create historic record; (6) collect benthic infaunal distribution and indicator data; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

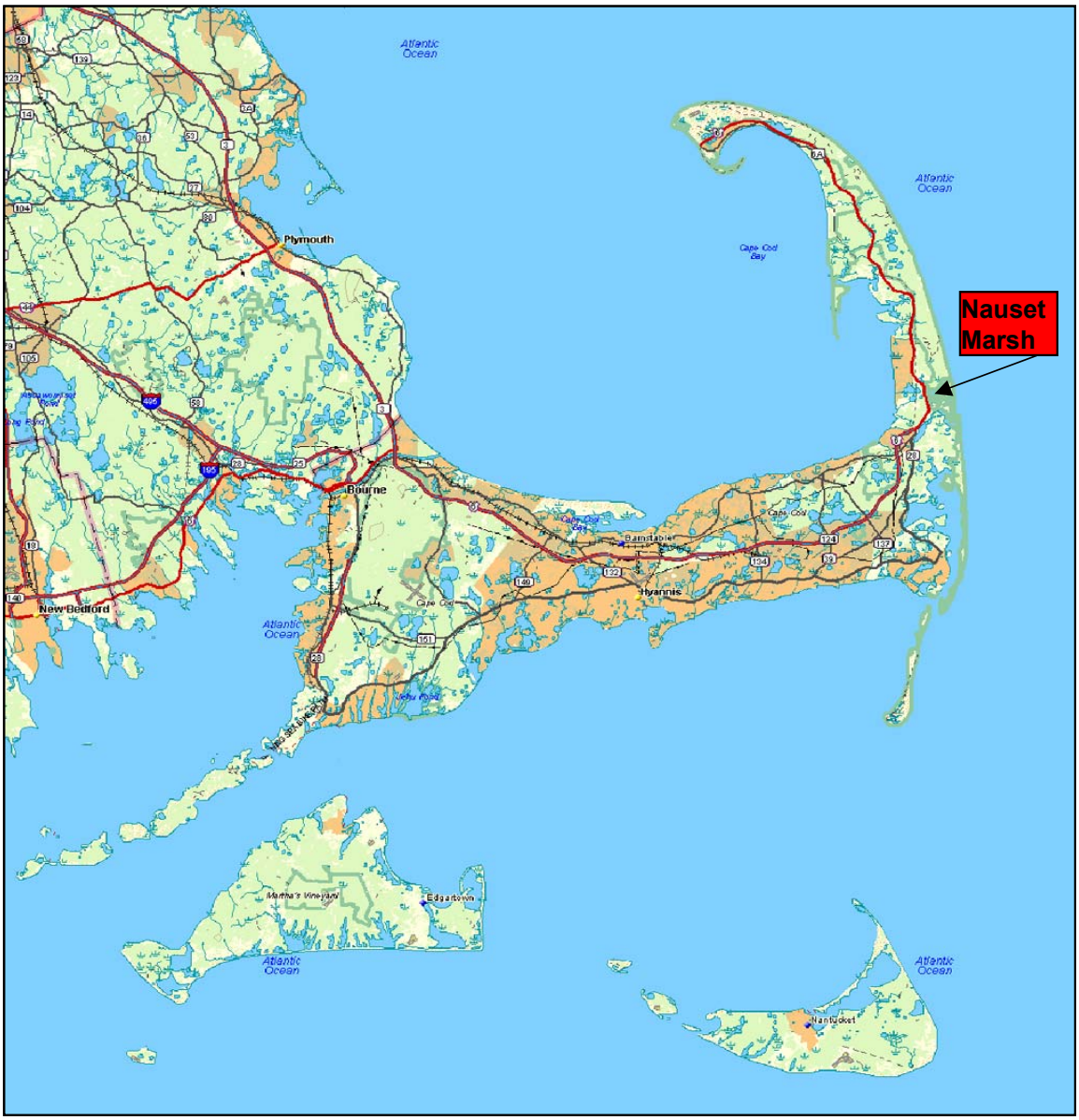
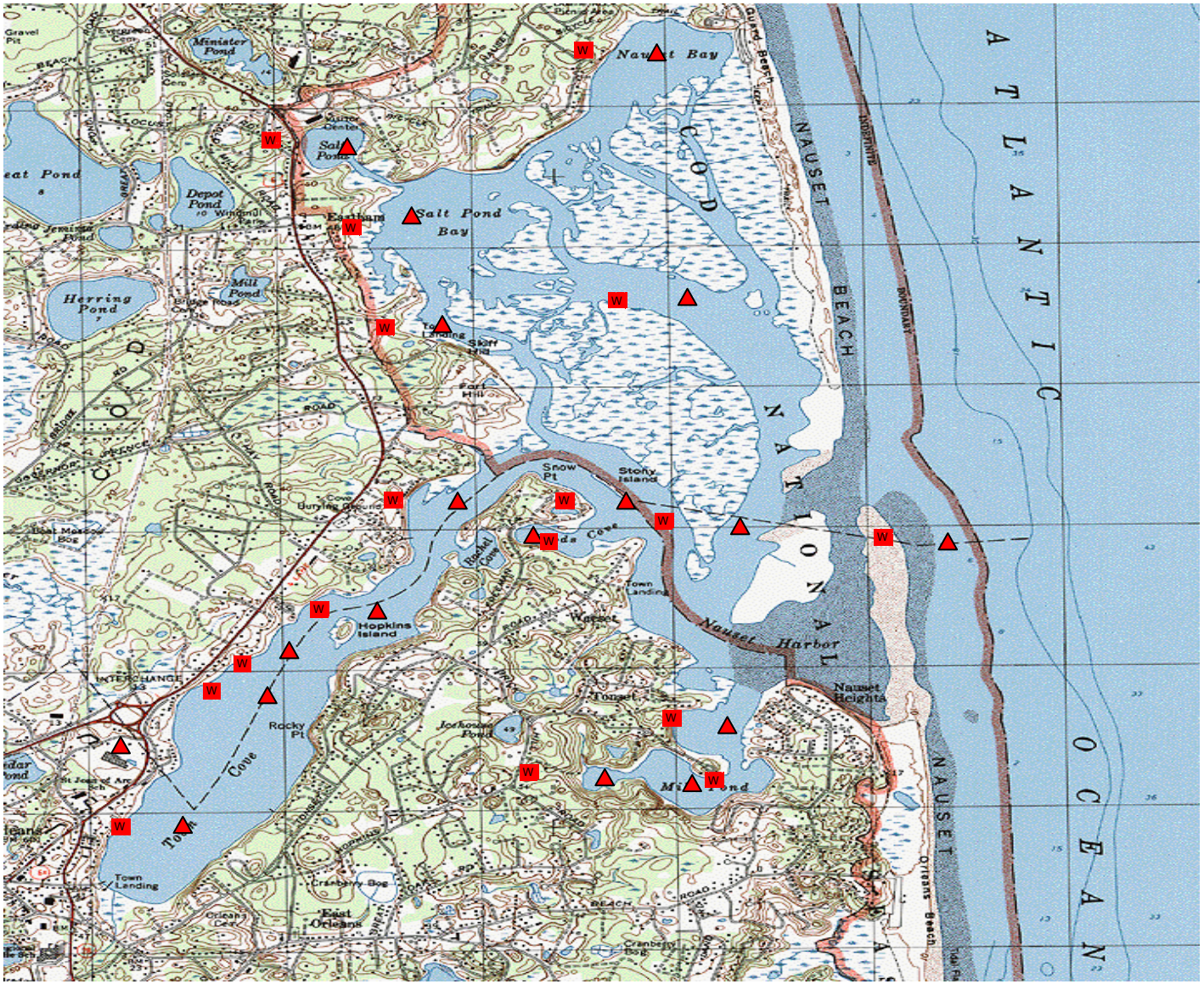
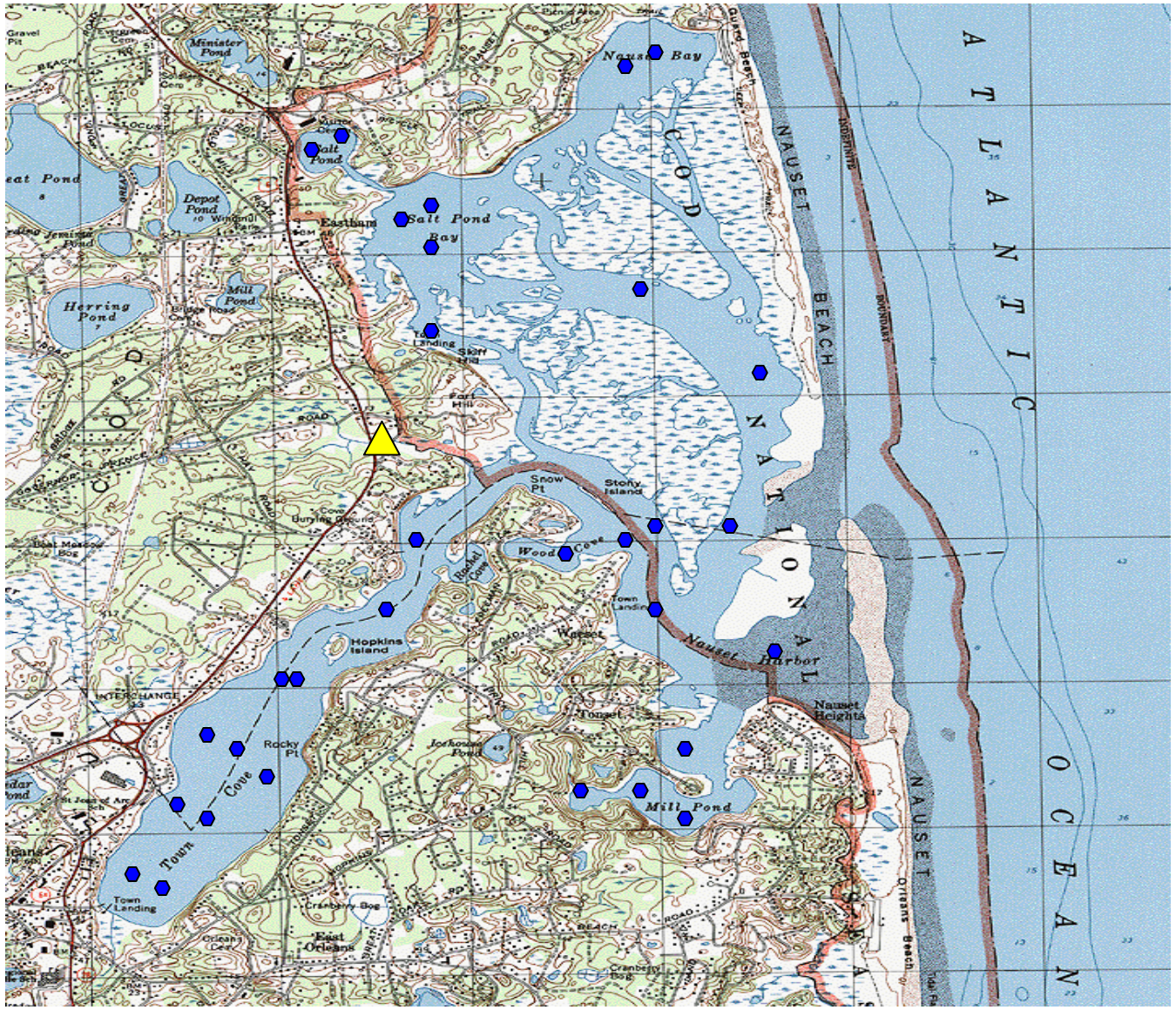

Nauset Marsh
Atlantic Ocean
Cape Cod Bay
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Edgartown
Nantucket

Figure 1

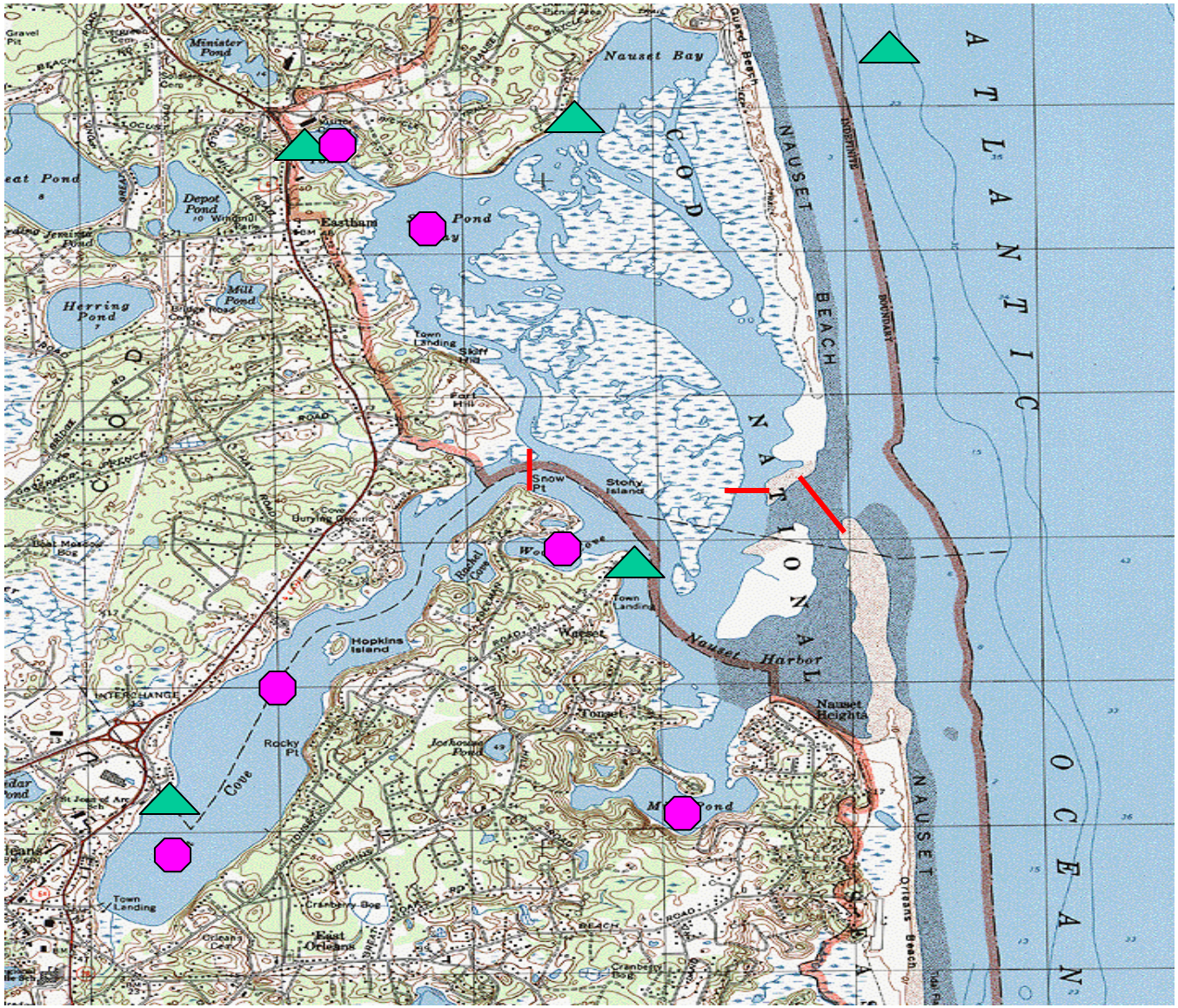


▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling Figure 3



Tide Gauge Location — ADCP — Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Nauset Marsh (24)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	29	Once/Embayment	29	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	6**	15 minutes ****	> 2880	54 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	15	Once/Embayment	15	15	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXV Upper Pleasant Bay
Towns of Orleans/Harwich/Brewster
Prioritization Rank: Round 2 - #25

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Upper Pleasant Bay, Orleans/Harwich/Brewster: This estuary consists of the upper region of Pleasant Bay, the largest enclosed embayment on Cape Cod. The system is primarily open water, although extensive salt marshes exist on the eastern shore. There are 3 terminal drowned kettle ponds which have been the focus of water quality concerns (Arey's, Lonnies, Meetinghouse Ponds). The Pleasant Bay System exchanges water with the Atlantic Ocean through a single main tidal channel within Chatham Harbor. This inlet historically has migrated, with the current inlet being the result of a relatively recent breach.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Town of Orleans Water Quality Monitoring Program. This program uses both technical staff and volunteers to perform the sampling. This water quality data set is integrated with the Pleasant Bay Alliance Monitoring Program data, which was collected under a DEP/EPA approved QAPP. There is also water quality data collected by the Town of

Orleans from lakes within the watershed. These data were collected under an approved QAPP with chemical assays primarily by the NPS Laboratory, with some checks by the SMAST Analytical Facility. The Pleasant Bay Alliance is assisting in the incorporation of historical data into the Estuaries Project Effort.

There are some existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and an ADCP validated hydrodynamic model for the River sub-system and a coarse hydrodynamic model for Upper Pleasant Bay, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream sites.

The main Estuaries Project efforts will be to (1) integrate the tributary embayment hydrodynamic models to a Project upgraded model for the central bay which will require limited placement of tide gauges and conducting ADCP measurements; (2) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (4) collect benthic cores and determine summer nitrogen regeneration rates; (5) collect distributed dissolved oxygen records to support the habitat assessment; (6) map eelgrass distribution and create historic record; (7) collect benthic infaunal distribution and indicator data; and (8) conduct the water quality modeling, thresholds analysis and synthesis.

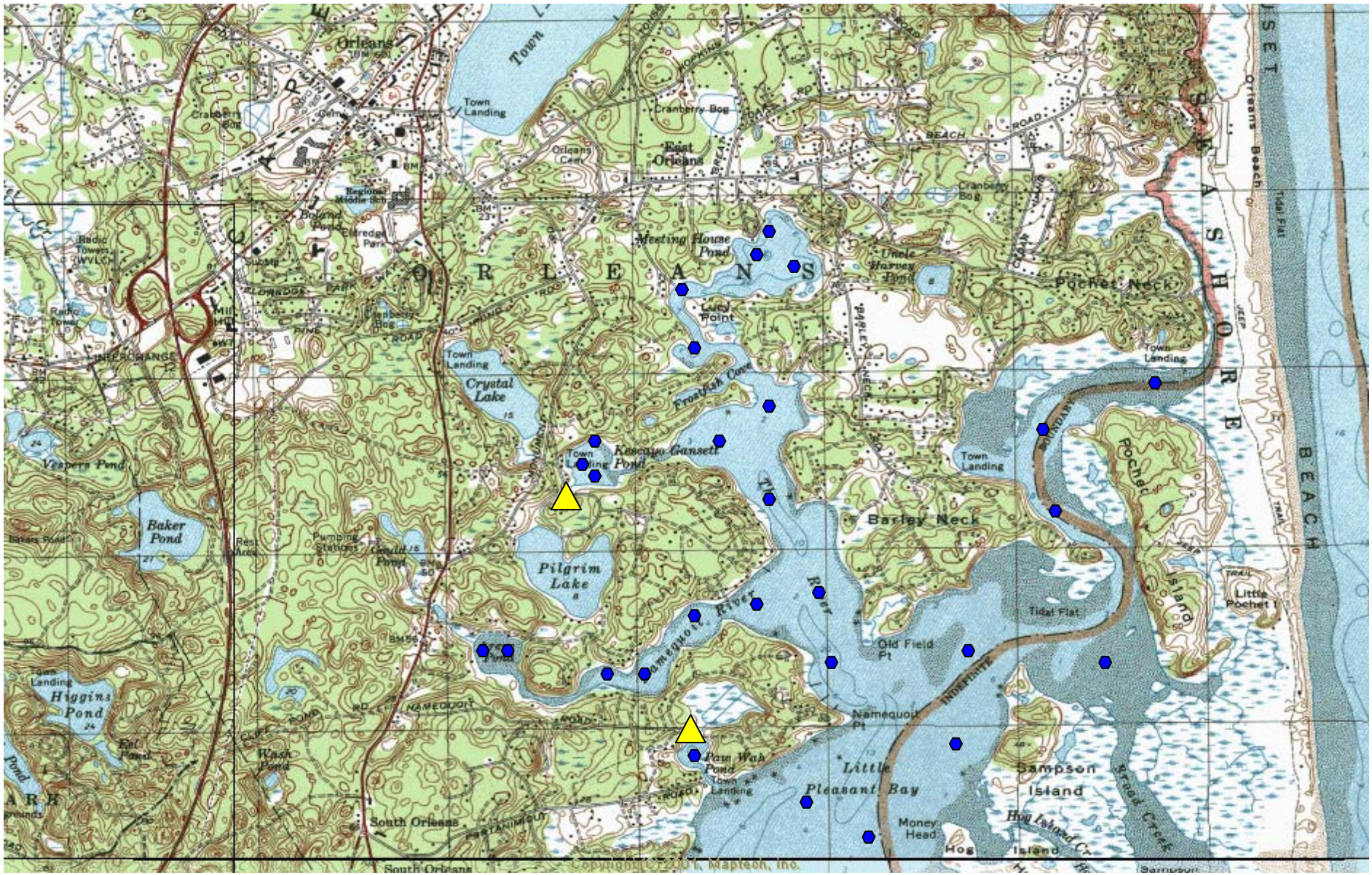

Atlantic Ocean
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Upper Pleasant Bay
Martha's Vineyard
Edgartown
Nantucket

Figure 1



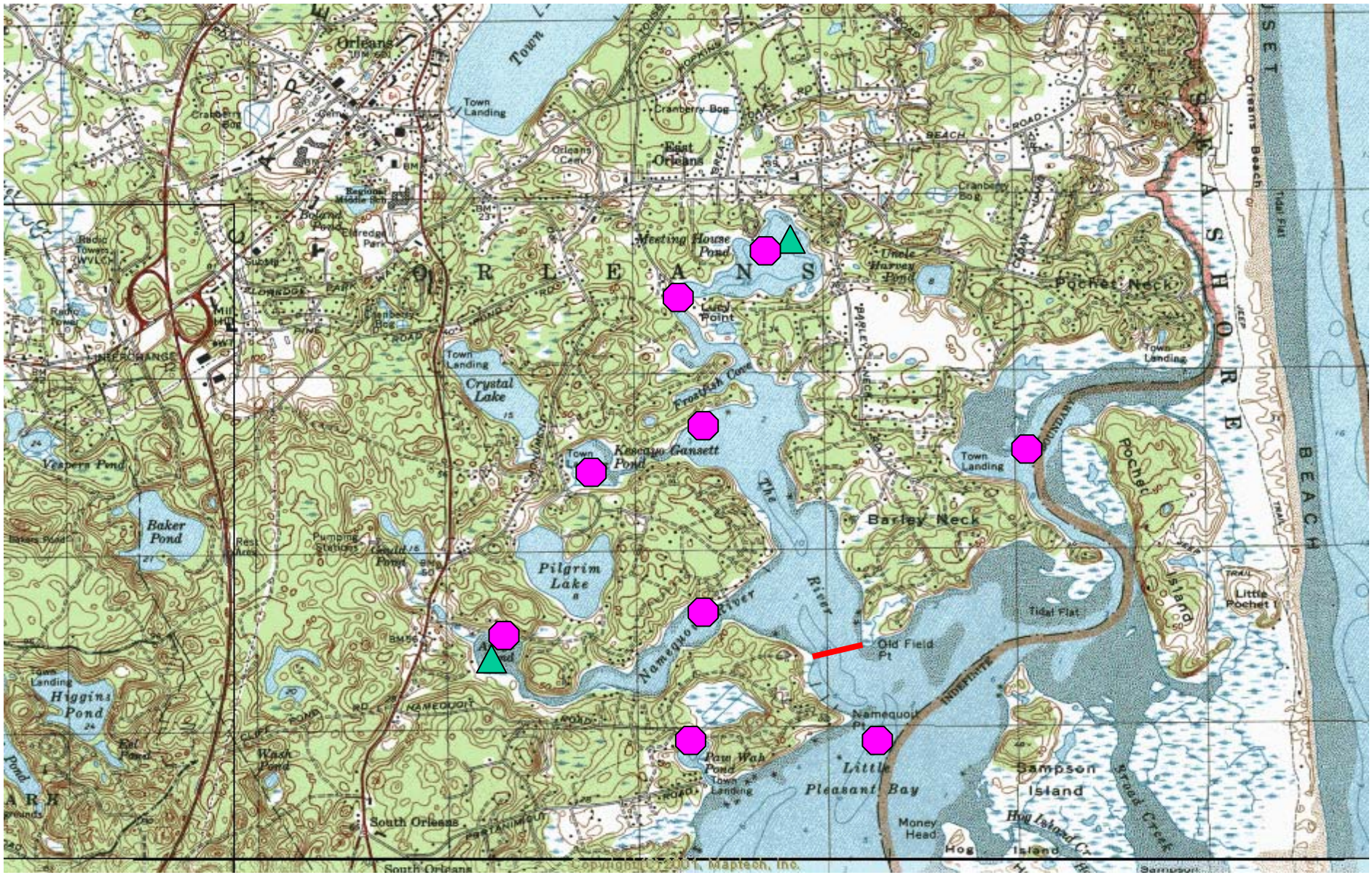
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Pleasant Bay - Upper (25)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	2	Weekly	120	12	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	26	Once/Embayment	26	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	8**	15 minutes****	> 2880	72 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	12	Once/Embayment	12	12	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXVI Lower Pleasant Bay
Town of Orleans
Prioritization Rank: Round 2 - #26

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Lower Pleasant Bay, Orleans/Harwich/Brewster: This estuary consists of the lower region of Pleasant Bay, the largest enclosed embayment on Cape Cod. The system is primarily open water. There are 4 tributary embayments to the central bay, which have been the focus of water quality concerns (Quanset Pond, Round Cove, Muddy Creek, Bassing Harbor). The Pleasant Bay System exchanges water with the Atlantic Ocean through a single main tidal channel within Chatham Harbor. This inlet historically has migrated, with the current inlet being the result of a relatively recent breach.

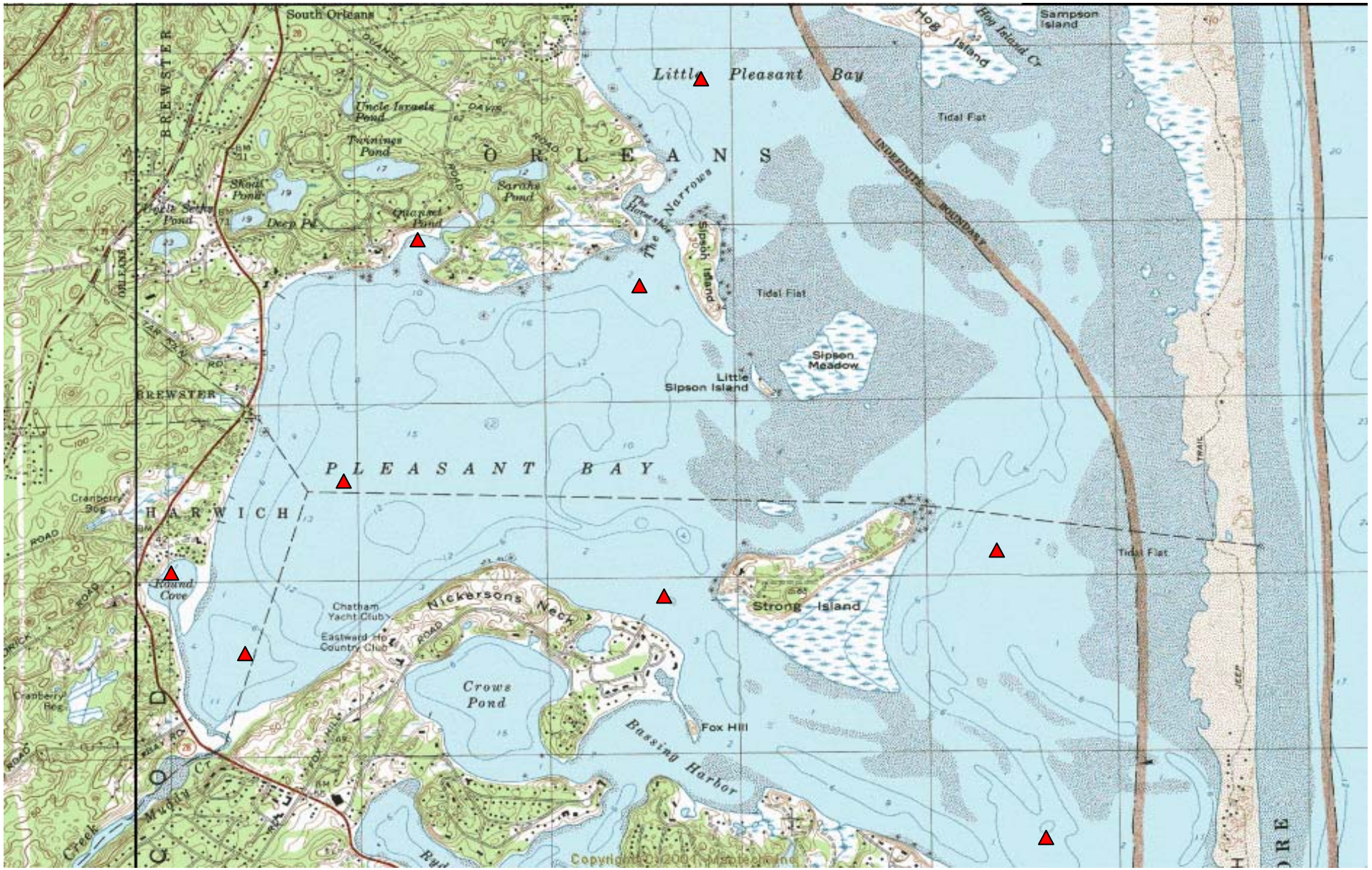
Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed under a DEP/EPA approved QAPP for the Pleasant Bay Alliance. Analyses have been conducted by the SMAST Analytical Facility. This program uses both technical staff and volunteers to perform the sampling. The Pleasant Bay Alliance is assisting in the incorporation of historical data into the Estuaries Project Effort.

There are some existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP. These data were collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) bathymetric and tidal data and a coarse hydrodynamic model for Pleasant Bay, (2) partial record of stream flow and nutrient load at the Estuaries Project proposed stream site, (3) Estuaries Project full analysis for the tributary embayments of Muddy Creek and Bassing Harbor, which will be linked to the Pleasant Bay model.

The main Estuaries Project efforts will be to (1) up-grade the current hydrodynamic model for the central bay which will require limited placement of tide gauges and conducting ADCP measurements; (2) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect stream flow/nitrogen load data to complete the requisite 14 months (building on the existing dataset); (4) collect benthic cores and determine summer nitrogen regeneration rates; (5) collect distributed dissolved oxygen records to support the habitat assessment; (6) map eelgrass distribution and create historic record; (7) collect benthic infaunal distribution and indicator data; and (8) conduct the water quality modeling, thresholds analysis and synthesis.

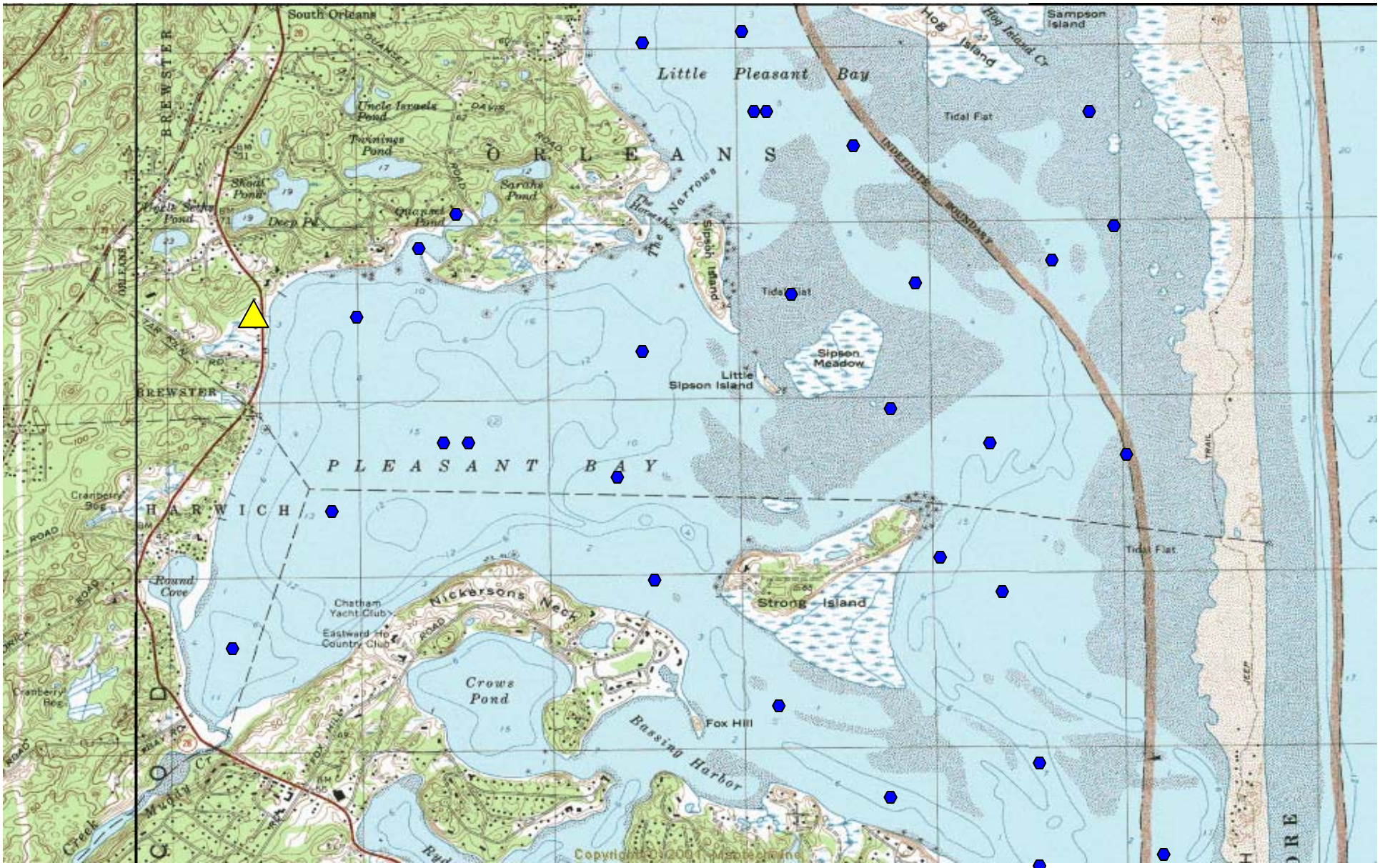

Atlantic Ocean
Plymouth
Cape Cod Bay
Atlantic Ocean
Bourne
Barnstable
Hyannis
New Bedford
Atlantic Ocean
Lower Pleasant Bay
Martha's Vineyard
Edgartown
Atlantic Ocean
Atlantic Ocean
Nantucket

Figure 1



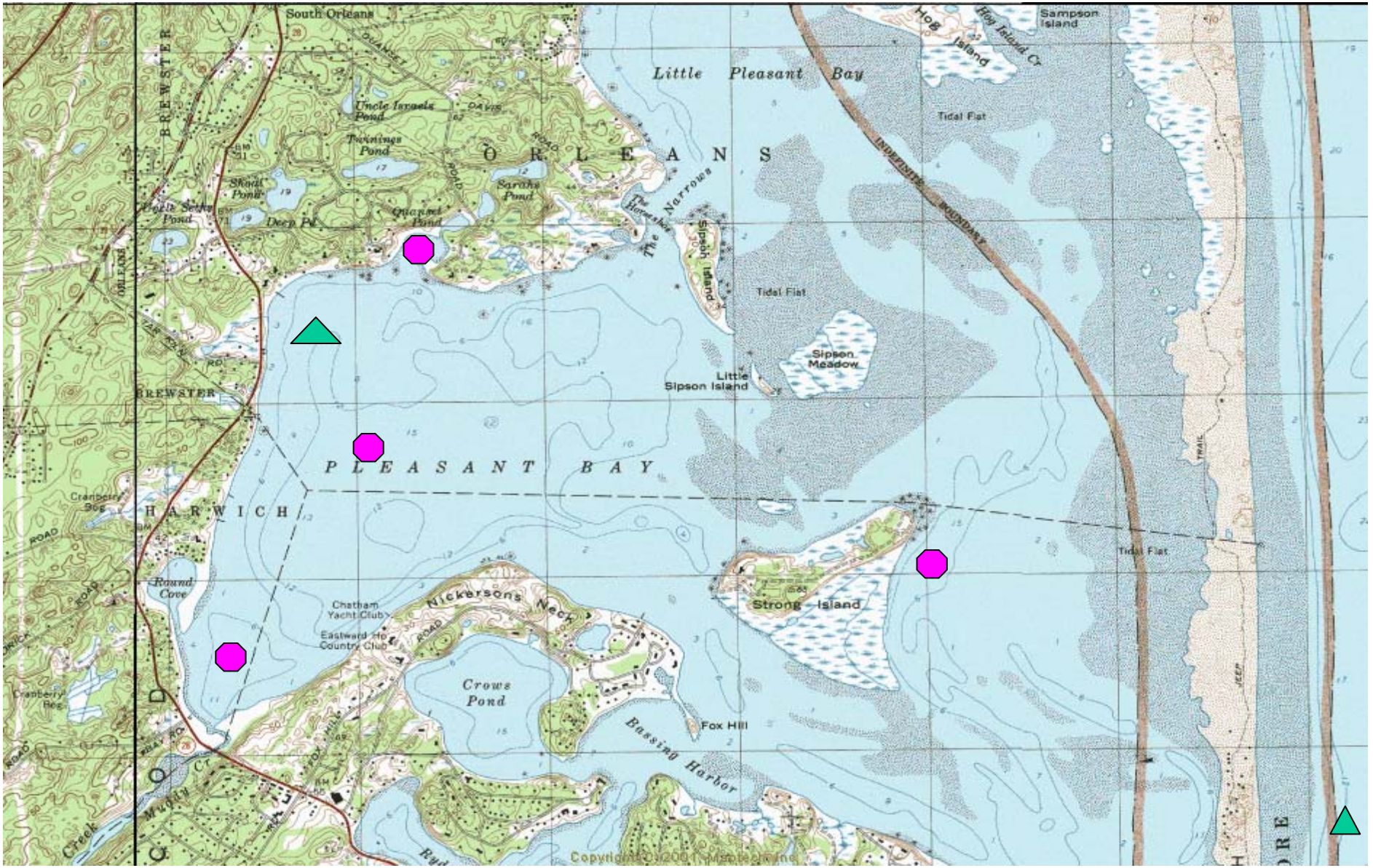
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling Location

Figure 3



Tide Gauge ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Pleasant Bay - Lower (26)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	30	Once/Embayment	30	2	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	4**	15 minutes ****	> 2880	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	12	Once/Embayment	12	12	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXVII Lake Tashmoo
Martha's Vineyard
Prioritization Rank: Round 2 - #27

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Lake Tashmoo, Martha's Vineyard: This estuary consists of a drowned river valley separated from offshore waters by a barrier beach with a maintained tidal inlet. The system is primarily open water with limited fringing salt marsh.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed by the Martha's Vineyard Commission following the Coalition for Buzzards Bay Monitoring QAPP (and may have had its own QAPP as well). Technical design details and analytical aspects of the monitoring program were reviewed by the Coastal Systems Program at SMAST for the MVC. Most of the assays were performed by the SMAST Analytical Facility. This program uses technical staff to perform the sampling. The Martha's Vineyard Commission is a formal partner to the Estuaries Project and is assisting in the incorporation of water quality data and historical data into the Estuaries Project Effort.

At present no existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP have been identified.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based which will require placement of tide gauges and conducting ADCP measurements; (2) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect stream flow/nitrogen load data; (4) collect benthic cores and determine summer nitrogen regeneration rates; (5) collect distributed dissolved oxygen records to support the habitat assessment; (6) map eelgrass distribution and create historic record; (7) collect benthic infaunal distribution and indicator data; and (8) conduct the water quality modeling, thresholds analysis and synthesis.

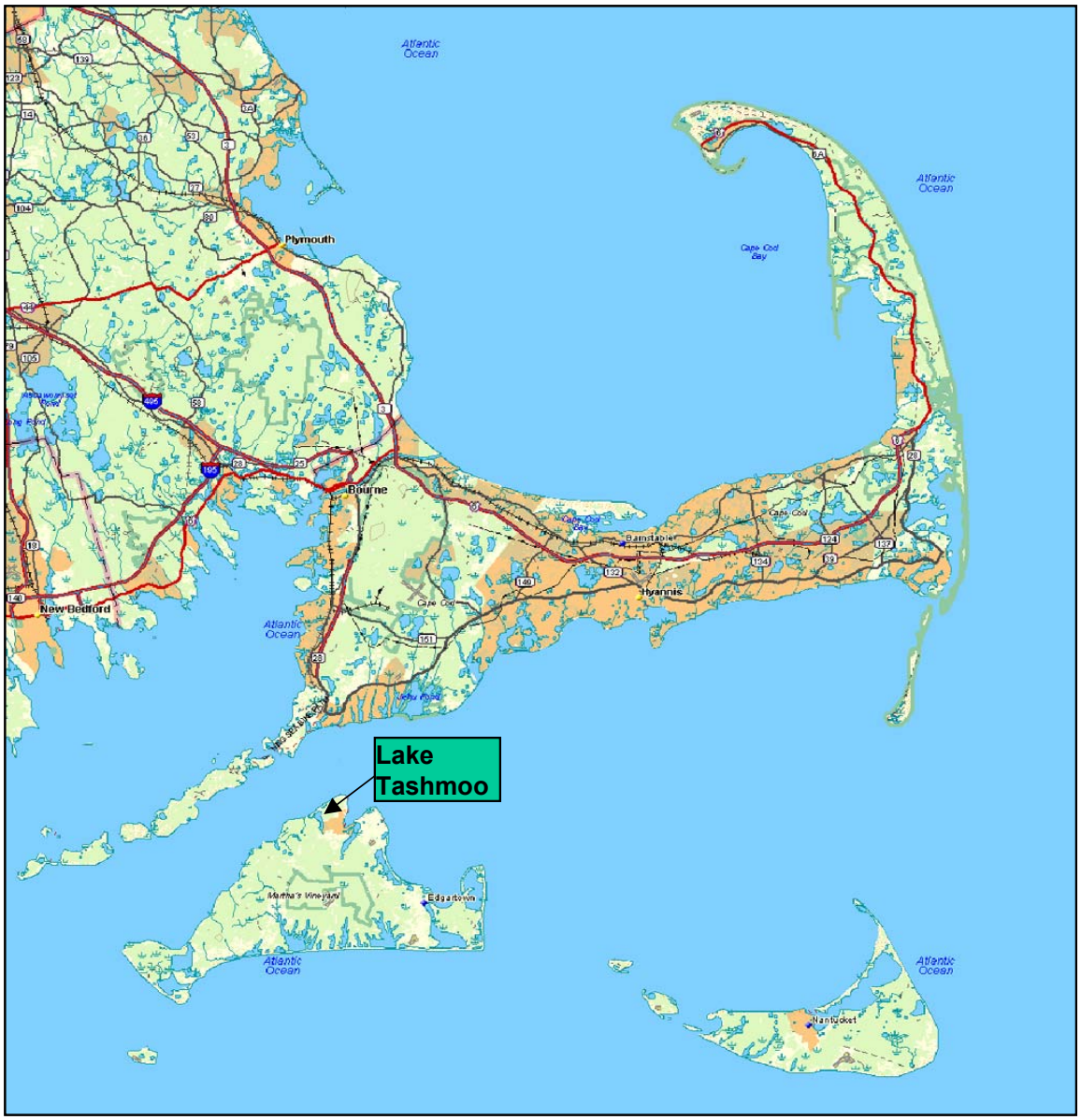
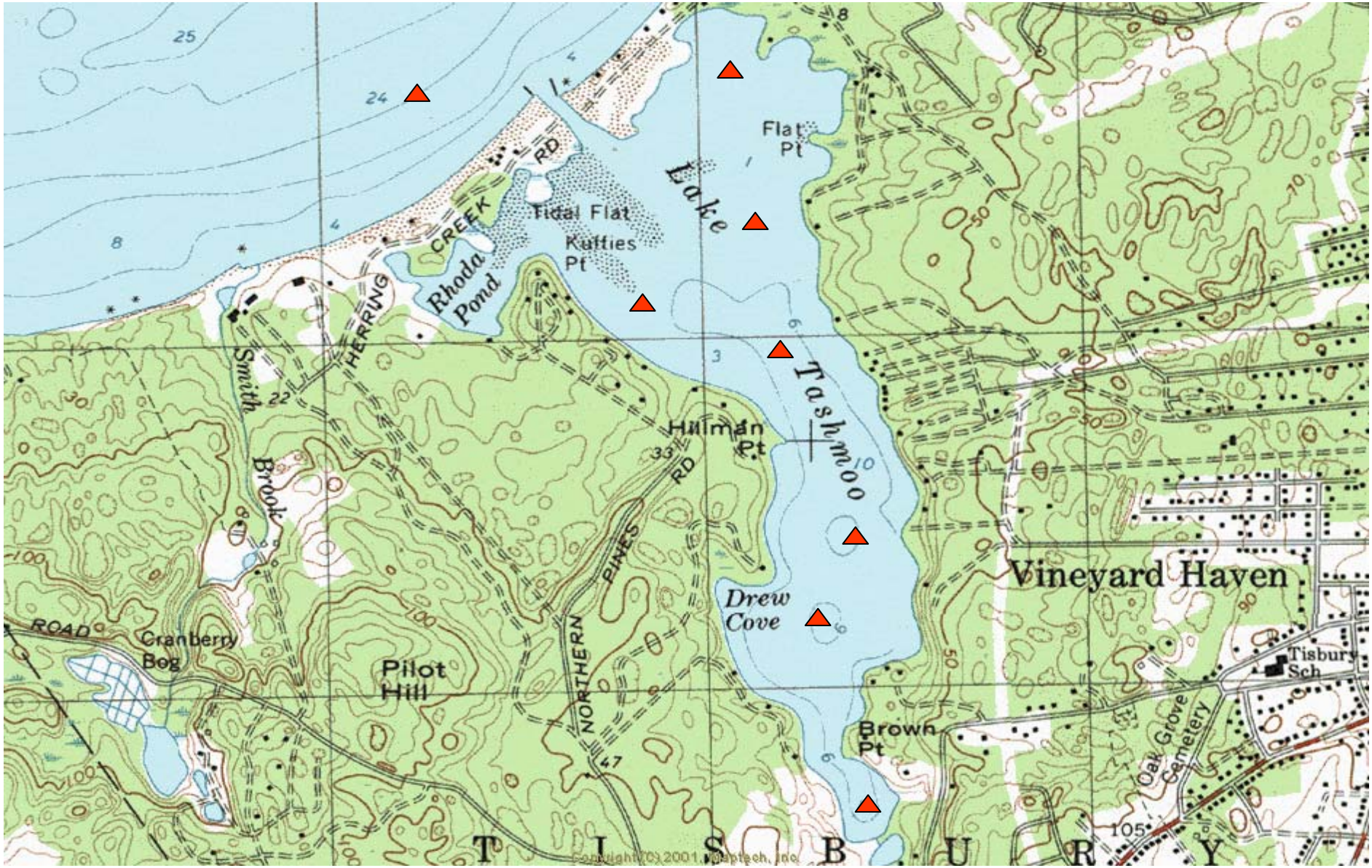
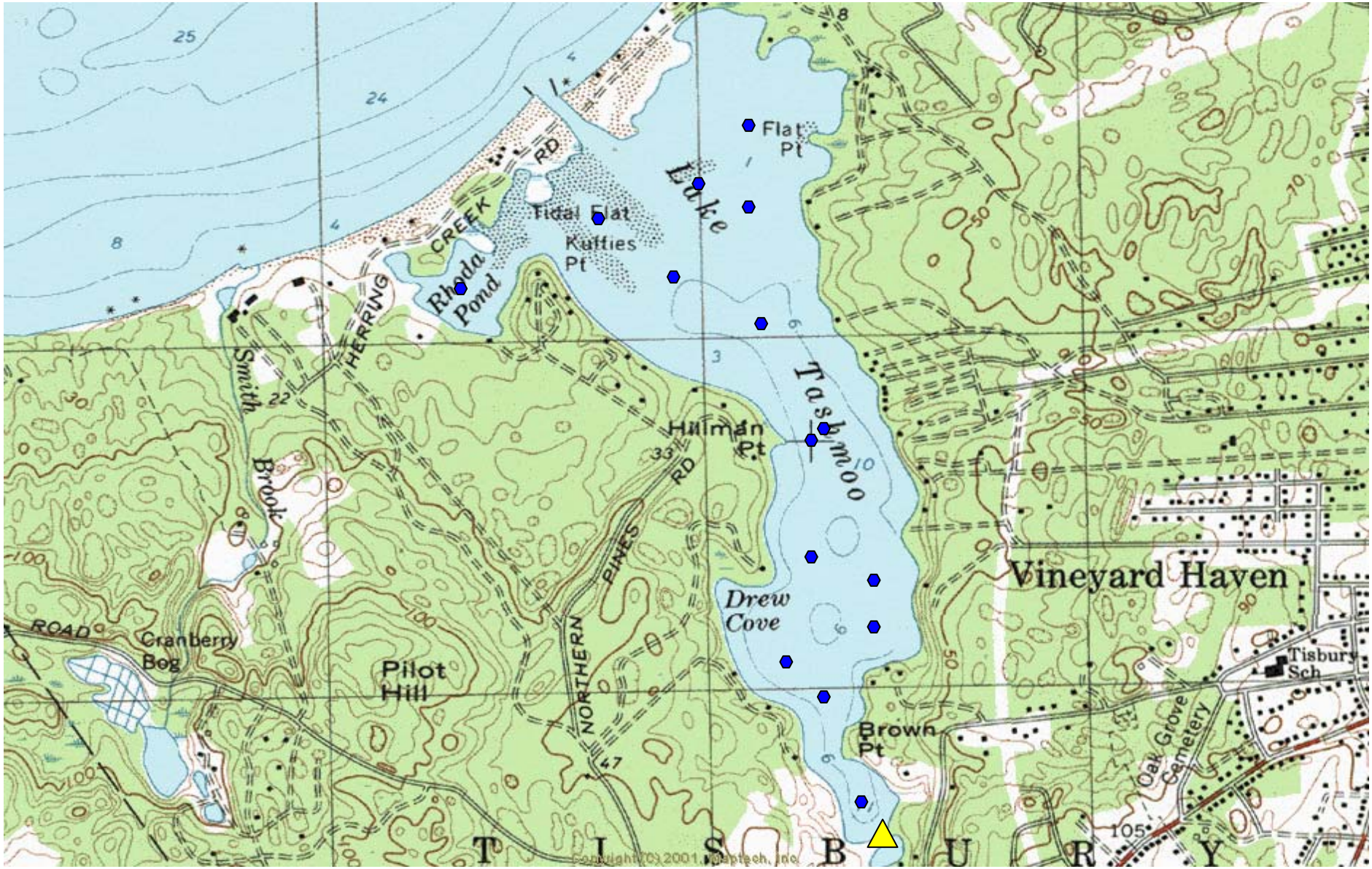

Atlantic Ocean
Plymouth
Cape Cod Bay
Atlantic Ocean
Bourne
Barnstable
Hyannis
New Bedford
Atlantic Ocean
Lake Tashmoo
Edgartown
Atlantic Ocean
Nantucket
Atlantic Ocean

Figure 1



▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3

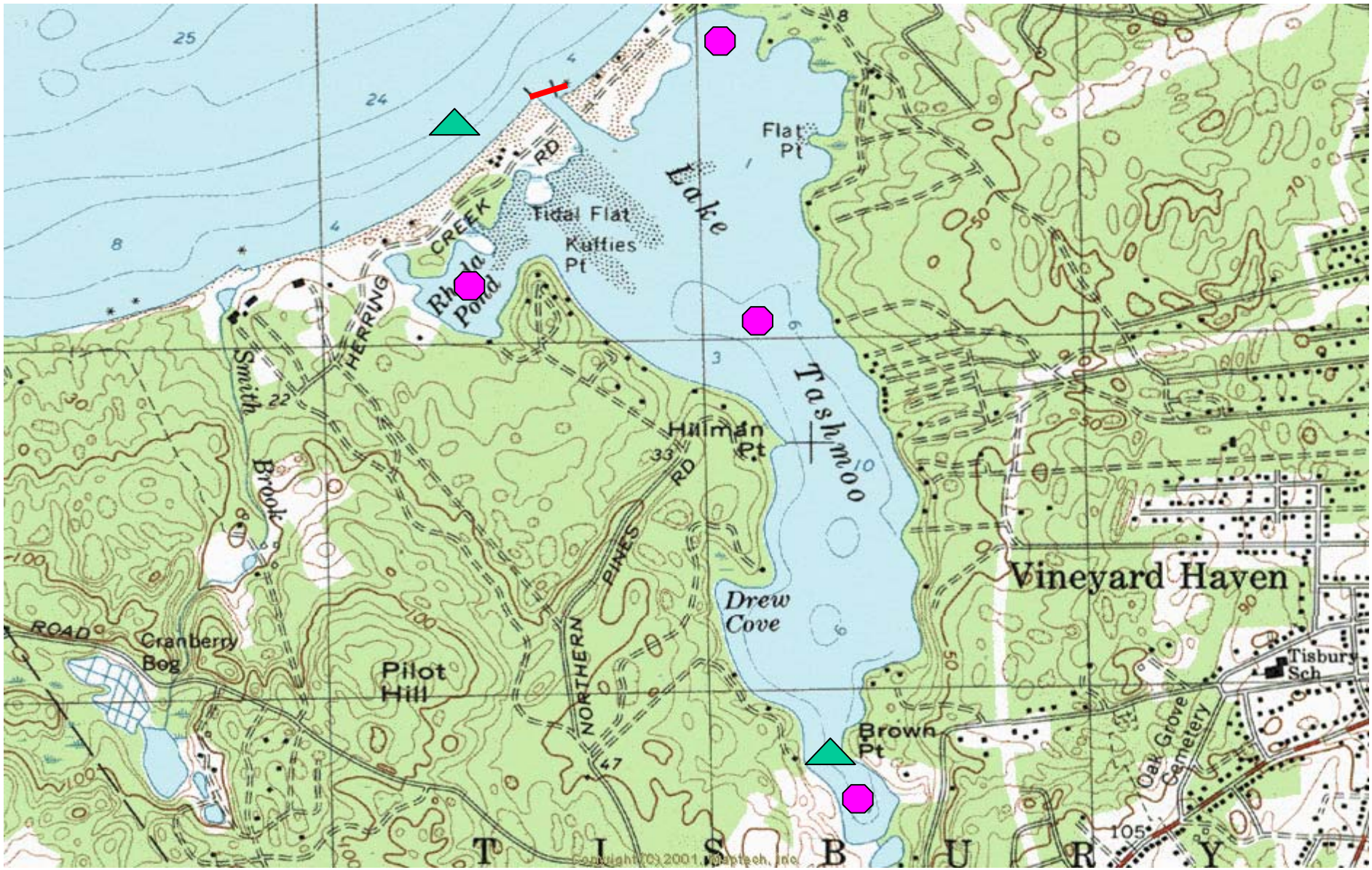

Flat Pt
Lake
Tashmoo
Tidal Flat
Kuffies Pt
Rhoda Pond
CREEK
HERRING
RD
Smith
Brook
Hillman Pt
PINES
NORTHERN
RD
Drew Cove
Vineyard Haven
Tisbury Sch
Oak Grove Cemetery
Brown Pt
Pilot Hill
Cranberry Bog
ROAD
TISBURY
Tide Gauge
ADCP
Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Lake Tashmoo (27)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	14	Once/Embayment	14	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	3**	15 minutes ****	> 2880	27 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	9	Once/Embayment	9	9	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXVIII Lagoon Pond
Martha's Vineyard
Prioritization Rank: Round 2 - #28

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Lagoon Pond, Martha's Vineyard: This estuary consists of a drowned river valley separated from Vineyard Haven Harbor by a causeway with a single maintained tidal inlet. The system is primarily open water with limited fringing salt marsh.

Only limited Estuaries Project data exist for this estuary. However, high quality water quality monitoring data exists which was collected and analyzed by the Martha's Vineyard Commission following the Coalition for Buzzards Bay Monitoring QAPP (and may have had its own QAPP as well). Technical design details and analytical aspects of the monitoring program were reviewed by the Coastal Systems Program at SMAST for the MVC. Most of the assays were performed by the SMAST Analytical Facility. This program uses technical staff to perform the sampling. The Martha's Vineyard Commission is a formal partner to the Estuaries Project and is assisting in the incorporation of water quality data and historical data into the Estuaries Project Effort.

At present no existing data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP have been identified.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based which will require placement of tide gauges and conducting ADCP measurements; (2) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect stream flow/nitrogen load data; (4) collect benthic cores and determine summer nitrogen regeneration rates; (5) collect distributed dissolved oxygen records to support the habitat assessment; (6) map eelgrass distribution and create historic record; (7) collect benthic infaunal distribution and indicator data; and (8) conduct the water quality modeling, thresholds analysis and synthesis.

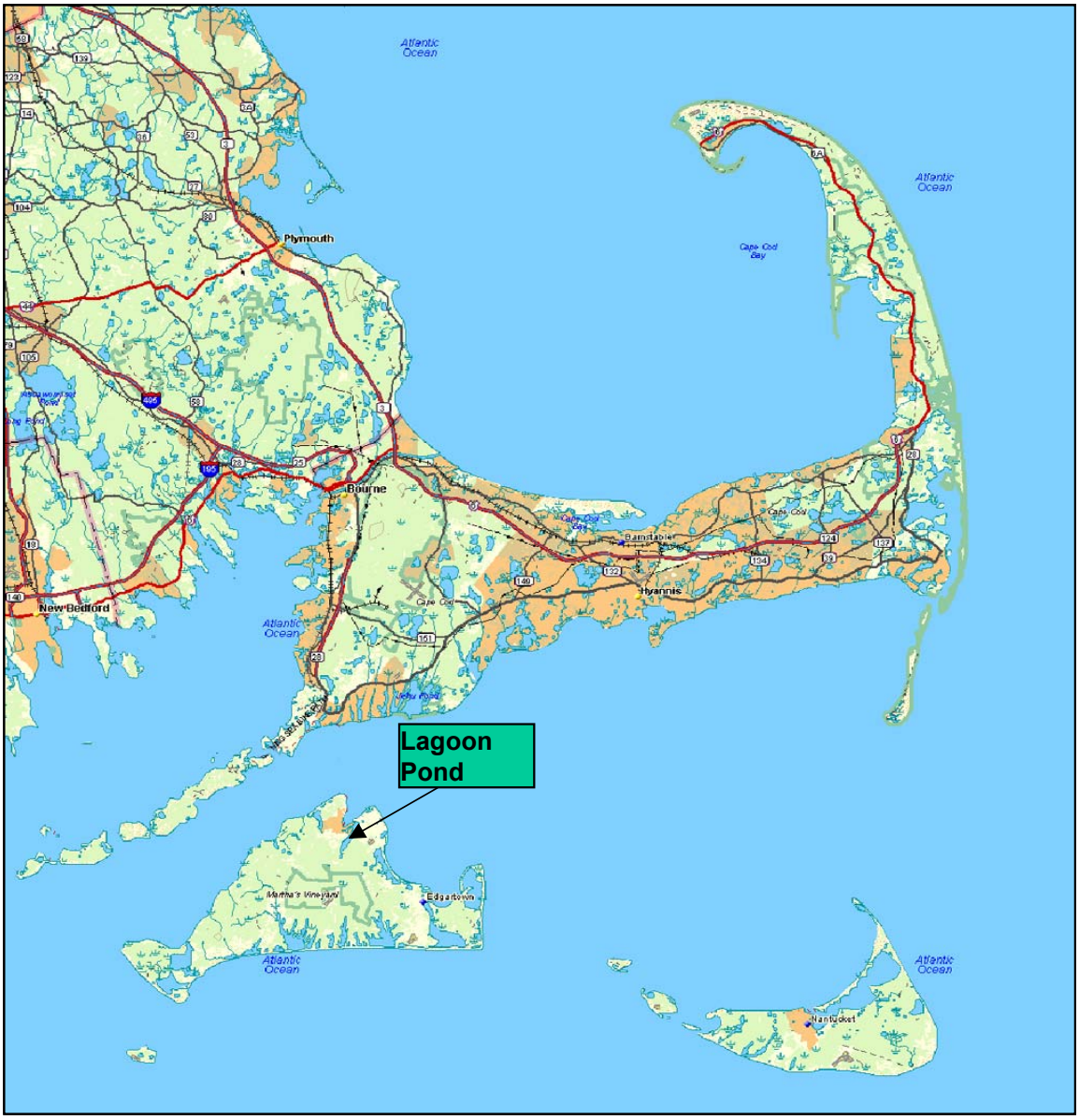
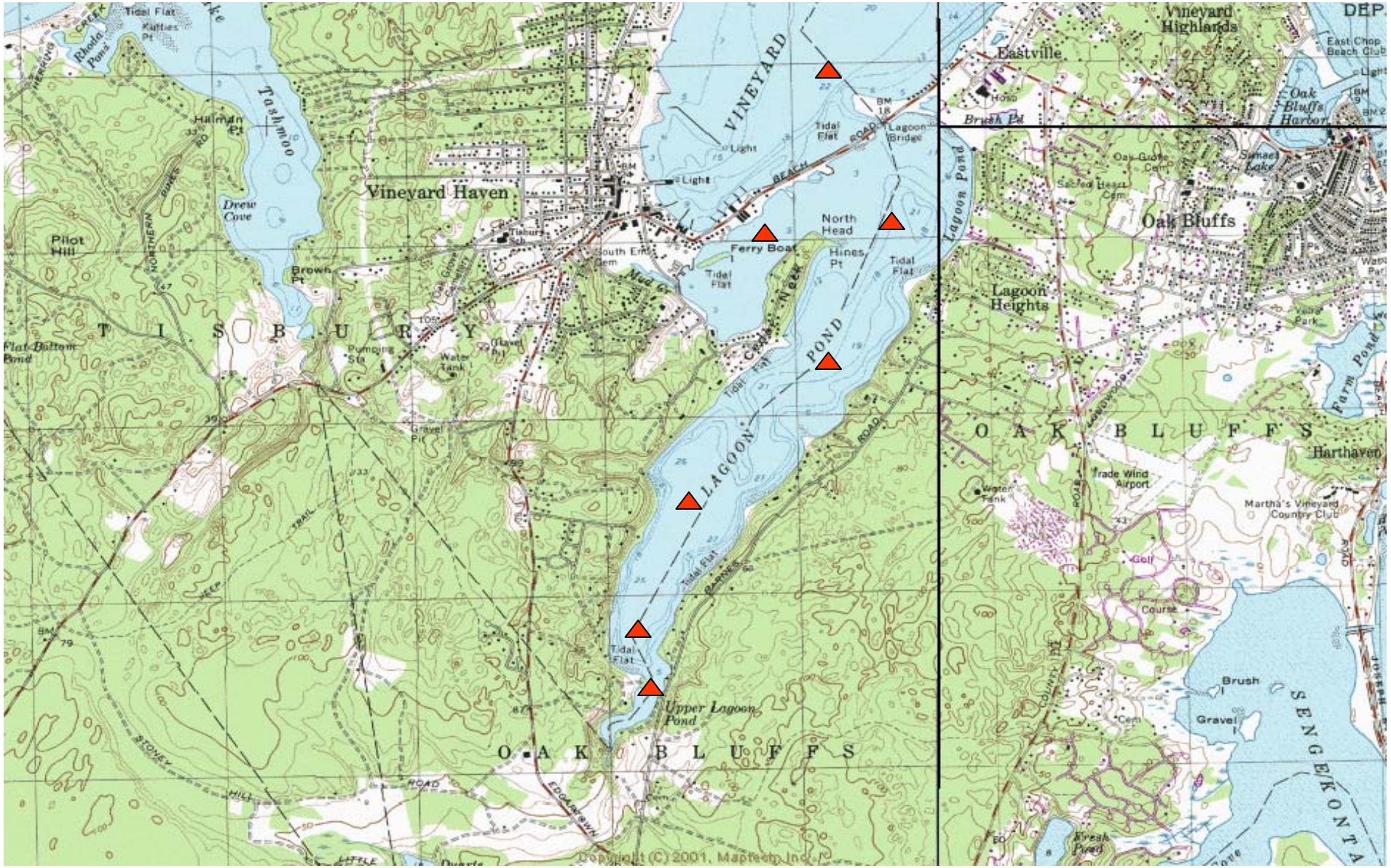
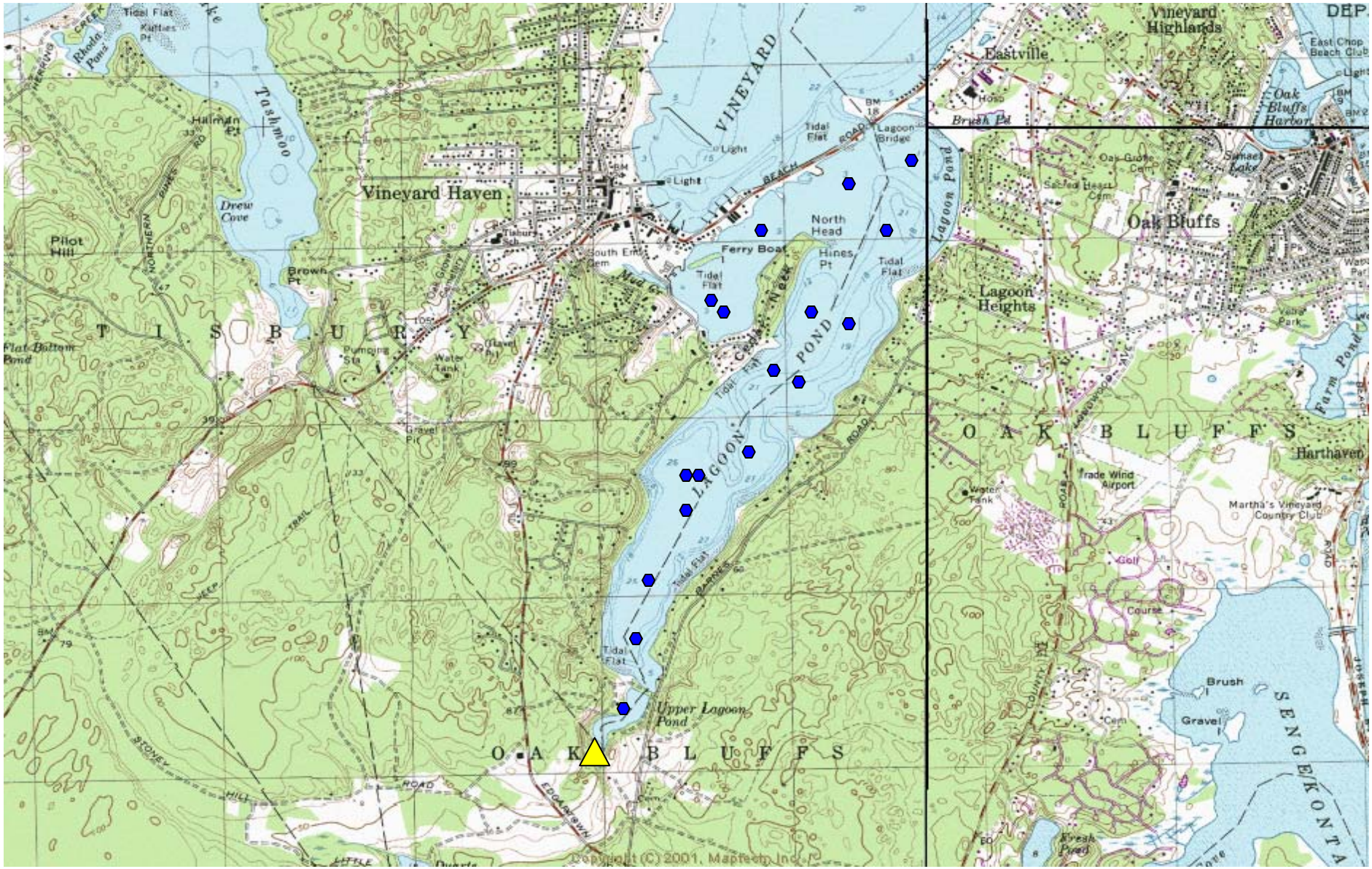

Atlantic Ocean
Plymouth
Bourne
New Bedford
Barnstable
Hyannis
Cape Cod Bay
Lagoon Pond
Edgartown
Nantucket

Figure 1



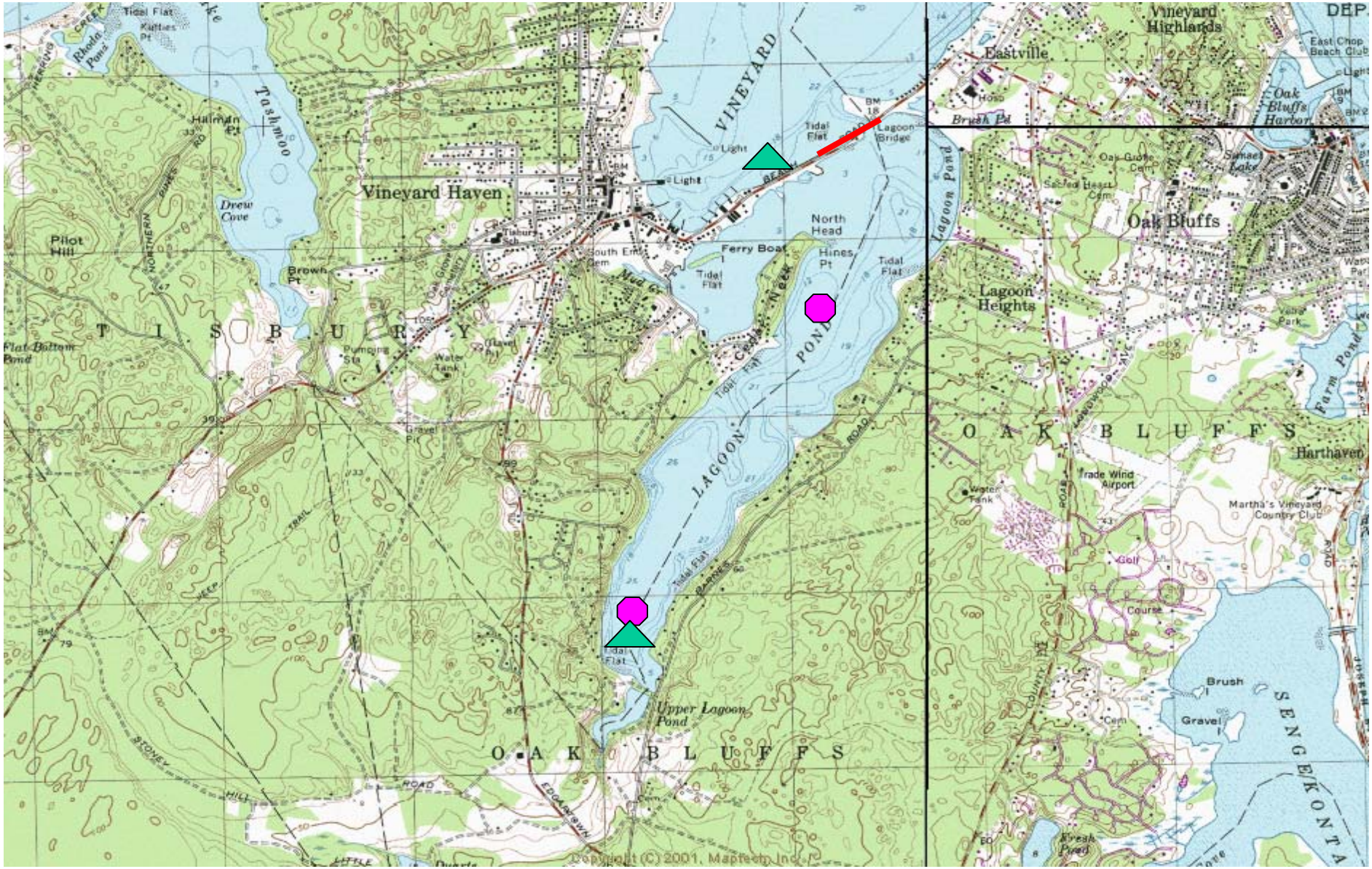
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge Location — ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Lagoon Pond (28)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	16	Once/Embayment	16	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	2**	15 minutes ****	> 2880	18 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	9	Once/Embayment	9	9	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXIX Eel Pond
Town of Mattapoisett
Prioritization Rank: Round 2 - #29

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Eel Pond, Mattapoisett: Eel Pond is a tributary embayment to Mattapoisett Harbor. This system is separated from the Harbor by a barrier beach. Tidal exchange is currently through a channel under the old railroad bridge and a newly breached inlet directly through the barrier beach. A bicycle path is being developed on the old railroad bed which runs the length of the barrier beach. As a result of this planned construction, Eel Pond has entered a 3 year Estuaries Project analysis (instead of the usual 2 year). The first year will focus primarily on assessing inlet size and dynamics and tidal exchange relating to the Bike Path.

A high quality nutrient monitoring data set is available from the Coalition for Buzzards Bay's Monitoring Program. The monitoring data has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program.

There have been several studies conducted on Eel Pond relevant to the Estuaries Project assessment and modeling effort. These studies provide supporting data on land-use, water quality and tidal exchange (pre-new inlet) and historic changes in the barrier beach. At present existing data fully compliant with this QAPP appropriate for directly parameterizing the Linked Nitrogen Management Model has not been identified.

The main Estuaries Project efforts will be to (1) construct the hydrodynamic model, which will require limited placement of tide gauges and conducting flow measurement following stream flow protocols; (2) land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) determine stream flow and nitrogen loading/attenuation; (4) conduct benthic infaunal survey; (5) collect dissolved oxygen records; (6) map eelgrass distribution; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

Note: Inlet flows will follow stream flow method, but will be conducted in time-series over a tidal cycle at each inlet. The Acoustic Doppler Current Profiler (ADCP) will not be used. The ADCP does not yield accurate results at the water depths (0.4m) and channel dimensions associated with the Eel Pond inlets.

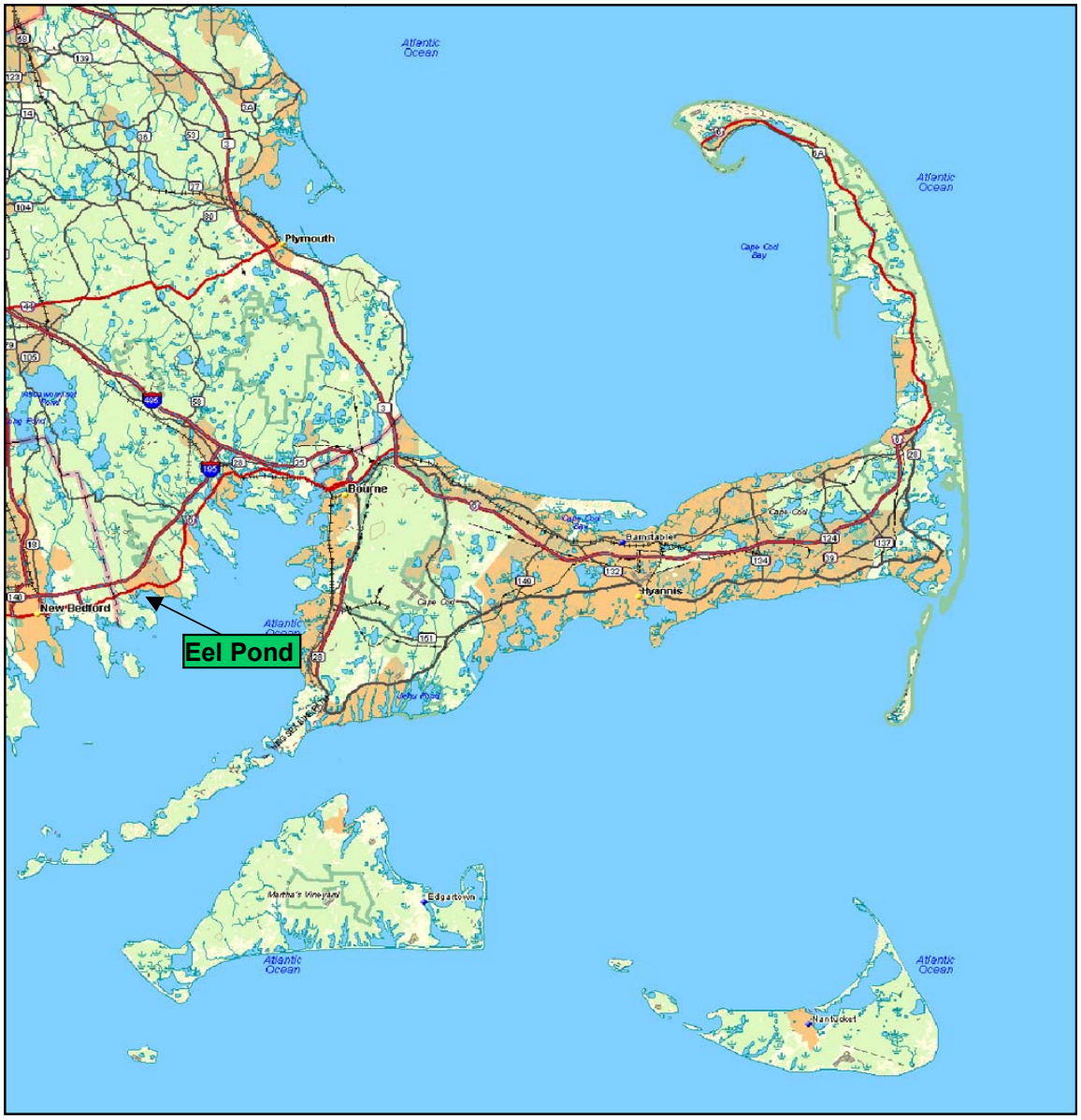
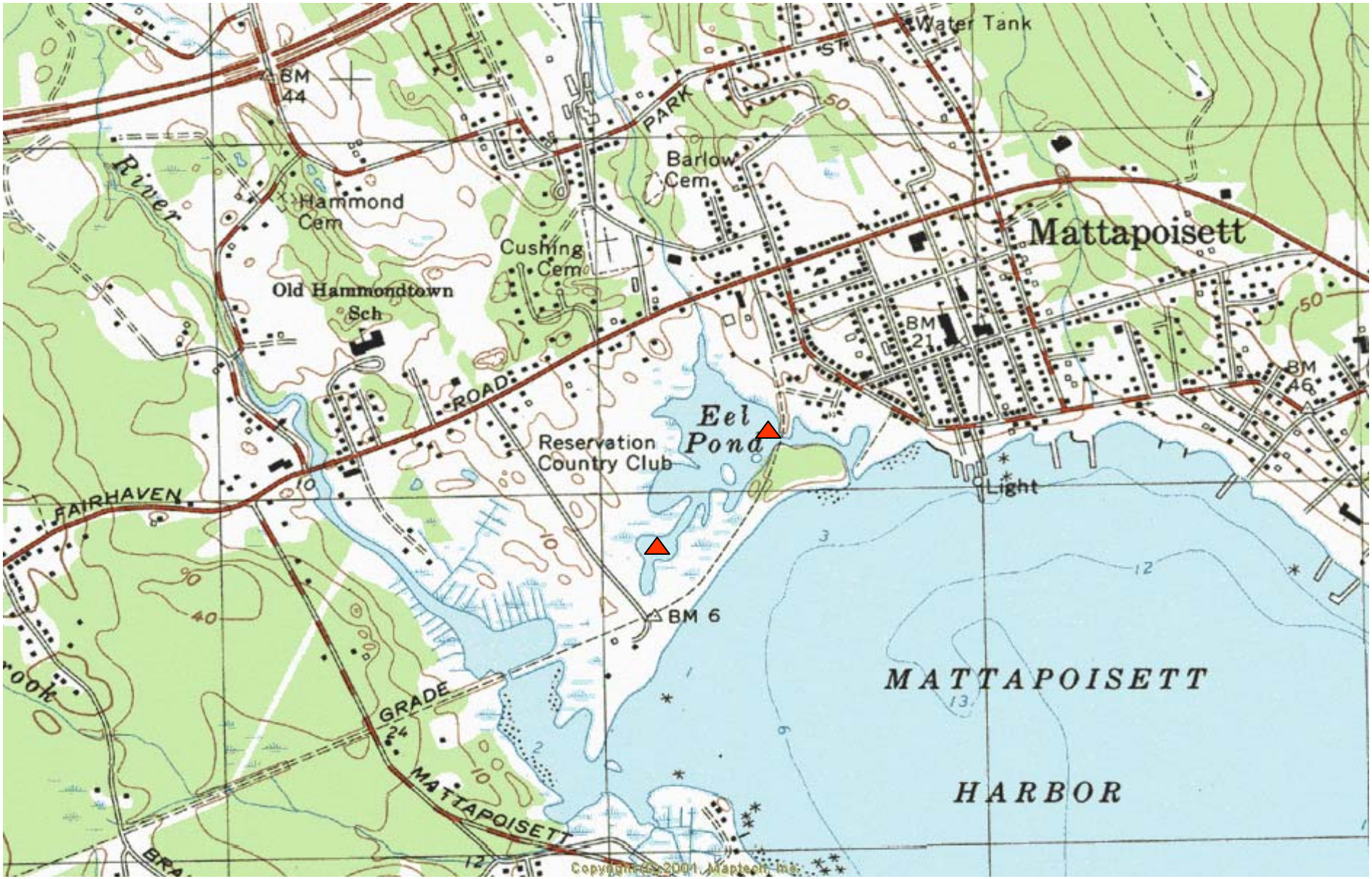
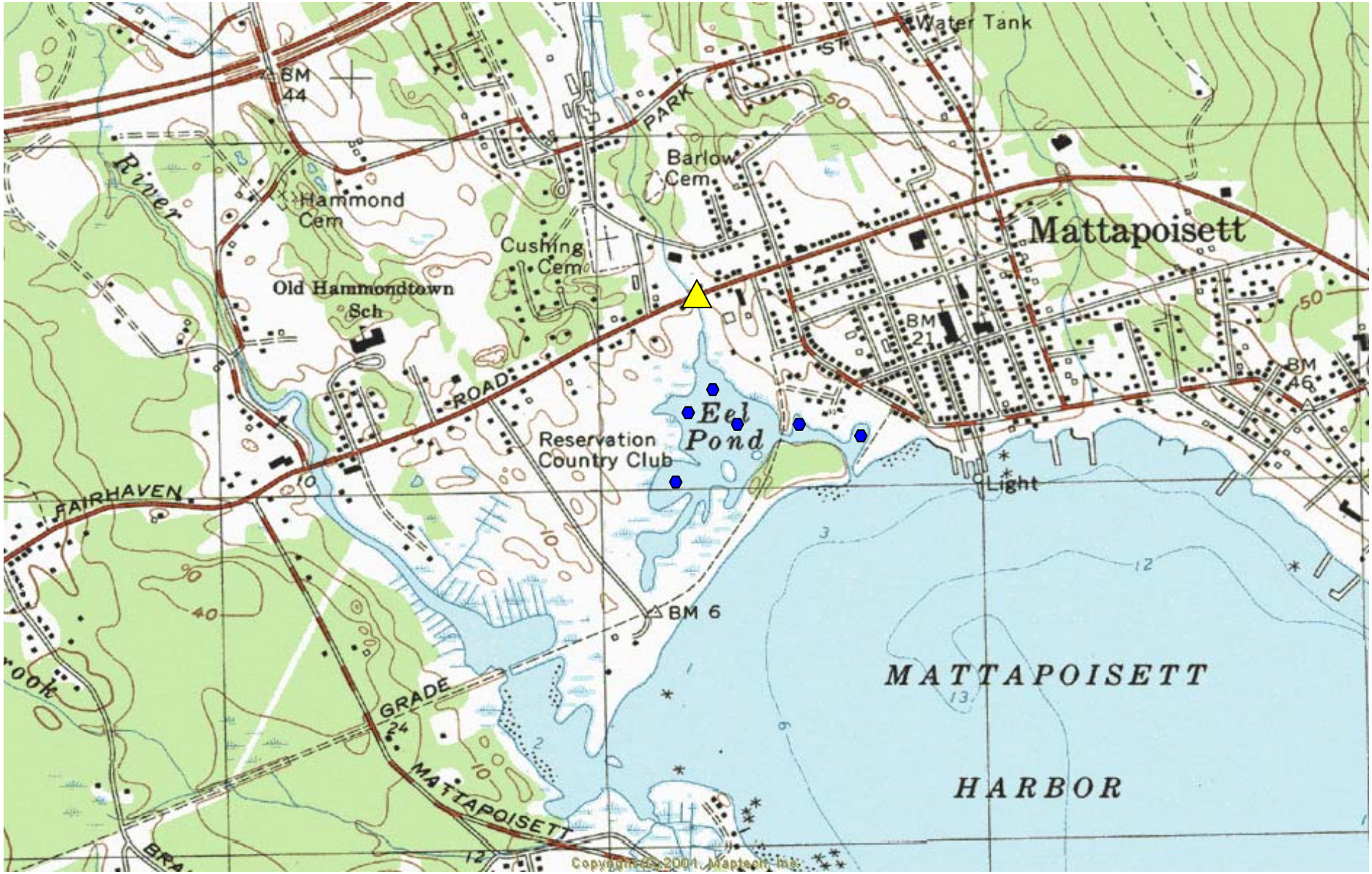

Atlantic Ocean
Plymouth
Cape Cod Bay
Atlantic Ocean
Bourne
Barnstable
Hyannis
New Bedford
Eel Pond
Atlantic Ocean
Martha's Vineyard
Edgartown
Atlantic Ocean
Nantucket
Atlantic Ocean

Figure 1



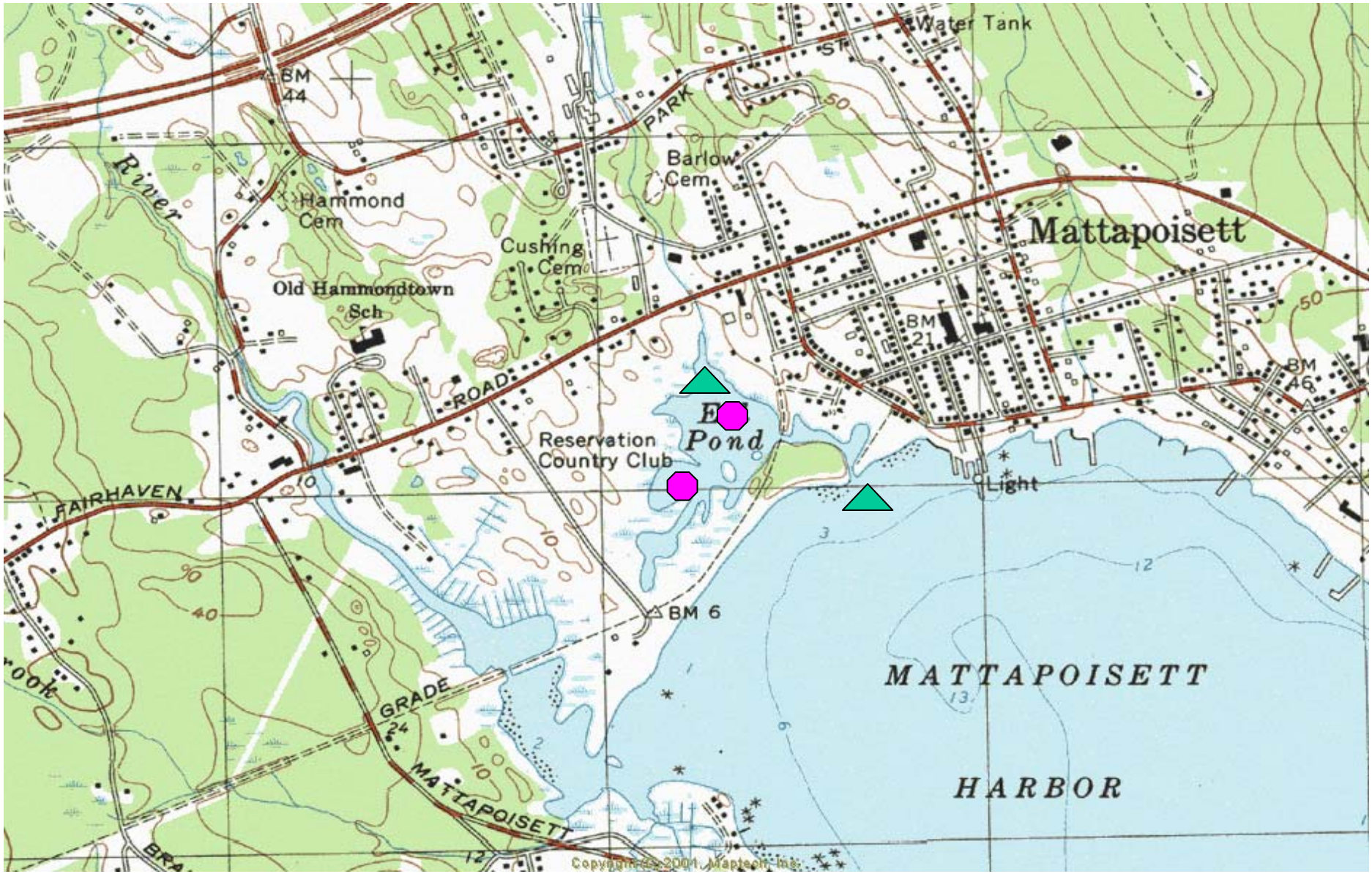
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Mattapoisett Harbor (43)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	2	Weekly	120	12	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	31	Once/Embayment	31	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	4**	15 minutes ****	> 11520	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	21	Once/Embayment	21	21	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the system
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval

NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXX Aucoot Cove
Town of Marion
Prioritization Rank: Round 2 - #30

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Aucoot Cove, Marion: Aucoot Cove is a relatively open embayment with open exchange with Buzzards Bay waters. The upper region of the Cove supports an extensive salt marsh system. One of the major marsh creeks receives the discharge from the Marion Wastewater Treatment Facility which is being upgraded.

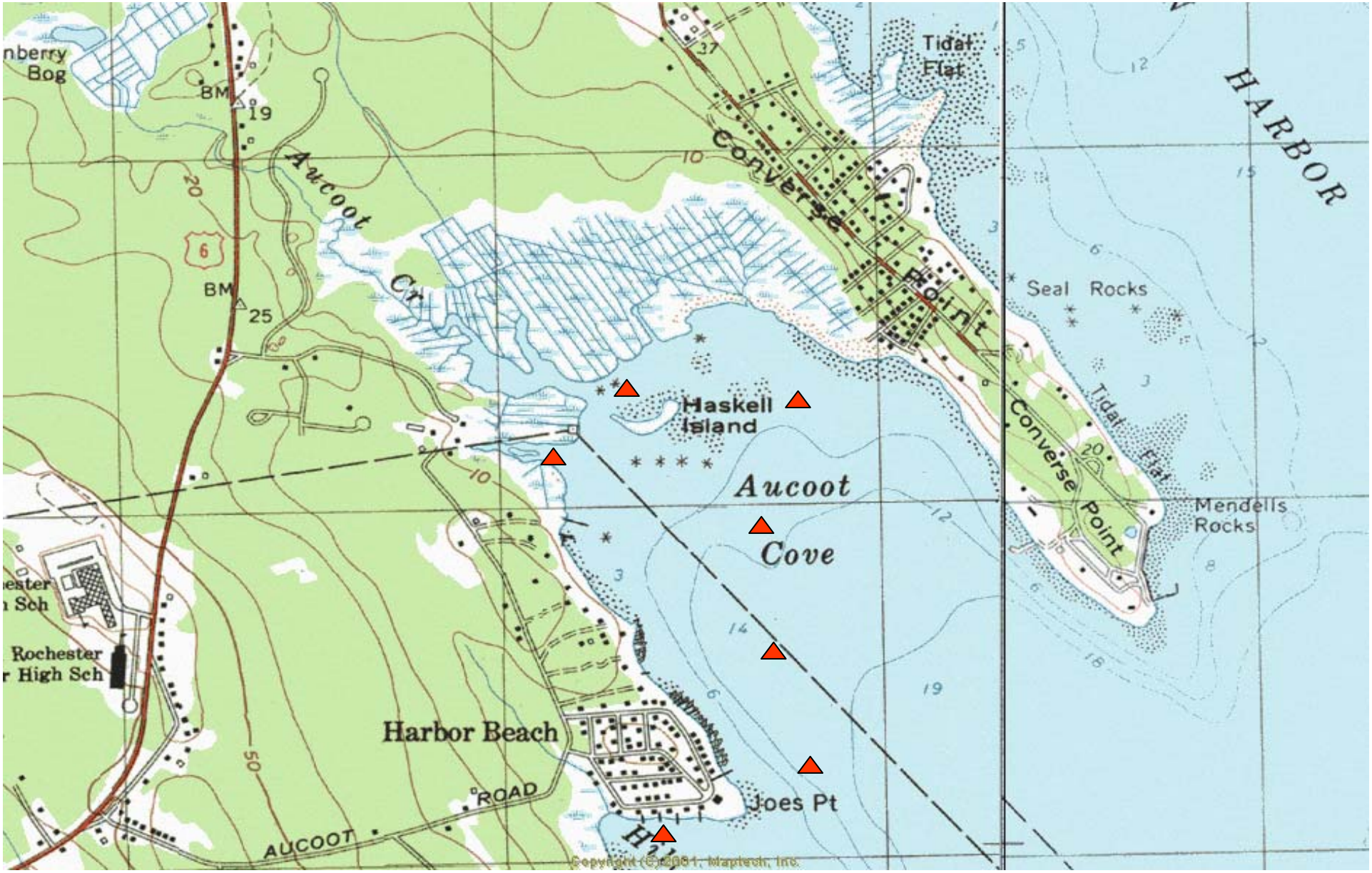
A high quality nutrient monitoring data set is available from the Coalition for Buzzards Bay's Monitoring Program. The monitoring data has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program. In addition, a system-wide high resolution nutrient related water quality dataset exists from the summer 1991, collected under a QAPP. Additional relevant data from the Wastewater Facilities Plan will be incorporated relative to wastewater nitrogen discharges, past and future.

At present existing data fully compliant with this QAPP appropriate for directly parameterizing the Linked Nitrogen Management Model has not been identified.

The main Estuaries Project efforts will be to (1) construct the hydrodynamic model, which will require limited placement of tide gauges and conducting an ADCP transect; (2) land-use and watershed nitrogen loading model based upon the USGS/Estuaries Project watershed delineation; (3) determine stream flow and nitrogen loading/attenuation and wetland attenuation; (4) conduct benthic infaunal survey; (5) collect dissolved oxygen records; (6) map eelgrass distribution; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

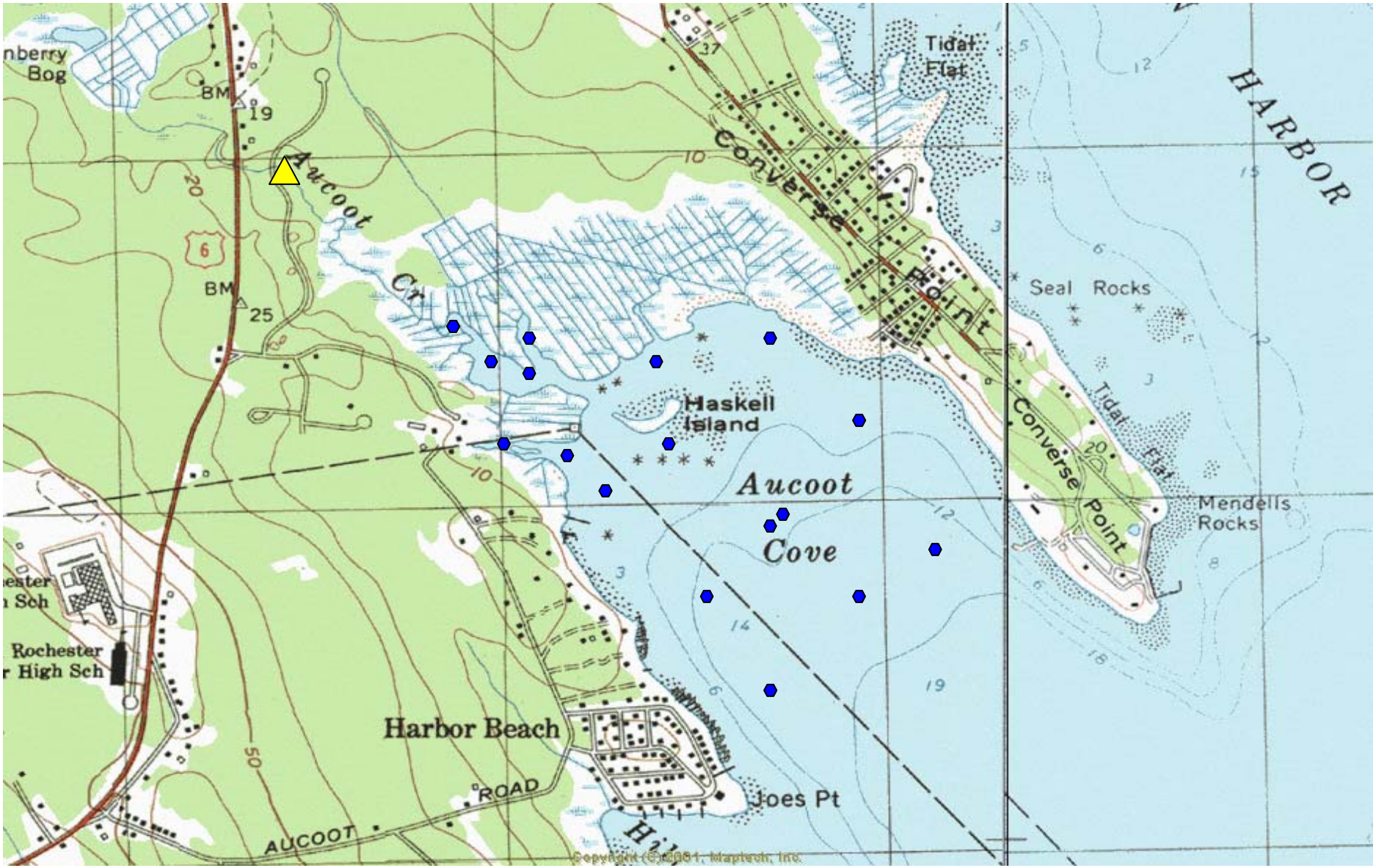

Atlantic Ocean
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Aucoot Cove
Martha's Vineyard
Edgartown
Nantucket

Figure 1



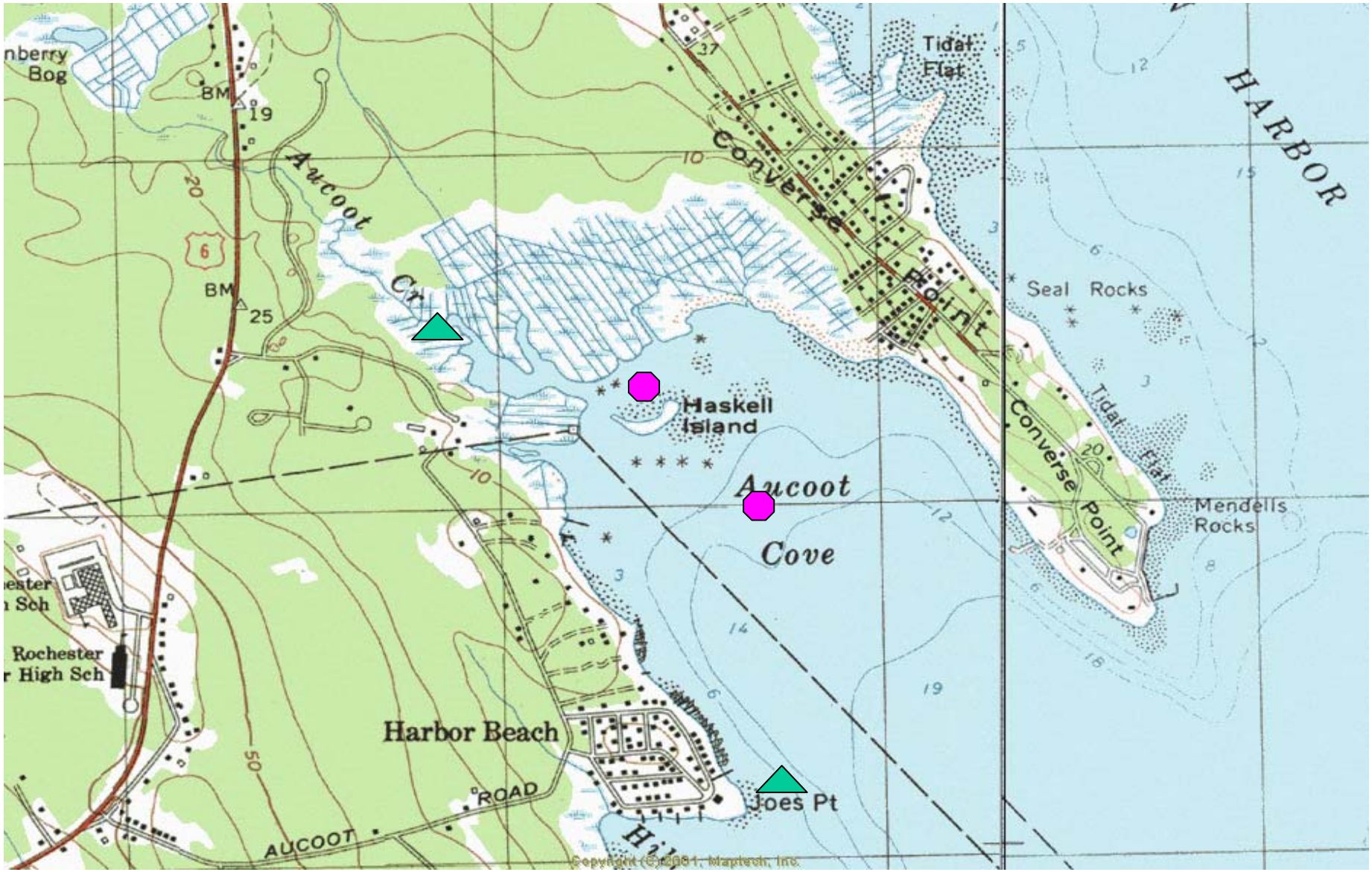
▲ Historical Nutrient Sampling Locations

Figure 2



● Benthic Coring Locations △ Stream Gage/MEP Nutrient Sampling Location

Figure 3



Tide Gauge ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Aucoot Cove (30)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	16	Once/Embayment	16	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	2**	15 minutes ****	> 2880	18 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	7	Once/Embayment	7	7	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXXI Madaket Harbor
Nantucket
Prioritization Rank: Round 2 - #31

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Madaket Harbor, Nantucket: This estuary consists of a relatively open basin (Madaket Harbor) with direct exchange with open ocean waters and a shallow enclosed basin (Hither Creek) which exchanges tidal water with Madaket Harbor and receives discharge from Long Pond. Madaket Harbor is primarily open water with limited fringing salt marsh.

Only limited Estuaries Project data exist for this estuary. However, water quality monitoring data exists from a several sources: Nantucket Marine Department sampling 2001, 2002; SMAST sampling following the present QAPP in 2002 and historical data from 1991 (consistent with the present QAPP) by WHOI. These data have been reviewed based upon the Estuaries Project QAPP as part of the prioritization process. All of the water quality data has been collected by professional staff. The Nantucket Marine Department is a formal collaborator with the Estuaries Project and is assisting in the incorporation of water quality data and historical data into the Estuaries Project Effort.

At present no existing process-level data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP have been identified. However,

a circulation study was performed in 2000-2001 which provides qualitative information relevant to nutrients and will be incorporated into the Estuaries Project assessment, as appropriate.

The main Estuaries Project efforts will be to (1) establish a hydrodynamic model based which will require placement of tide gauges and conducting ADCP measurements; (2) perform land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) collect stream flow/nitrogen load data; (4) collect benthic cores and determine summer nitrogen regeneration rates; (5) collect distributed dissolved oxygen records to support the habitat assessment; (6) map eelgrass distribution and create historic record; (7) collect benthic infaunal distribution and indicator data; and (8) conduct the water quality modeling, thresholds analysis and synthesis.

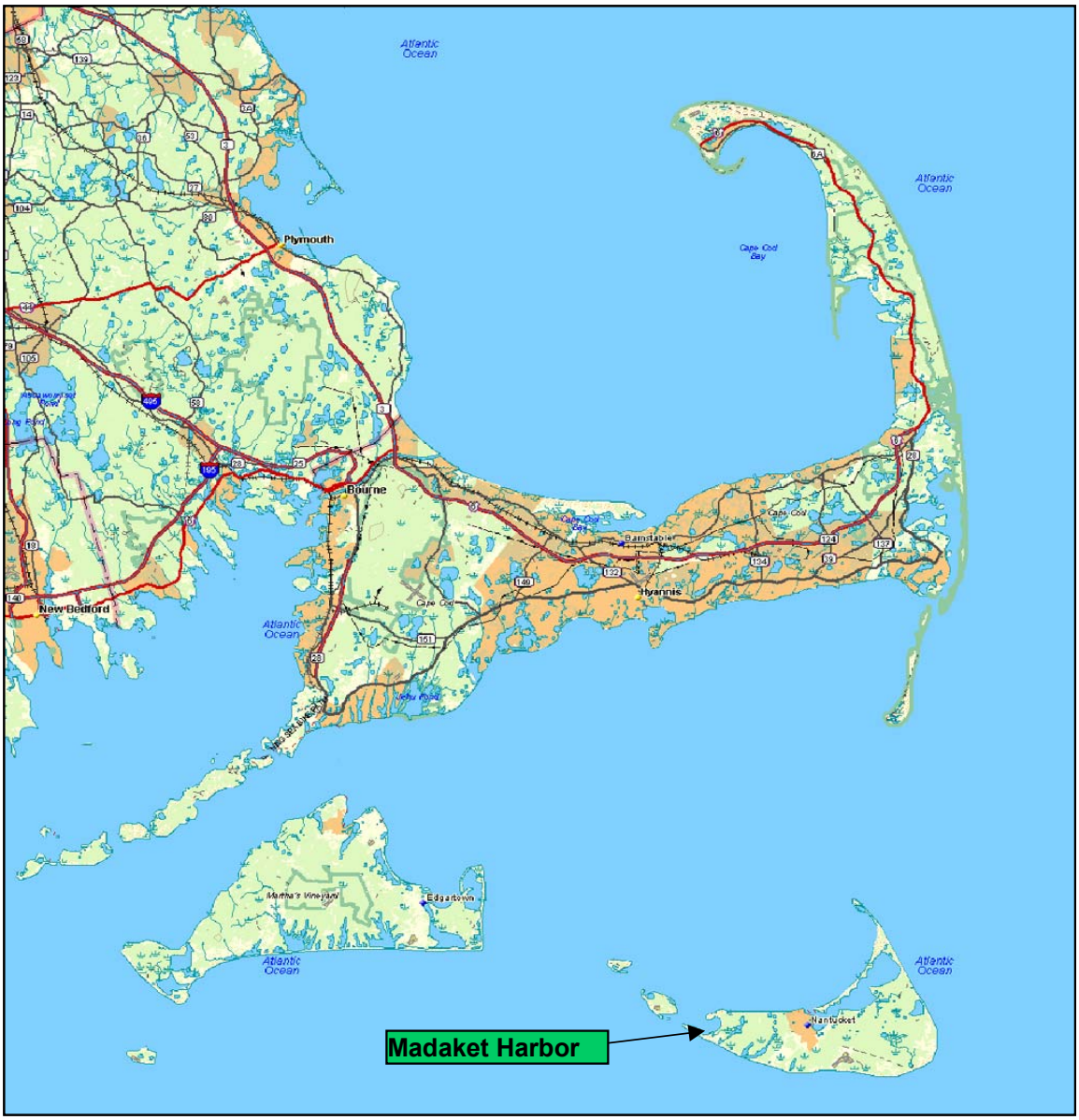
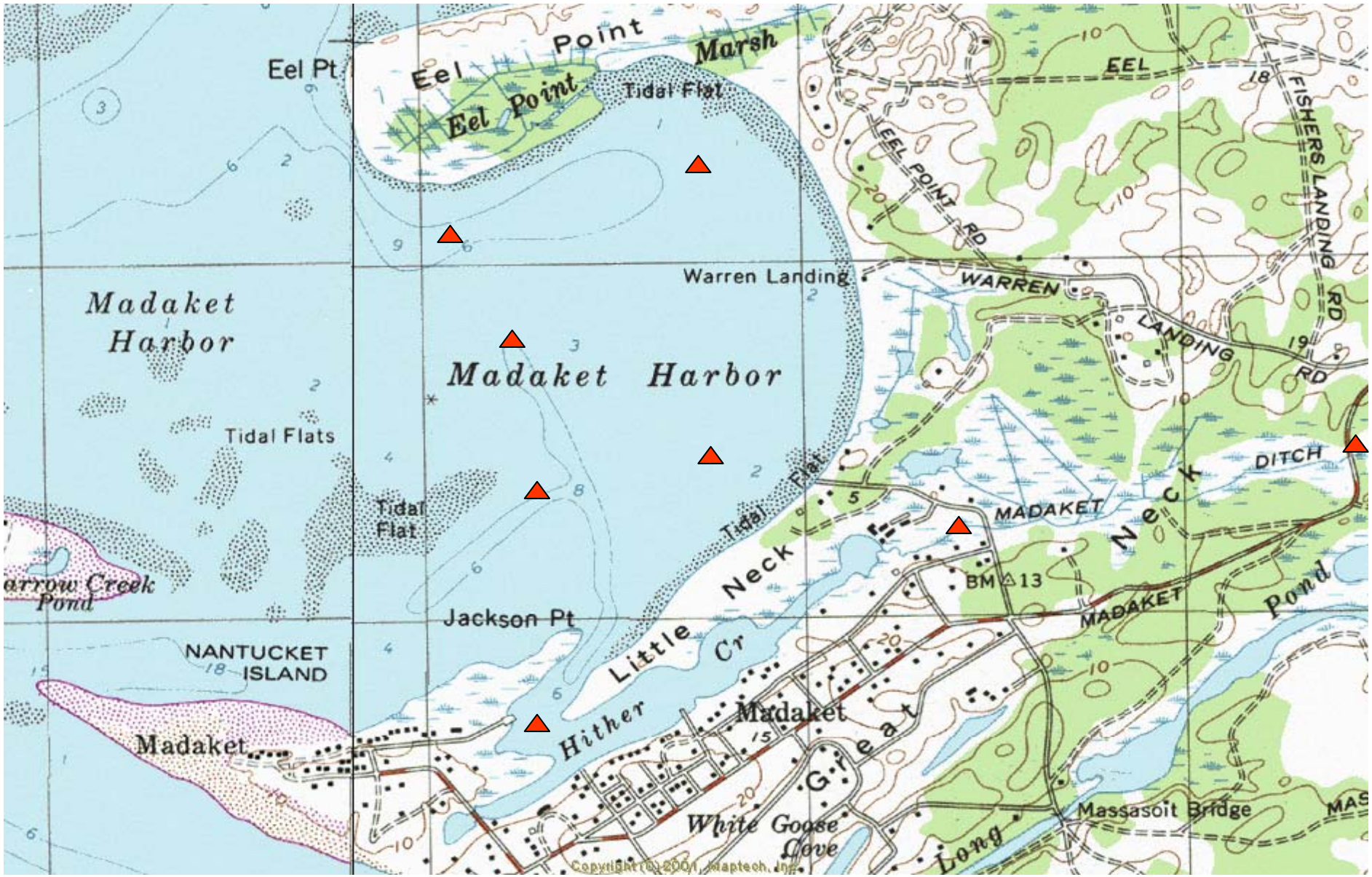
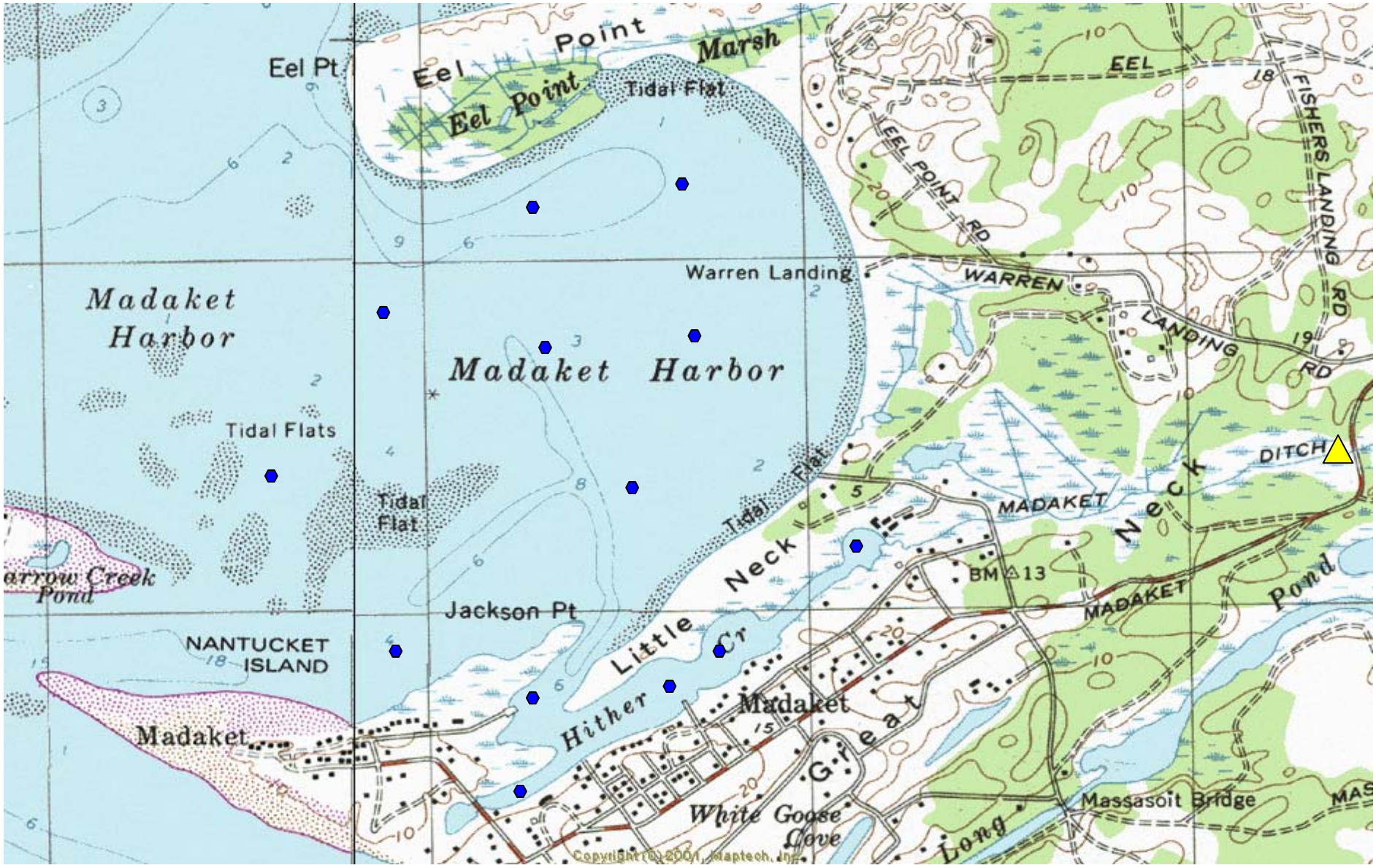

Atlantic Ocean
Plymouth
Cape Cod Bay
Atlantic Ocean
Bourne
Barnstable
Hyannis
New Bedford
Atlantic Ocean
Martha's Vineyard
Edgartown
Atlantic Ocean
Nantucket
Atlantic Ocean
Madaket Harbor

Figure 1



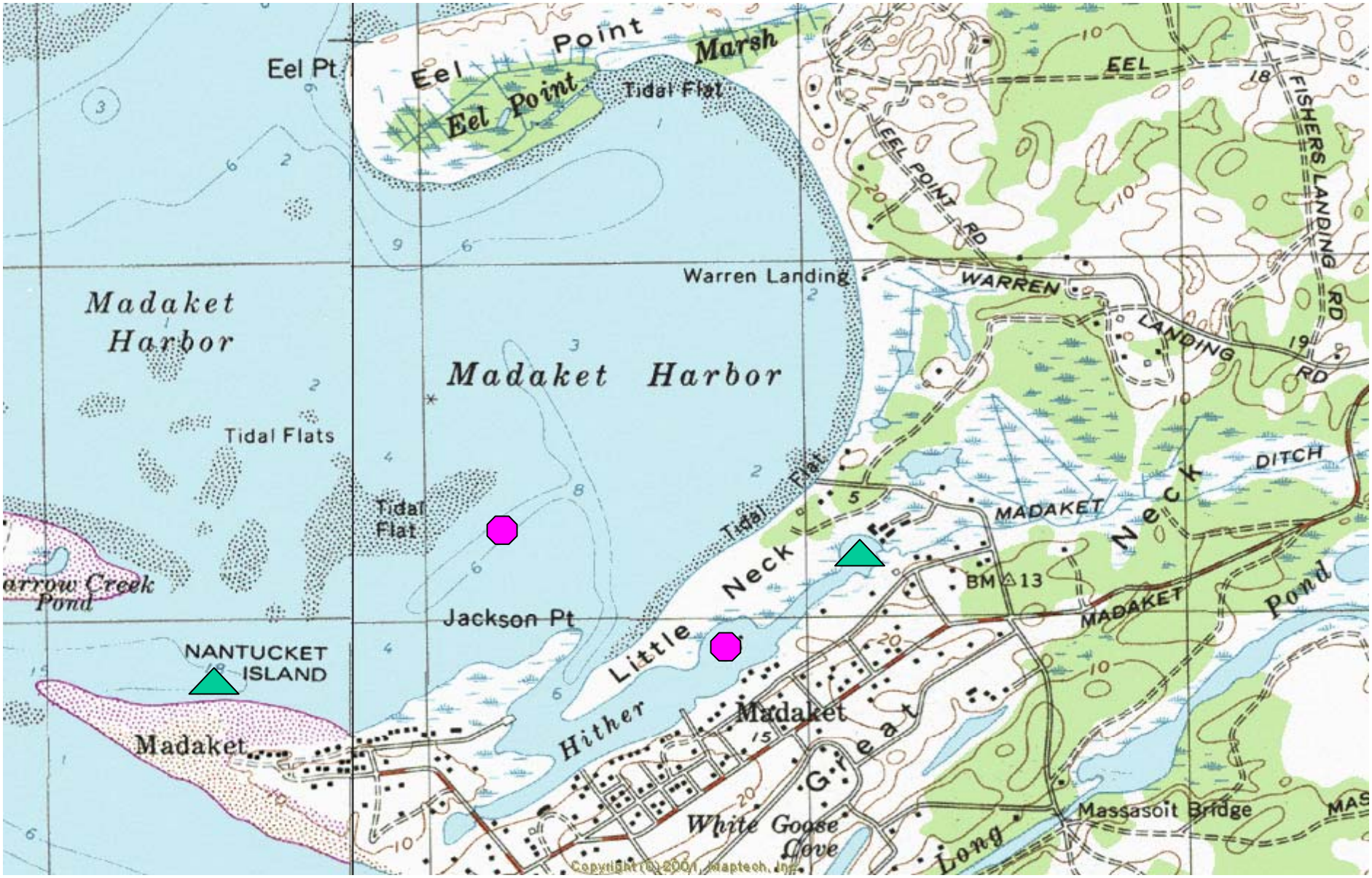
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge ADCP Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Madaket Harbor (31)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	NA	NA	NA	NA	NA	NA	NA
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	13	Once/Embayment	13	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	2**	15 minutes ****	> 2880	18 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	8	Once/Embayment	8	8	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXXII Long Pond
Nantucket
Prioritization Rank: Round 2 - #32

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Long Pond, Nantucket: Long Pond is a man-made estuary, created opening Madaket Ditch between the Pond and Hither Creek/Madaket Harbor. This system exchanges tidal water and is currently brackish. This estuary is totally enclosed (except for the Ditch) and contains wetland resources.

Only limited Estuaries Project data exist for this estuary. However, water quality monitoring data exists from a several sources: Nantucket Marine Department sampling 2001, 2002; SMAST sampling following the present QAPP in 2002. Historical nutrient data were collected by the Nantucket Land Council in the early 1990's, which will be review and incorporated as appropriate. The recent data have been reviewed based upon the Estuaries Project QAPP as part of the prioritization process. All of the water quality data has been collected by professional staff. The Nantucket Marine Department is a formal collaborator with the Estuaries Project and is assisting in the incorporation of water quality data and historical data into the Estuaries Project Effort.

At present no existing process-level data suitable for parameterizing the Linked Approach which are fully compliant with the Estuaries Project QAPP have been identified.

The main Estuaries Project efforts will be to (1) construct the hydrodynamic model, which will require limited placement of tide gauges and conducting flow measurement following stream flow protocols; (2) land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) determine stream flow and nitrogen loading/attenuation; (4) conduct benthic infaunal survey; (5) collect dissolved oxygen records; (6) map eelgrass distribution; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

Note: Inlet flows will follow stream flow method, but will be conducted in time-series over a tidal cycle in upper Madaket Ditch. The Acoustic Doppler Current Profiler (ADCP) will not be used. The ADCP does not yield accurate results at the shallow water depths and small channel dimensions associated with the Long Pond tidal exchange channel (Madaket Ditch). There will also be a recording gauge at this site to allow assessment of the magnitude and frequency of saltwater inflow to Long Pond.

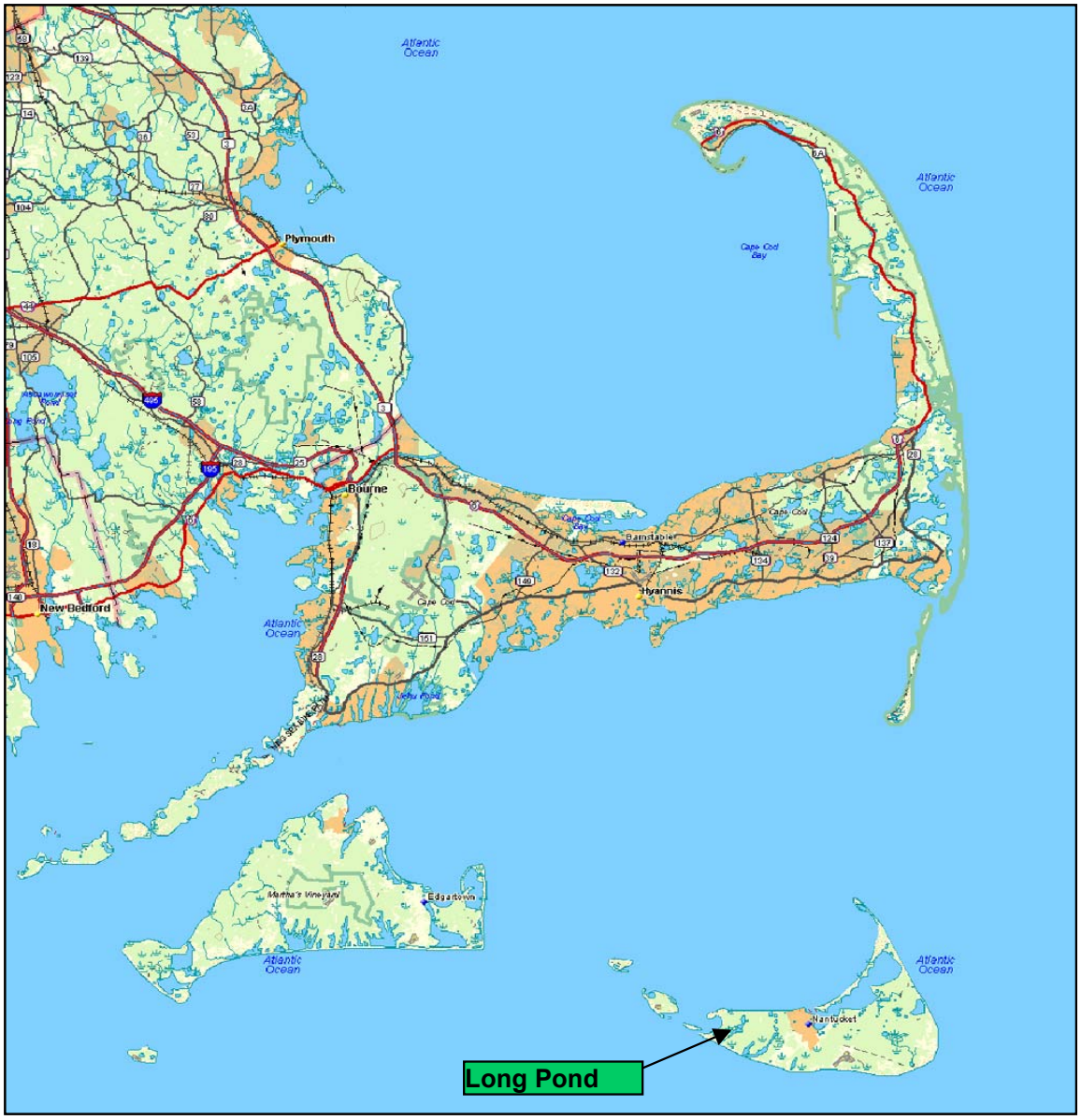
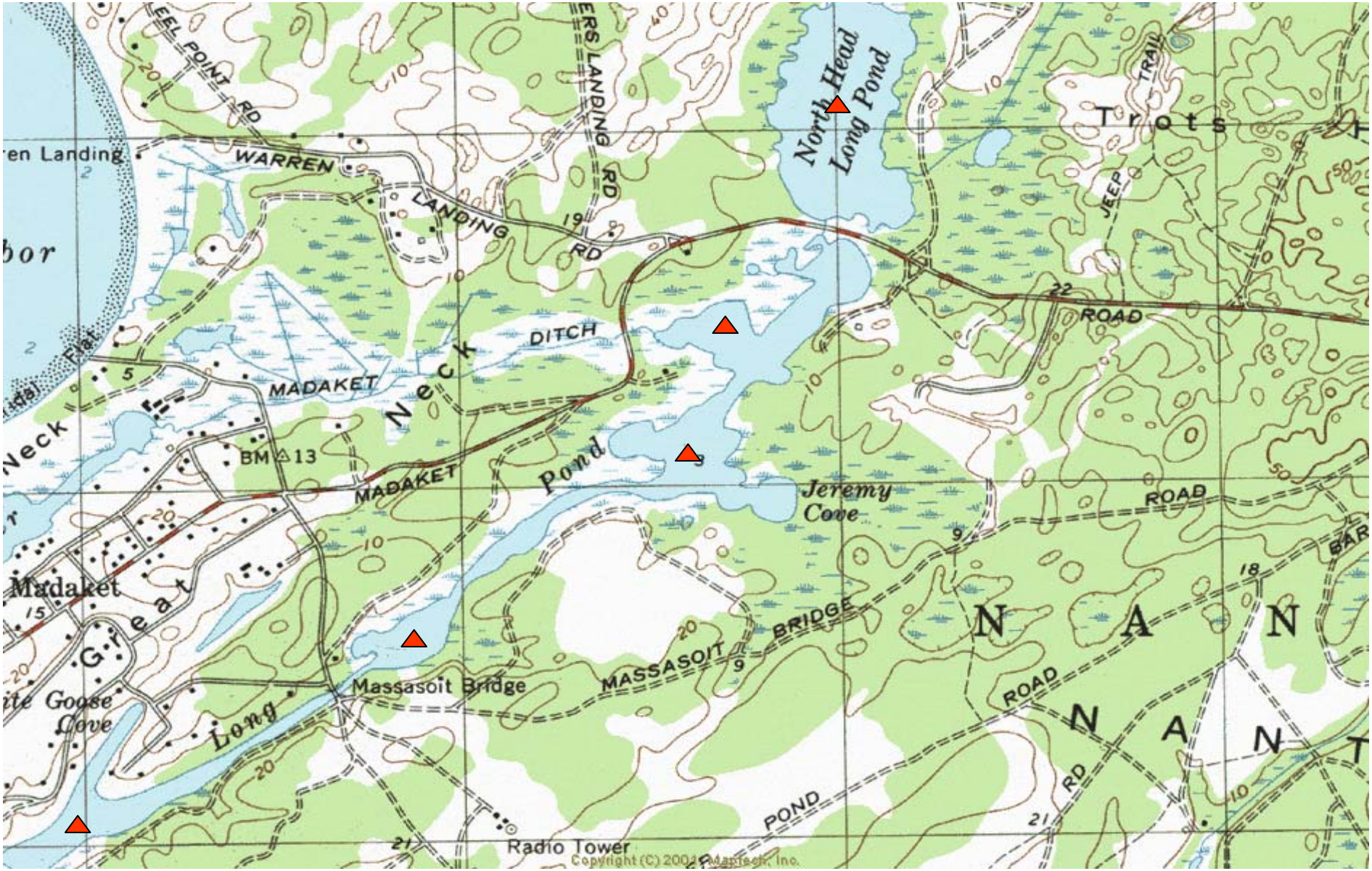
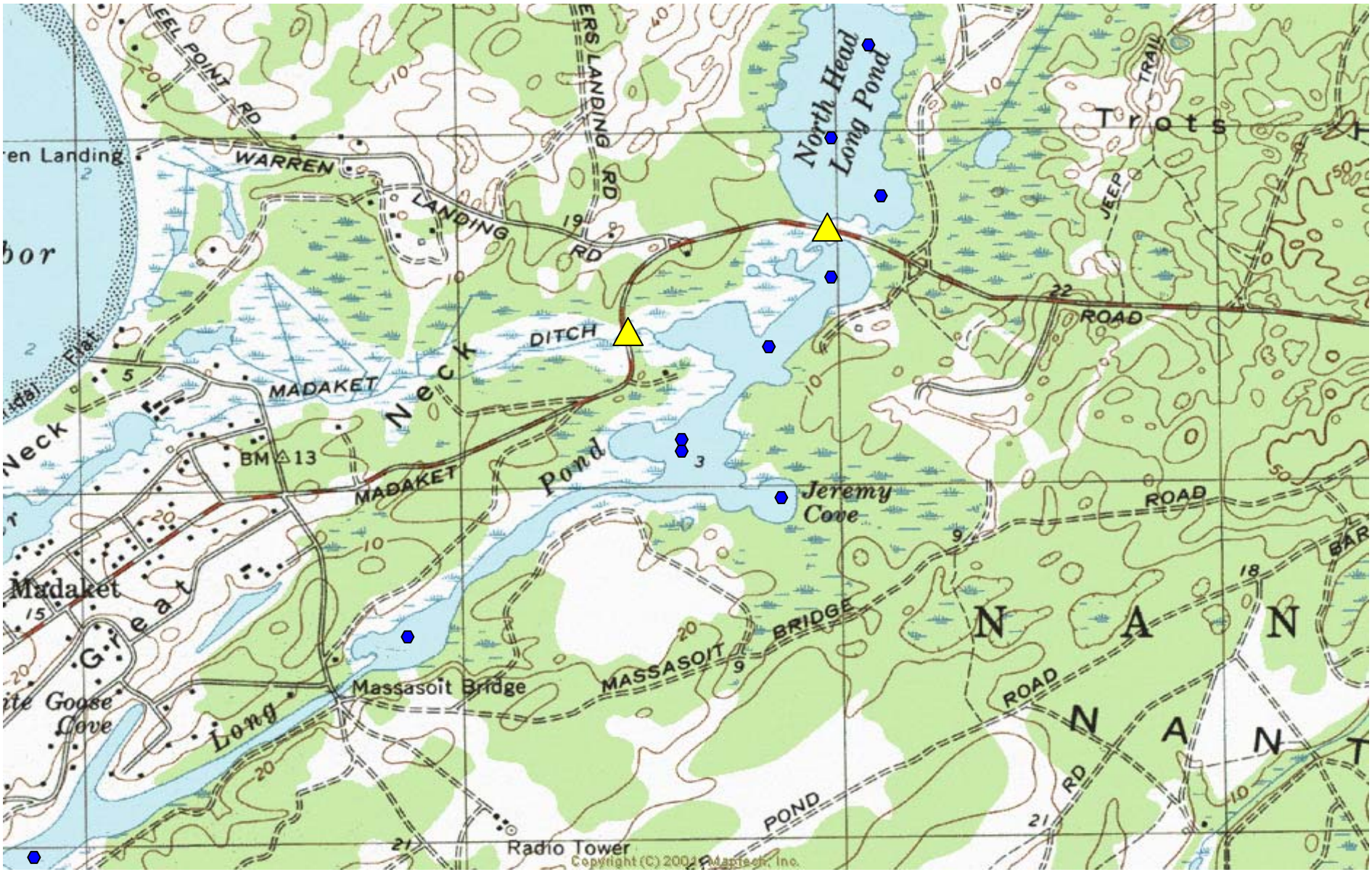

Atlantic Ocean
Plymouth
Bourne
New Bedford
Barnstable
Hyannis
Cape Cod
Cape Cod Bay
Martha's Vineyard
Edgartown
Nantucket
Long Pond

Figure 1



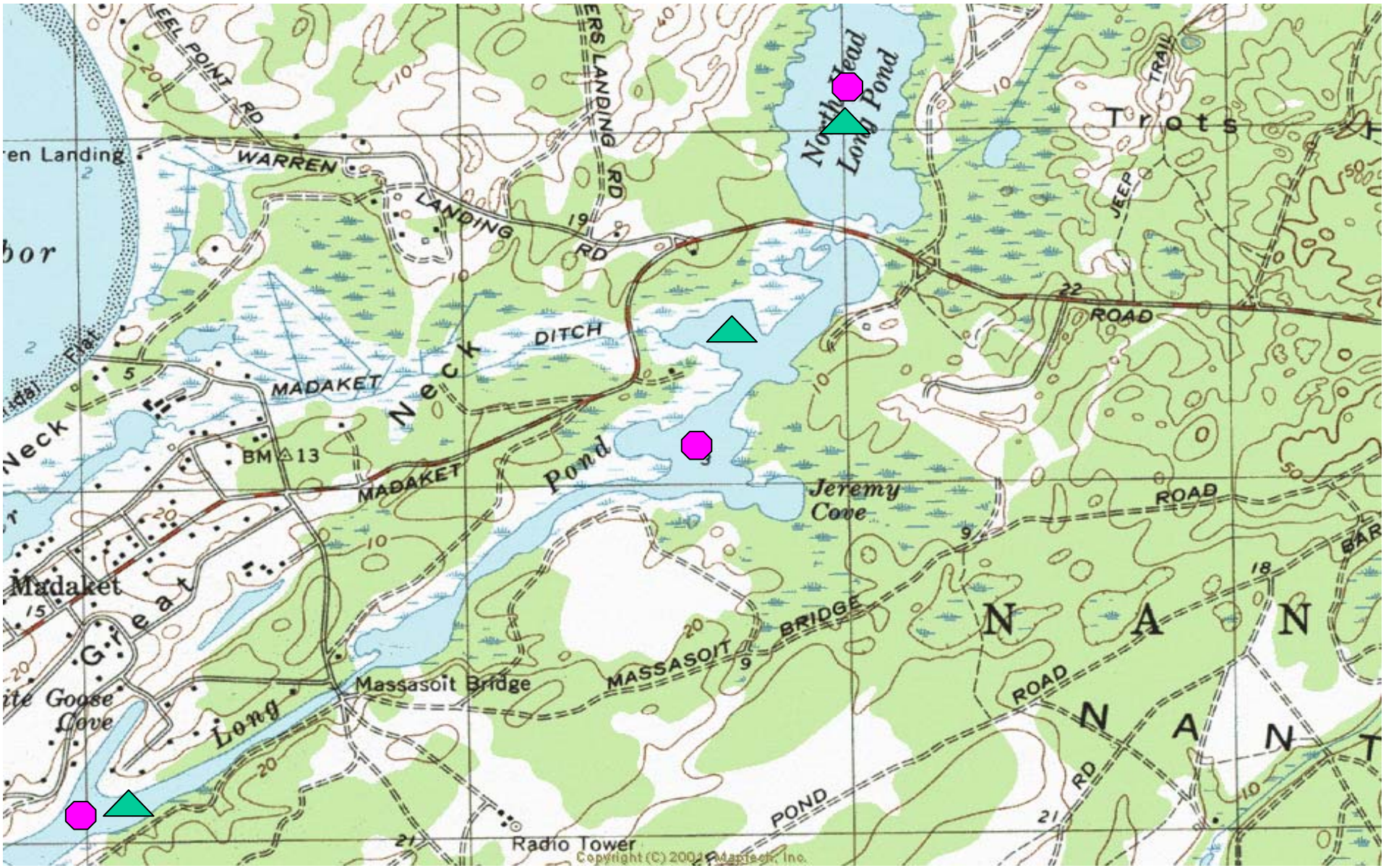
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling

Figure 3



Tide Gauge Location — ADCP Transects — Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Long Pond - Nantucket (32)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g,p	Grab	2	Weekly	120	12	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	9	Once/Embayment	9	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	3**	15 minutes ****	> 2880	27 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	5	Once/Embayment	5	5	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXXIII Red Brook Harbor
Town of Bourne
Prioritization Rank: Round 2 - #33

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Red Brook Harbor System, Bourne*:* The Red Brook Harbor System consists of the embayment formed by Wings Neck, Scraggy Neck and Bassetts Island. This system has seen significant activity as part of the Massachusetts Military Reservation (MMR) Groundwater Remediation Program. The MMR Landfill Plume discharges to Red Brook. Data on nutrient levels and groundwater plume tracking will be incorporated into the Estuaries Project assessment.

A high quality nutrient monitoring data set is available from the Coalition for Buzzards Bay's Monitoring Program. The monitoring data has been collected and analyzed following the Coalition for Buzzards Bay Monitoring QAPP. All technical design details and analytical aspects of the monitoring program were conducted by the Coastal Systems Program at SMAST for the Coalition for Buzzards Bay Monitoring Program.

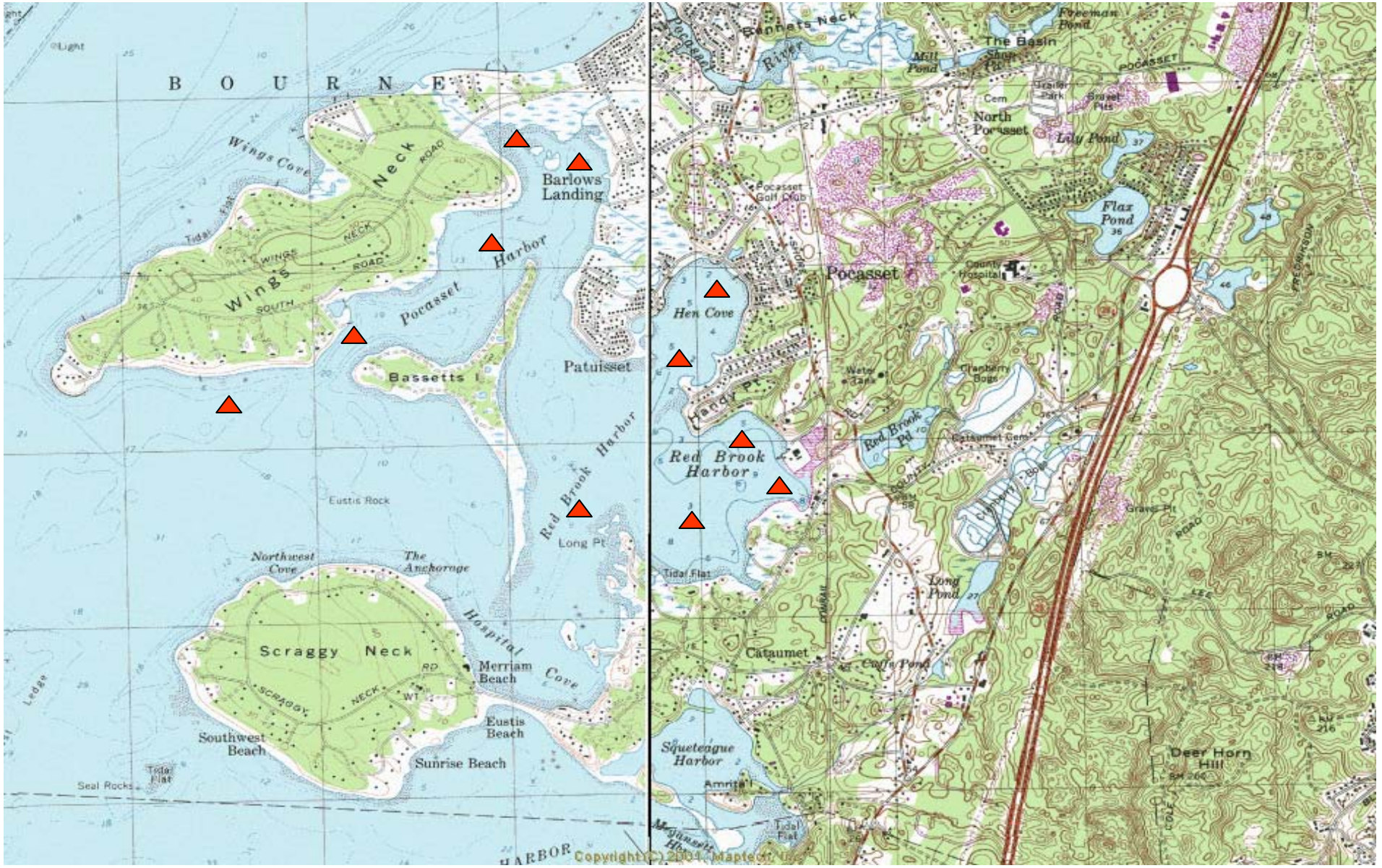
The existing key data which will be used is fully compliant with this QAPP and was collected and analyzed by present Estuaries Project Technical Team members. These data sets include: (1) limited stream nitrogen loading (from MMR); (2) tide gauges,

bathimetry and a preliminary hydrodynamic model; and (3) landfill nitrogen loading measurements to support the watershed nitrogen modeling.

The main Estuaries Project efforts will be to (1) up-grade the current hydrodynamic model for the central bay which will require limited placement of tide gauges and conducting ADCP measurements; (2) update the existing land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) enhance the stream flow and nitrogen loading database to bring in to QAPP compliance; (4) conduct benthic infaunal survey; (5) collect dissolved oxygen records within each of the key tributary embayments; (6) map eelgrass distribution; and (7) conduct the water quality modeling, thresholds analysis and synthesis.

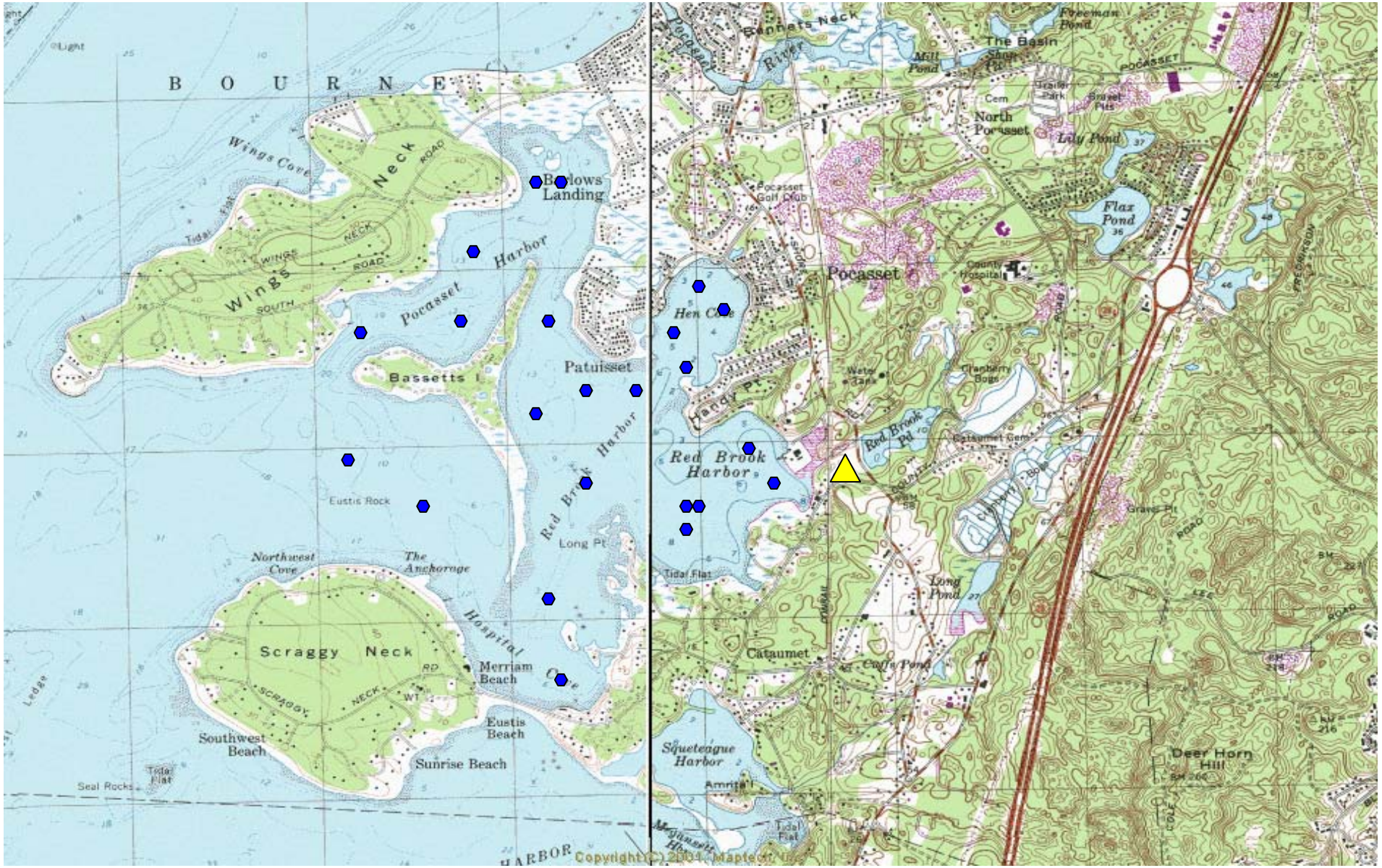

Red Brook Harbor
Atlantic Ocean
Plymouth
Cape Cod Bay
Bourne
Barnstable
Hyannis
New Bedford
Martha's Vineyard
Edgartown
Nantucket

Figure 1



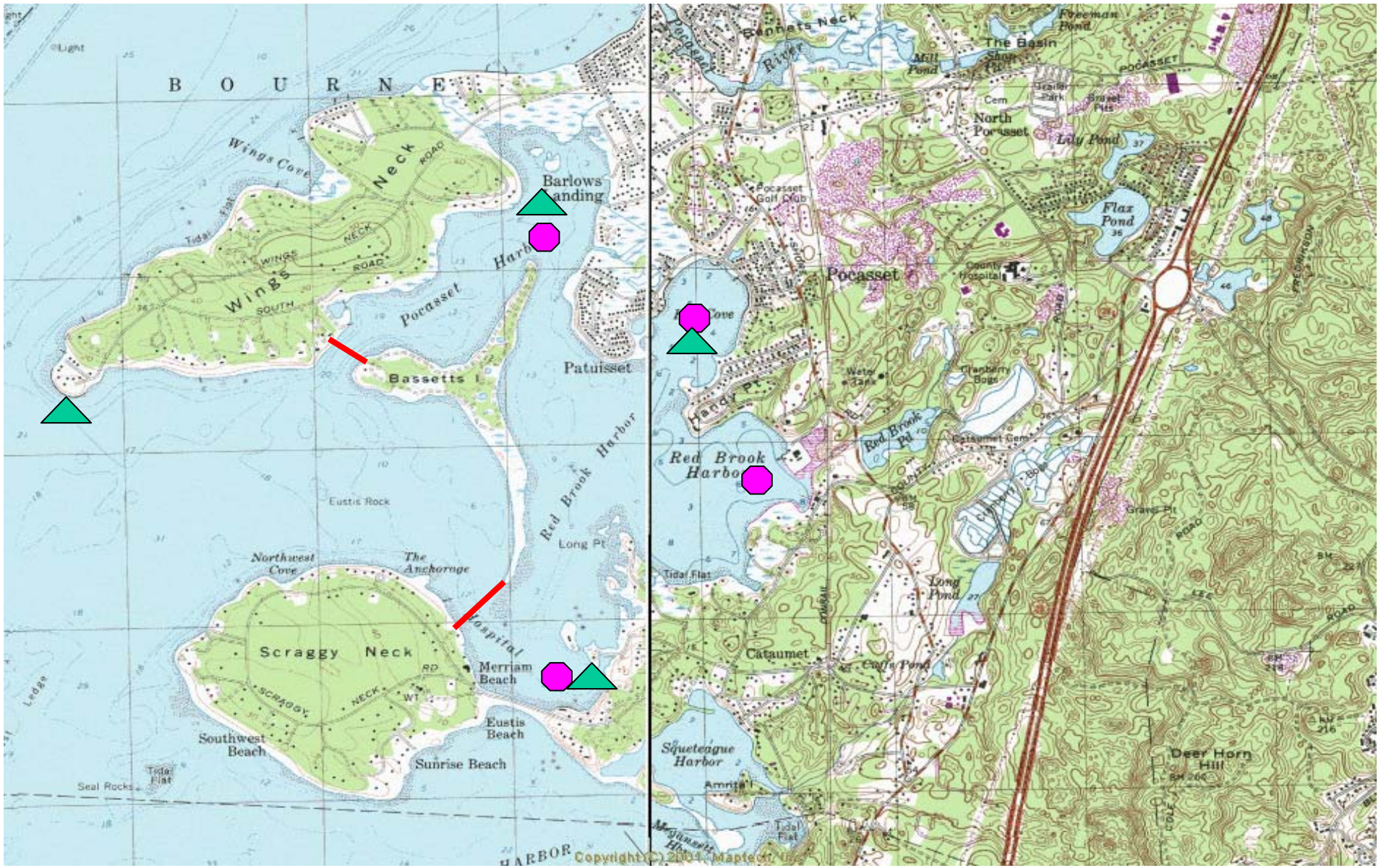
▲ Historical Nutrient Sampling Locations

Figure 2



⬣ Benthic Coring Locations △ Stream Gage/MEP Nutrient Sampling Location

Figure 3



Tide Gauge Location — ADCP — Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Red Brook Harbor (33)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Streamflow/Nitrogen Loading	a,b,c,d,e,g	Grab	1	Weekly	60	6	14 months
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	21	Once/Embayment	21	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	4**	15 minutes ****	> 2880	36 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	10	Once/Embayment	10	15	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the systems
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

MA Estuaries Project QAPP
Appendix A-XXXIV Round Cove
Town of Harwich
Prioritization Rank: Round 2 - #34

Figure 1. Location Map

Figure 2. Nutrient Sampling Locations

Figure 3. Benthic Regeneration and Stream Discharge Sampling Locations

Figure 4. Hydrodynamic Data Collection Sites: Tide Gauges and ADCP transects

Embayment Specific Plan:
Data Collection consists of Hydrodynamic Data (field data and model), Stream gauging and nitrogen sampling, GIS based Land-use analysis, Nitrogen recycling via Benthic Regeneration, Habitat Assessment (Eelgrass, macroalgae, benthic animals, DO records). Synthesis is primarily covered in the Water Quality Modeling and Reporting components. The efforts of the Estuary Project will be to fill in data gaps to allow parameterization and full modeling and synthesis following the Linked Management Approach.

Many of the embayments currently have existing data that can be incorporated into the Linked Approach. A detailed description of previous data, its quality and how it was collected will be part of the Report. However, it is useful to indicate the existing data and our initial assessment of its quality and to present the additional field and modeling work required to fully implement the Estuaries Project Management Approach.

Round Cove, Harwich*:* The Round Cove System consists of a tributary sub-embayment to the greater Pleasant Bay embayment system.

The main Estuaries Project efforts will be to (1) incorporate Round Cove into an up-graded current hydrodynamic model for the greater Pleasant Bay system which will require limited placement of tide gauges and conducting point velocity measurements; (2) update the existing land-use and watershed nitrogen loading model based upon the new USGS watershed delineation; (3) conduct benthic infaunal survey; (5) collect dissolved oxygen records within each of the key tributary embayments; (6) map eelgrass distribution; and (7) conduct the water quality modeling, thresholds analysis and synthesis.


Round Cove
Atlantic Ocean
Plymouth
Bourne
Barnstable
Hyannis
New Bedford
Cape Cod Bay
Martha's Vineyard
Edgartown
Nantucket

Figure 1



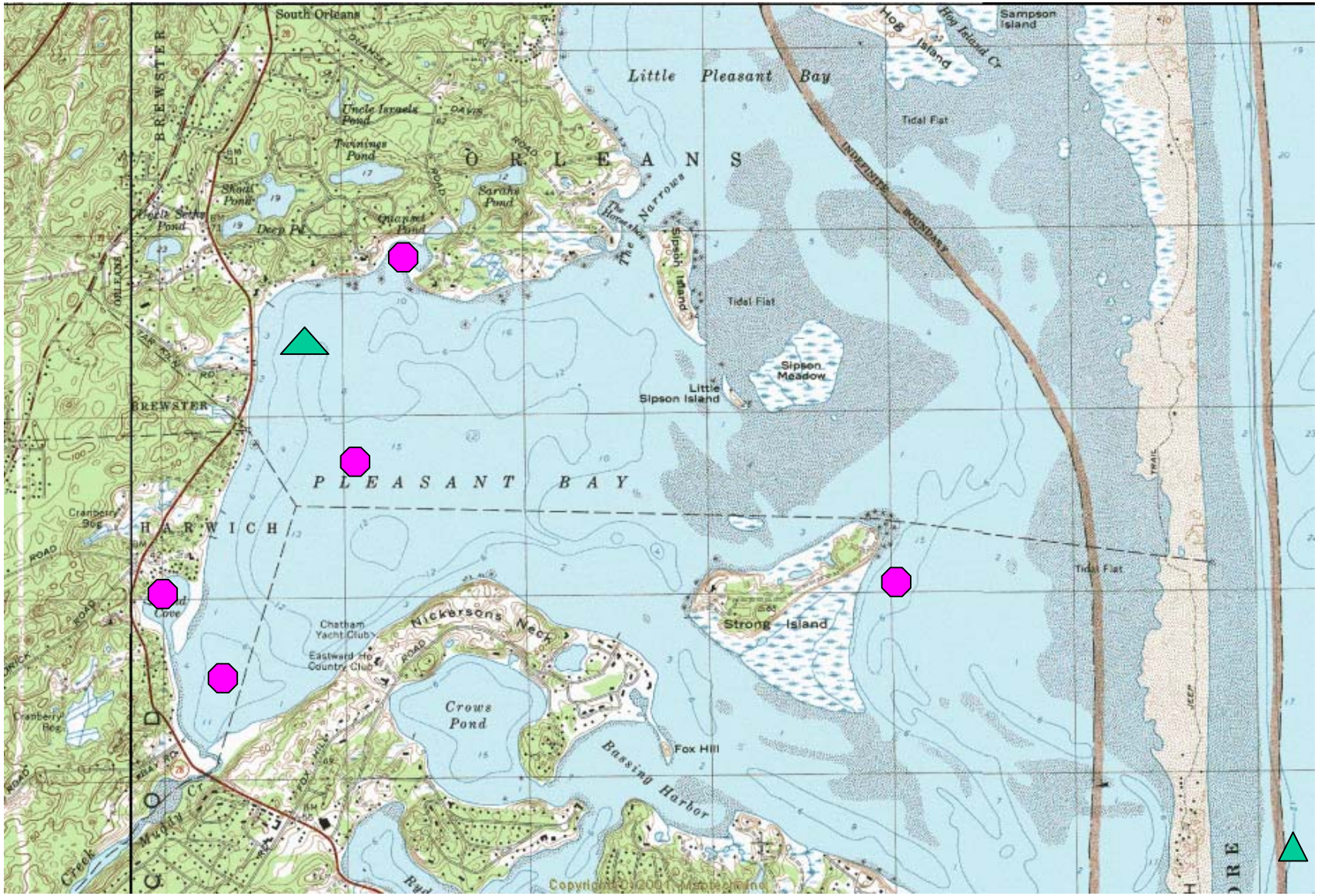
▲ Historical Nutrient Sampling Locations

Figure 2



Benthic Coring Locations Stream Gage/MEP Nutrient Sampling Location

Figure 3



Tide Gauge Location — ADCP Transects — Dissolved Oxygen Mooring

Figure 4

Massachusetts Estuaries Project
Tabulations of Field Samples
Round Cove (34)

PROGRAMMATIC ELEMENTS *	SAMPLE CATEGORY	MEASURED PARAMETERS	SAMPLE TYPE	NUMBER OF SAMPLING STATIONS	SAMPLING FREQUENCY	NUMBER OF SAMPLES	NUMBER OF QC SAMPLES	COLLECTION PERIOD
HYDRODYNAMIC MODELING:								
	Bathymetric Survey	NA	NA	NA	NA	NA	NA	July - June
	Tidal Exchange ADCP	NA	NA	NA	NA	NA	NA	July - June
	Modeling/Validation	NA	NA	NA	NA	NA	NA	July - June
WATERSHED NITROGEN LOADING:								
	Freshwater Ponds	NA	NA	NA	NA	NA	NA	NA
	Watershed Delineation	NA	NA	NA	NA	NA	NA	NA
	Land Use Analysis	NA	NA	NA	NA	NA	NA	NA
	Stream flow/Nitrogen Loading	a,b,c,d,e,g	NA	NA	NA	NA	NA	NA
	Watershed N Loading Model	NA	NA	NA	NA	NA	NA	NA
NITROGEN REGENERATION:								
	Benthic Coring	a,b,c,d	Time Course Incubation	8	Once/Embayment	8	1	July - August
HABITAT ASSESSMENT:								
	Dissolved Oxygen	f,h,i,j,l,m	sensor	1**	15 minutes ****	> 2880	9 ***	July - Sept.
	Macrophyte Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Eelgrass Survey	o	Survey	NA	Once/Embayment	1	NA	July - Oct.
	Benthic Infauna	n	Grab	8	Once/Embayment	8	2	Oct. - Dec.
LINKED WATERSHED EMBAYMENT N MODEL:	NA	NA	NA	NA	NA	NA	NA	NA
SYNTHESIS OF MODELING AND HABITAT ASSESSMENT:	NA	NA	NA	NA	NA	NA	NA	NA

NOTE: * Each programmatic element of the Estuaries Project is listed regardless of whether or not it requires field data collection
** Moored Instruments in the system
*** Number of Winkler Titrations, conductivity and chlorophyll samples/assays
**** Parameters measured at 15 minute interval
NA = Not Applicable. Data collection does not involve the collection of water or sediment samples. If samples are not collected there are therefore no associated QC samples.
Measured Parameters include the following:

a = Ammonia
b = Nitrate + Nitrite
c = Phosphate
d = Dissolved Organic Nitrogen
e = Particulate Organic Nitrogen/Carbon
f = Dissolved Oxygen
g = Total Phosphorous
h = Salinity
i = Temperature
j = Secchi Depth
k = Total Depth
l = Chlorophyll / Pheophytin
m = Stage Height
n = Macro-invertabrates
o = Aquatic Plant Coverage
p = Fecal, Enterococci, E. Coli

Massachusetts Estuaries Project QAPP

Appendix B-1 Field Protocols and Data Sheets

A. Chain of Custody Record (Coastal Systems Group)

B. Bathymetric Mapping Field Data Sheet

C. Gauge Placement and Recovery Field Data Sheet

D. Field ADCP Program Data Sheet

E. Benthic Flux Field Data Sheet

F. Benthic Infauna Field Data Sheet

G. Bacteria Sampling Field Data Sheet
Bacteria Sampling Techniques

H. Nutrients Sampling Field Data Sheet
Nutrient Sampling Techniques

I. Stream Gaging Field Data Sheet
Stream Gaging Techniques

J. Basic Parameter Sampling and Analytical Protocols

K. Field Instrument Calibration Protocol

L. Eel Grass Survey Protocol

COASTAL SYSTEMS GROUP
Chain of Custody Record

Personnel Contacts

COLLECTED		RECEIVED	
name		name	
date	time	date	time
RELINQUISHED		CONTACT	
name		name	
date	local	phone/address	

Sample Notes

Special notes/ Sample Handling	Total number of samples

Sample Status

Sample ID	NH4	PO4	NO3/NO2	TDN	POC/N	TSS	CHLA	TP	Salinity	pH	Alkalinity				

Relinquished by: Date: Time:
1 _____
3 _____

Received by: Date: Time:
2 _____
4 _____

Overview: Most information is recorded with instruments (DGPS/fathometer) or paper trace

Date: _____ Notes:

Embayment: _____

Personnel: _____

Signature: _____

Weather: _____

Time on site: _____ Time off site: _____

Location: _____ Lat. _____ Lon. _____

Transect	Location Start (LAT/LON)	Location Stop (LAT/LON)	Time Start	Time Stop	Distance	Macrophytes	Transect Notes

Date: _____

Embayment: _____

Location: _____

Personnel: _____

Signature: _____

Weather: _____

Notes:

Time on site: _____

Time off site: _____

Gauge ID.	Location Description	Latitude (degrees/min.)	Longitude (degrees/min.)	Time	Height of Water above Gauge (cm)

Date: _____

Embayment: _____

Location: _____ Lat. _____ Lon. _____

Personnel: _____

Signature: _____

Weather: _____

Time on site: _____ Time off site: _____

Run No.	Tide Direction (ebb/flood)	Transect Start Time	Transect Stop Time	Max.Depth (meters)	Secchi Depth (meters)

Date: _____

Embayment: _____

Station Location: _____

Personnel: _____

Signature: _____

Weather: _____

Time on site: _____

Station: _____

Notes:

Time off site:_____

LAT: _____ LON: _____

Core Collection Time:	
Core Collection Depth:	
Secchi Depth:	
BOD (yes/no):	
Temp (deg. C):	
Nutrient Sample (yes/no):	
Filter Sample Collected (yes/no):	
Dissolved Oxygen (DO):	
Sediment Type:	
Infauna presence:	
Macrophytes (type):	
Observations:	

Date: _____

Embayment: _____ Notes:

Station Location: _____

Personnel: _____

Signature: _____

Weather: _____

Time on site: _____ Time off site:_____

Station: _____

LAT: _____ LON: _____

Van Veen 25x25 (y/n)	
Other	
Screen Mesh Size 300 mm (y/n)	
Other	
Sample ID.	
Sediment Type	
Macrophytes	
Eel Grass	
Observations:	

Bacteria Sampling Techniques and Protocol 2001

Samples will be collected by the grab sampling technique. Depending on outfall volumes, and beach access, samples will be collected in one of two ways. If flow volumes and hazards are low, samples will be collected by hand filling a sterile 500 mL nalgene bottle placed directly into the outflow. If flow volumes are high and/or there is a potential for hazard at the site (slippery access, etc.), samples will be collected using a sampling pole. A pole that holds a sample bottle securely in place during collection. Samples will be collected according to the following procedures:

1. Fill out weather and environmental information on datasheet.
2. Using a new surgical glove pick up a sterile sample container and label it with site ID, date and time.
3. Remove the lid on the bottle taking care not to contaminate inside the lid or bottle. Hold the lid.
4. Face into the flow or current.
5. Turn the bottle upside down so that the opening is facing straight down and plunge the bottle into the water approximately 12 inches.
6. Turn the bottle horizontal with the mouth facing into the current and allow to fill as you “wiggle” the bottle mouth into the flow.
7. Raise the bottle out of the water and pour off enough water to have the water level at the shoulder of the bottle (this allows for the laboratory to shake the sample), cap the sample tightly and place the bottle on blue ice in a cooler.
8. If using a sample pole, lower the sampling pole into the flow of water at an angle, just below the water surface. Position the bottle so the opening is upstream from the pole. Water should flow directly into the bottle and should not contact the pole or base of the bottle before flowing into the mouth.
9. Fill to the fill line marked on the bottle leaving a half inch of air space.
10. Cap the bottle, remove it from the sampling pole and it on blue ice in a cooler.
11. Record sample ID, collection time, air temperature, water temperature (if thermometer is available) on the data sheet. Include tide if it is a beach sample.
12. Move to next location, use a new glove (to prevent any cross contamination) and repeat steps 1-12.Place all samples into the cooler with ice and ensure bottles are capped tightly.
13. Complete and sign data sheet (Chain of Custody form) before delivering samples to the laboratory or drop off location as soon as possible.

Submittal of Samples during Lab Hours
Iced samples will be delivered to the Project Coordinator, or directly to Barnstable County lab, Superior Courthouse, Barnstable MA.

Sample Processing

The laboratory will filter and culture samples for fecal coliform in accordance with the Membrane Filtration Technique (Standard Methods, 18th Edition) using m-FC agar by DIFCO. Samples will be filtered within 6 hours of collection time.

Sampling Equipment

- cooler
- blue ice
- 500 mL sterile bottles (minimum size – 100ml)
- graduated cylinder for temperature and salinity parameters
- field thermometer
- Hydrometer or refractometer
- sampling pole
- disposable surgical gloves
- (4) large rubber bands to attach bottle to pole
- waterproof pen
- permanent markers (Sharpie)
- data sheet & Chain of Custody

Embayment: _____ Shore/Boat: _____
Town: _____ Last Rain: _____
Area Description: _____ Amount: _____
Personnel: _____
Signature: _____
Date of Collection: _____ Page _____ of _____
Low Tide: High Tide: Air Temp: Wind Dir:

Lab ID	Station ID	Location Description	Collection Time	Tide (E/F)	Grab or Composite	Pipe Flow (estimate)	Temp. (deg. C)	Salinity (ppt)	pH	Comments	Results

Relinquished by: Date: Time: Received by: Date: Time:
1 _____ 2 _____
3 _____ 4 _____

Massachusetts Estuaries Project
Field Sampling Protocol: Nutrients

Water Quality Program

Nutrient Sample Collection Overview

The goal of the Water Quality Monitoring Program is to provide needed data with which to evaluate overall water quality conditions in nearshore waters and harbors. These waters are most likely to be impacted by excessive nutrient loading originating from local land use. Because of the value of this data, it is very important that measurements are made using the protocol provided AND that collections be during the last three hours of an outgoing tide. Through training sessions, hands-on instruction and sampling tips, we will provide you with the information necessary to ensure efficiency and accuracy in the measurements. Please call (Roland Samimy 508-910-6314) if you have any questions and note any problems on the data sheet.

In addition to nutrient sample collection and filtering, the following measurements need to be taken **at each station**: **water temperature, salinity, water clarity** (secchi disk) and **total depth**. Samples collected for nutrients will be analyzed at the SMAST laboratory for:

Ammonium	Nitrate+Nitrite	Particulate Organic Nitrogen
Ortho-Phosphate	Chlorophyll a & pheophytin a	Particulate Organic Carbon
Diss. Org. Nitrogen	Total Phosphorus (as needed)	Specific Conductance

GENERAL/ WEATHER CONDITIONS Record parameters listed on data sheet:

*Time of nearest low tide from tide table and whether the tide is ebbing (approaching low) or flooding (approaching high)
*Wave conditions - see Beaufort scale
*Wind direction - the direction the wind is coming from
*Weather conditions
*Rainfall in last 24 hours.

SECCHI DEPTH/TOTAL DEPTH

Step 1. Lower Secchi disk into water slowly from shady side of a boat, dock or pier until it just disappears from view. Raise and lower slightly to insure the proper average depth of disappearance.

Step 2. Read depth on tape where it intersects the water surface, record on data sheet. *Note: Sometimes the secchi disk will hit the bottom before it disappears — in this case write "visible on bottom" or "vis/btm" on disk depth on data sheet.*

Step 3. Lower secchi disk slowly until it touches bottom, record station total depth.

NUTRIENT SAMPLE COLLECTION PROTOCOL

Each of these steps will be performed by you at each station in your embayment beginning in the inner portion and moving outward (toward the inlet). Samples are collected by Sampling Pole or Niskin Bottle. A surface sample will be collected at every station at 15 cm

below the surface at pre-selected depths with the bottom sample 50 cm above sediment surface (be sure not to hit the bottom).

COLLECTION

MAKE SURE **ICE** IS IN COOLER

1. **a)** Label one 1 liter nutrient (white) bottle and one 1 liter chlorophyll (brown) bottle with station I.D., date, depth, and time of collection).
   b) Lower sampling pole with the 1 liter nutrient (white) sample bottle and oxygen bottle to 15 cm below the surface, pull oxygen stopper and then the white 1 liter bottle stopper, bring to surface, shake and dump to rinse bottle; replace stoppers then repeat, making sure to pull the oxygen bottle stopper first and let the bubbles stop before pulling the white 1 liter bottle stopper.
   c) Immediately cap nutrient (white) bottle, put in cooler, and shut cooler lid.
   d) Use the water in the oxygen bottle to determine water temperature with thermometer.
   e) Lower sampling pole again with 1 liter brown Chlorophyll bottle to 15 cm below surface, pull stopper, bring to surface, cap and put in cooler. Shut cooler.

******PUT NUTRIENT AND CHLOROPHYLL SAMPLES IN COOLER IMMEDIATELY*****

2. Take secchi depth and total station depth.
3. If a bottom sample is required, repeat ***a*** through ***e*** at a depth of 30cm above the bottom. If water is >3 meters (depth of sampling pole) a Niskin Sampler should be used.
4. Move to next station, repeat.

Note: Surface samples can be taken by hand or with the sampling pole. If taking samples by hand you must hold the open bottle in **a** inverted vertical position while submerging to the desired depth and then tip upright to fill.

You have just collected:
White 1 liter bottle - used for two analysis, dissolved and particulate nutrients
Brown 1 liter bottle – particulate (phytoplankton) chlorophyll content and total phosphorus (on stream samples)
Water Temperature
Secchi and Total Depths

On station (preferable) or back on shore

FILTERING

- TO BE DONE AS SOON AS POSSIBLE AFTER COLLECTION,

- Filtered samples are to be shipped in the small white 60 cc plastic bottle (these bottles are acid leached),
- Write label directly on plastic bottle with provided permanent marker (date, time, station, depth, embayment name)

Procedure:

1) Remove white 1 liter sample bottle from cooler, one station bottle at a time.
2) Label a 60cc btl with identical station information:
   - Embayment name
   - Station ID
   - Sample Depth (in meters)
   - Date (mo/dy/yr)
3) Place filter (using provided forceps) in clear plastic filter holder. (white filter, not the blue paper).
4) Shake 1 liter nutrient (white) sample bottle (in case of particulate settling) and fill 60cc syringe with water from bottle by removing plunger and pouring in, replace plunger.
5) Attach filter (cup side up) to syringe (most filter holders have an arrow drawn on side indicating the direction of flow) and push through and discard the first approx. 30 cc of water through the filter.
6) Push next 20 cc - 30 cc of water through the filter into the small 60 cc sample bottle, replace cap, shake and discard water.
7) Now refill syringe, **attach to filter** (cup side up) and collect all water through the filter into the now rinsed bottle until bottle is full to shoulder, **taking care that no unfiltered water drips into sample**, Fill bottle to top leaving only a small (2-3 ml) bubble, cap and put on ice.
8) Cap 1 liter nutrient (white) sample bottle with the remaining water, check label and put on ice. The bottle must be at least ¾ full to be used for analysis.
9) Remove used white filter paper and discard.
10) Repeat steps a) through h) for each 1 liter nutrient (white) sample bottle.
    The samples must remain in the dark and cold. Keep cooler lid closed.

Samples must be returned the same day as collected to the designated shipping point and Chain of Custody forms signed. Samples can be brought directly to the SMAST Laboratory at 706 Rodney French Blvd, New Bedford, MA 02744. Questions call Roland Samimy 508-910-6314 or the Laboratory at 508-910-6352.

Embayment: _____

Personnel: _____

Signature: _____

Date of Collection: _____ Page _____ of _____

Station ID / Description	Sample Depth (m)	Collection Time	Secchi Depth (m)	Total Depth (m)	Temperature (degree C)	Salinity (ppt)	D.O

Relinquished by: Date: Time: Received by: Date: Time:

1 _____ 2 _____

3 _____ 4 _____

Massachusetts Estuaries Project
Field Measurement Protocol: Stream Gaging

The overarching mission of the Massachusetts Estuaries Project is the protection and restoration of the health of each of the each coastal embayments within Southeastern Massachusetts through integrated watershed-embayment nitrogen management planning. The proposed effort will provide technical guidance to DEP relative to policies on nitrogen sensitive embayments and will perform the data collection and modeling required for the management and restoration of southeastern Massachusetts' 89 embayment systems. This program will also provide the scientific foundation for DEP's development of nitrogen (and to a lesser extent bacterial) TMDL's on these estuaries.

The goal of the stream gaging component of the Estuaries Program is to quantify the nutrient load and freshwater inflow from major streams which discharge to each estuary. These data will be used to:

- Validate the USGS watershed discharge modeling results
- Quantify the surface water nitrogen load
- Determine site-specific nitrogen attenuation values for the surface water flows to each embayment (comparison of watershed model to stream nitrogen discharge results).

Approach
Nutrient loading to an embayment through a stream is in part dependent on quantifying surface water flows (Q, volumetric discharge) and the associated nitrogen concentration in that discharge volume. For the purpose of this stream gaging protocol, flow will be calculated from continuous measurements of water level, stream cross sectional area, and periodic measurements of velocity. Stream water levels will be measured (15 minute intervals) using a Global Waters Water Level Logger: WL-15 or equivalent. The gauges will be vented to the atmosphere. Stream cross sectional areas will be measured using a top-setting wading rod. Permanent markers will establish the cross-section location. A Marsh McBirney Flow-mate Model 2000 or equivalent current meter will be used to measure stream velocities. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities will represent the computation of stream flow (Q). A rating curve will be developed for each gauge to transform level data to discharge rates.

Station Location
Selection of stream gaging station locations will be based on:

- Accessibility
- Lack of tidal influence
- Section of stream providing a generally straight channel
- Streambed is free of aquatic growth and relatively smooth
- Unchanging natural control
- Stream channel does not go dry during low flow periods
- Gage site is not influenced by backwater effects (culverts, dams, confluences)

- Stable channel cross section

It will not be likely that all the above listed criteria will be able to be satisfied by all sites being considered, however, attempts will be made to find gauging sites that meet as many of the listed criteria as possible.

Ingress and egress to a potential site will be field verified and ownership of the site will be investigated. Permission to access a potential site will be gained from the owner of the site prior to using the site as a stream gauging station location.

Tidal influence on stream flow will be assessed prior to selection of a gaging station location. The assessment of tidal influence will initially be based on observation of stream habitat flora. Observations will be made in the field to determine the presence of freshwater plant species. Should the site under consideration be selected, a water level indicator will be installed to record stream levels and lack of tidal influence will be confirmed via instrument measurement. Should a slight tidal influence be present, numerical filtering techniques will be applied to the data to screen the tidal influence out of the data.

All stream gauging locations will be selected in stream reaches that are not influenced by backwater effects resulting from the presence of stream confluences, drainage culverts, dams or other naturally occurring or artificial structures. The gauging location will be situated down-gradient from culverts and dams and far enough up-gradient from a confluence that water level not be effected. In the absence of stage and discharge data at a potential gauge site or concurrent stage at the stream confluence, the gauging site selected will be the one located furthest away from the known confluence.

Stream Cross Section Measurements
After having identified an acceptable stream cross section where velocity measurements will be made, the selected cross section will be waded with a top setting wading rod in order to establish the profile of the cross section. The stream channel profile will be established before each run of velocity measurements.

A measuring tape will be manually stretched across the width of the stream channel and, while facing up-stream, the left and right banks of the channel will be noted in feet using the measuring tape. The transect will be marked with permanent markers to which the tape measure will be affixed on each sampling occasion. Water depth across the width of the stream will be measured in 0.5 foot increments using the top setting wading rod. Water depth will be measured in meters. Total stream channel cross sectional area will be the summation of the total number of segment cross sectional areas.

The stream cross section location will also be described in the field record book in order to maintain a record of changes in the channel bottom or bank characteristics.

Stream Water Level Measurements
Stream water level measurements will be obtained using a Global Waters Water Level Logger (WL-15) or some equivalent instrument. The factory calibrated water level loggers will be prepared in the laboratory for deployment in selected streams by checking that the

instrument is properly sealed to prevent malfunctions resulting from moisture build up in the instrument casing. Deployments will typically be continuous for approximately one year.

The water level instrument will typically be encased in a PVC tube, open ended on the bottom so that the instrument cable can run freely and capped on the top so that moisture cannot degrade the instrument communication port. The PVC encased instrument will be mounted to a convenient and permanent natural or artificial structure and the water level probe held in the desired location in the stream reach using either a stilling well or placement on a flat weight (ca. 40 lbs) in shallow streams. The instrument cable will be run as unobtrusively as possible so as to be hidden from view and to not become an obstacle. The water level probe will be placed at the deepest point in the stream channel so as to remain submerged during low flow seasons and mean sea level will be used as the vertical datum to which the probe is referenced. The water level probe will be weighted down appropriately so as to prevent the probe from migrating down stream during increased flow rates.

Water level data will be down loaded monthly in the field via lap top computer. Water level data will be field verified each month against either an in-stream surveyed staff gage or by making a manual water level measurement of height of water over the water level probe using a tape measure. Measured height of water over the in-stream water level probe will be compared to water level data record to confirm that data record is comparable.

Stream Water Velocity Measurements

Stream water velocity measurements will be taken, at a minimum, each time the WL-15 water level logger is down loaded. Additional velocity measurements may be taken in between instrument down loads depending on weather conditions in order to capture high or low flow events. Nutrient samples for total nitrogen will be collected on each visit to the gauge site.

Field data sheet for collection of velocity data have been developed and will be used to record velocity measurements, stream depths, and distance from the right or left bank where a velocity measurement is taken. In the absence of a field sheet, the same information can be recorded in a field stream gauging book (as used by the USGS).

Field data collected for each specific stream being profiled will include:

- Name of the embayment receiving the stream discharge
- Name of the stream/river being profiled
- Name of the person doing the velocity measurements and those assisting
- Date/time
- Weather conditions (clear, fog, cloudy, drizzle, intermittent rain, rain, snow, etc.)
- Left bank distance in meters (facing upstream)
- Right bank distance in meters (facing upstream)
- Distance from bank where velocity measurement is being taken

- Velocity (m/s)
- Depth (meters)
- Height of water above water level logging probe (meters)
- Staff gage measurement (where available)
- Nutrient sample collection (sample ID)

Stream Flow Calculation

Determination of stream flow will be calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge will be represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section WILL NOT be averaged and then applied to the total stream cross sectional area.

The formula that will be used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/day)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Nitrogen discharge is calculated using the paired discharge and nitrogen concentration data to determine the mass flux of nitrogen through the gauging site. These data are expressed as nitrogen mass per unit time (kg/d). The mass flux over the period of interest (month, season, year) is determined by integrating the area under the appropriate interval of the daily mass flux versus date graph.

Instrument Calibration and Verification

Instrumentation deployed or utilized as part of the stream gauging program are factory calibrated. The factory calibration is checked for the Marsh McBirney Flow mate 2000 velocity meter by placing the velocity probe into a test tank containing still water. The velocity meter probe is mounted on a sled that runs the length of the test tank at a constant speed. The speed of the sled is varied in order to check the velocity meter function at low, medium, and high flow rates. Sled runs should be conducted at speeds that capture the range of flow rates that are encountered in the field program. Four sled speeds have been traditionally used in previous SMAST studies to check the calibration of the velocity meter (2.0 cm/s, 20cm/s, 40cm/s, and 80cm/s). Multiple repetitions at a selected sled speed are performed. A three to ten minute time interval is typically used between runs to allow the water in the test tank to return to still conditions. Potassium

permanganate is introduced to the tank between the runs at higher speeds to check that the water in the test was sufficiently still to begin the next run.

The velocity meter calibration check is begun by running the test tank sled at the lowest check speed of interest and then increasing the speed of the calibration check runs incrementally until the highest check speed is reached. Afterwards, the lowest speed is re-run to check that instrument drift is not occurring. If a drift of more than 5% is encountered the instrument is sent back to the manufacturer for maintenance.

Water level loggers are factory calibrated prior to the start of the field season. The function of the probe is field verified each time a velocity profile is being run by measuring the height of water over the probe with a measuring tape and comparing the manual measurement with the instrument measurement. Manual measurements are subsequently plotted against instrument measurements and simple linear regression analysis is performed on the data to determine the linear relationship. The calibration is acceptable if the $r^2 > 0.98$.

Watershed / Embayment: _____
Stream / Creek: _____
Gauge ID.: _____
Date: _____
Time: _____
Personnel: _____
Signature: _____
Gauge Data Downloaded (y/n): _____

Height of Water above Transducer (cm): _____

Nutrient Sample (y/n): _____ Sample ID: _____ Sample Depth: _____

Parameters	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8	Section 9	Section 10
Velocity (cm):										
Measurement Depth (cm):										
Total Water Depth (cm):										
Total Width (cm):										
Notes:										

Massachusetts Estuaries Project
Field Sampling Protocol: Physical Parameters

Water Quality Program

BASIC PARAMETER SAMPLING AND ANALYTICAL PROTOCOLS

MONITORING OVERVIEW

1) Record weather and general observations
2) Measure secchi depth and total depth
3) Collect surface sample -analyze temperature, dissolved oxygen, salinity
4) Collect bottom sample* -analyze temperature, dissolved oxygen, salinity

GENERAL/ WEATHER CONDITIONS

Record parameters listed on data sheet:

* Time of nearest low tide from tide table and whether the tide is ebbing (approaching low) or flooding (approaching high)
* Wave conditions- see Beaufort scale
* Wind direction- the direction the wind is coming from
* Weather conditions
* Rainfall in last 24 hours.

SECCHI DEPTH/TOTAL DEPTH

Step 1. Lower Secchi disk into water slowly from shady side of a boat, dock or pier until it just disappears from view. Raise and lower slightly to insure the proper average depth of disappearance.

Step 2. Read depth on tape where it intersects the water surface, record on data sheet. *Note: Sometimes the secchi disk will hit the bottom before it disappears — in this case write "visible on bottom" or " vis/btm" on disk depth on data sheet.*

Step 3. Lower secchi disk slowly until it touches bottom, record station total depth.

COLLECTING A WATER SAMPLE

Note: *For simplicity we use the sampling pole for both surface and deep water sample collection.*

Step 1. Put stopper in salinity/temperature bottle(1 liter narrow mouth) and in the oxygen bottle (0.5 liter wide mouth). Make sure the tube on the oxygen bottle is secured in the wire loop at the mouth of the bottle.

Step 2. Move a couple of feet up current from where you measured total depth (to avoid disturbed sediments from the secchi). Lower the sampling pole gently to the appropriate depth (6 inches (15 cm) below the water surface for the surface sample and 1 foot (30 cm) above the bottom for bottom sample)[Use total depth minus 30cm to calculate depth for bottom sample] *Collect surface and bottom samples when there is at least 1.2 meters (4 ft) of water at your station. If there is less than 1.2 meters (4ft) collect a bottom sample 30 cm (1ft) up from the bottom sediment without disturbing bottom sediment. However, if there is less than 50 cm (1.6 ft) only collect a surface sample at*

that location (if there is sufficient depth to collect a sample without hitting the sediment with the sampling gear).

Step 3. While holding sampling pole in place, pull the colored string oxygen bottle stopper first, let sample bottle fill.

Step 4. When all bubbles have ceased coming to the surface then pull salinity/temperature bottle stopper (1 liter), allow to fill. *NOTE: It is imperative that the oxygen bottle (colored string) is filled first to avoid oxygenating the sample from air within the salinity bottle.*

Step 5. Keeping the pole vertical, bring the samples on deck for analysis.

Step 6. Record sampling collection time and sample depth on datasheet.

WATER SAMPLE ANALYSIS

First: Fill glass O_2 reagent bottle from blue oxygen kit:

Step 1. Remove glass stopper.
Step 2. Lower rubber tube from oxygen bottle on pole to the bottom of the glass reagent bottle from the blue oxygen kit.
Step 3. Drain ¾ of the poles plastic oxygen (0.5 liter) bottle through the glass bottle, overflowing the glass bottle.
Step 4. Gently tap glass bottle to insure that no bubbles stick to sides.
Step 5. As volume reaches ¾ of the 0.5 liter plastic bottle, slowly remove the rubber tube from the glass bottle and then carefully insert glass stopper so as not to trap any bubbles. Dropping glass stopper in from above works best.
Step 6. Set sample aside in the shade for now.

Next: Put thermometer in the salinity/temperature bottle on pole, let stabilize, record this as "water temperature". Remove thermometer and cap the salinity bottle and set it aside till after the dissolved oxygen is tested.

Now: Continue the dissolved oxygen analysis instruction below....

DISSOLVED OXYGEN

1. open Reagent packet #1 (use the scissors in your kit);
2. open Reagent packet #2
3. remove glass stopper from glass oxygen reagent bottle;
4. pour Reagent #1 into bottle and then add reagent packet #2 to bottle.
5. replace glass stopper, careful not to trap bubbles.
6. shake bottle vigorously holding bottle and stopper (some reagent may stick to bottom of bottle...this is O.K.).
7. let stand 2 minutes, shake again.

NOTE: If you have a hydrometer for salinity, YOU CAN MEASURE SPECIFIC GRAVITY (Salinity) WHILE YOU WAIT, if you are sending samples to the laboratory for salinity analysis, check the bottle label and put in ice chest.

8. After a total of 5 minutes (when the chemical floc has settled the second time and there is a clear division), open Reagent packet #3, remove glass stopper, add powder to bottle, replace stopper (no bubbles), shake vigorously until water in bottle becomes clear (no #3 particles). *THE SAMPLE IS FIXED NOW AND CAN BE TRANSPORTED TO THE LABORATORY IF APPROPRIATE – IN THE ICE CHEST AND DARK*. If you are titrating the samples in the field proceed to #9 below.

9. Remove glass stopper and fill small plastic tube from kit to top TWICE (two volumes) pouring each time into the square glass bottle in the kit. It helps to tip the bottle to overcome the surface tension.

10. To determine the oxygen content, shake the sodium thiosulfate solution in the brown plastic bottle in kit. Take the eyedropper and fill with sodium thiosulfate solution. Now the critical part: (be sure to hold dropper upright) add 1 drop to the square bottle and swirl. Continue to add and count drop by drop (about 10 seconds between drops) and swirl until the yellow color goes away. Record the number of drops (1 drop = 0.5 mg O_2/liter-ppm).

***NOTE**: Be careful not to contaminate sodium thiosulfate solution by touching the dropper in O_2 sample.*

11. Pour waste reagent in to waste bottle and save for disposal.
12. Rinse all the oxygen kit bottles and plastic tube with tap water and shake dry before processing next sample.

SALINITY = SPECIFIC GRAVITY/TEMPERATURE WITH HYDROMETER

Step 1. Rinse 500 ml graduated cylinder with 100-200 ml sample from 1 L salinity bottle on pole.
Step 2. Rinse hydrometer directly from bottle with a little water (50-100 mls).
Step 3. Fill graduated cylinder with 500 ml of sample.
Step 4. Gently place hydrometer in cylinder (do not drop).
Step 5. Read number on stem of hydrometer where it intersects the water line in the cylinder, record.
Step 6. Take hydrometer out and put thermometer into cylinder and measure temperature (AGAIN); record as cylinder temperature on data sheet.
Step 7. Obtain salinity in ppt. from your table, record on data sheet.
Step 8. Rinse equipment with tap water from squirt bottle.

Rinse off sampling pole and allow kit to air dry in cool dry place.

Look over your data sheets to make sure everything is complete.

Mail or Deliver data to: Coastal Systems Program, SMAST-UMassD, 706 Rodney French Blvd, New Bedford, MA 02744. Questions to Roland Samimy 508-910-6314.

Massachusetts Estuary Project
Standard Operating Protocol: Field Instruments

Field Instrument Calibration Protocol

Calibration of Field Equipment
NEW EQUIPMENT CALIBRATION PROCEDURES:

THERMOMETERS:

- Set up an ice bath in a large bucket. Fill the bucket close to the top with small ice cubes and water. Be sure the ice is distributed evenly throughout the entire bucket. You will want to be sure the sensors are not in a pocket of water.
- Set up a room temperature water bath. Fill another large bucket close to the top with tap water.
- Set aside an undisturbed area in which to take air temperature.
- Place all the thermometers as close as possible and record all air temperatures after allowing them to stabilize.
- Place all the thermometers in holes made in a cardboard sheet placed over the water temperature bath. Allow them to stabilize for a few minutes then record temperatures.
- Place the cardboard sheet and thermometers over the ice bath. Allow them to stabilize and record the temperatures.
- Calculate differences. Any thermometer with a difference greater than 1.0 degree should be recalibrated if possible or else discarded.

HYDROMETERS:
Take refractometer readings of each solution before and after testing hydrometers.

- Rinse all hydrometers to be calibrated with deionized water and dry.
- Fill one 500 ml graduated cylinder with fresh water.
- Fill a second 500 ml graduated cylinder with water known to be of 10 ppt salinity.
- Fill a third 500 ml graduated cylinder with water known to be of 20-25 ppt salinity.
- Place calibrating thermometer in fresh water cylinder. Read each hydrometer and record the temperature at the time of each reading.
- RINSE EACH HYDROMETER WITH DEIONIZED WATER AND DRY
- Place calibrating thermometer in the 10 ppt salinity cylinder. Read each hydrometer and record the temperature at the time of each reading.
- RINSE EACH HYDROMETER WITH DEIONIZED WATER AND DRY
- Place calibrating thermometer in the 25 ppt salinity cylinder. Read each hydrometer and record the temperature at the time of each reading.
- Calculate the salinity for each reading and compare. Discard any hydrometer with a salinity more than 1.5 ppt off standard.

OXYGEN

- Have volunteers simultaneously lower sampling poles, pull stoppers and collect sample. Have each volunteer record the temperature, process and record oxygen concentration.
- Check value with oxygen meter value. Repeat test if oxygen differs by more than 0.5 ppm.

FIELD TESTING OF EXISTING EQUIPMENT

Additionally, the Coordinator will field test and calibrate existing equipment in the field against new calibrated equipment and replicate an oxygen analysis during field visits. The Coordinator will make sure that each thermometer and hydrometer are within acceptable ranges and will record the results. If the equipment is not within range it will be replaced with pre-calibrated equipment. The equipment will then be calibrated within the new equipment procedures and if it fails to measure within the limits will be discarded. In addition, parallel samples will be sent to the laboratory for assay by specific conductivity meter (3-4 times per season) as an additional QA check. Any discrepancies in oxygen analysis will be resolved in the field through repeated sampling or correction of improper sampling techniques by the Coordinator.

Any new or additional sampling equipment (DO meters, refractometers, etc) will be maintained and calibrated under the manufactures specifications and requirements with assistance from the SMAST Lab or the manufactures maintenance program if contracted.

Massachusetts Estuary Project
Standard Operating Protocol: Habitat Assessment

Eel Grass Surveying Protocol

The purpose of the Eelgrass Mapping Study is to provide critical site specific information on this key habitat quality indicator. The synthesized data takes the form of present maps of eelgrass distribution and historic trends in eelgrass coverage. This work is a continuation of the DEP mapping program (C. Costello). Data will be recorded and displayed on a digital base map which will include the accurate location of field note information and graphic representation of specific sampling points. Transects will be surveyed by differentially-corrected GPS to provide accurate coordinates for subsequent monitoring efforts. High resolution underwater digital videography (GPS stamped) will be collected and stored for the specific point and transect sites. This digital imagery will be included in the database and will be available for distribution.

EQUIPMENT: The following equipment is required to safely and efficiently conduct the fieldwork:

A power boat with a dependable outboard motor
A differentially corrected GPS receiver linked through
a laptop with GIS software to GPS points and fieldnote information.
An underwater color video camera system which produces high resolution digital imagery.

SITE SELECTION PROCESS:
All of the eelgrass beds within the selected embayment will be surveyed. In larger beds or beds where changing conditions have been pre-determined, several survey points and/or transects may be established. All known sites of Ruppia maritima, widgeon grass, will be surveyed within each embayment.

TRANSECT SELECTION PROCESS:
A minimum of two transects will be completed in each waterbody where an eelgrass polygon has been selected. These transects will represent several accurate "replicate sampling points" within each waterbody which can be monitored for changes over time. The transects will be conducted on a course which runs perpendicular to the shoreline unless site specific conditions (mooring lines/lobster pot lines) require another course direction.

METHODOLOGY

1. Two floating markers (buoys) will be placed to create a transect line at right angles to the shoreline. Buoy A will be placed as close as possible to the shoreline edge of the eelgrass bed as is safely possible. This inshore point will be called Point 1 and a GPS position will be recorded for this point. Buoy B will be placed outside the deeper edge of the eelgrass bed.
2. Once the transect line is established, the boat will be operated seaward from Buoy A to Buoy B with the towed underwater video camera (TOV) functioning and sending video signals to the color monitor in the boat. The boat will be operated at a speed not to exceed 3 km/hr. The monitor will be observed by the field crew and observations will be recorded into a digital database. This digital data base is geo-referenced by means of a GPS unit coordinated with the digital NOAA Coastal Chart displayed on the computer.
3. One point will be selected from each transect line as being representative (or an unusual observation within the transect). This point will be called Point 3 and a buoy will be deployed to accurately mark this point for later data capture.
4. The boat will continue on its transect to a point where the eelgrass bed terminates (where no more plants are observed). This point will be called Point 2 and a GPS position for this point (called the outer edge) will be recorded.
5. The boat will return to Point 3. The following sampling method will be completed: The boat will anchor and be allowed to come up into the wind to a relatively stable position. The TOV will be deployed in the vertical position to produce a sampling unit displayed in the monitor and viewed in the boat.

The following information will be recorded into the digital field notes for each point:

- Eelgrass polygon identifier number (referenced to embayment)
- Date/Time
- Location (lat/long)
- Tidal Stage (as referenced to Boston or Newport tide charts).
- Depth
- Presence/Absence of Eelgrass
- Percent Cover Eelgrass
- Presence/Absence Macroalgae
- Percent Cover Macroalgae
- Substrate Type (mud/sand/muddy sand)
- Secchi Depth
- Epiphytic presence
- Evidence of disease
- Other observations

Samples of the digital videography of the bottom conditions at the point will be recorded and saved to the file.

FIELDWORK GUIDELINES

The fieldwork season is limited by many factors which effect the quality of the data and also the safety of the crew.

Sampling Period: May thru September.

Weather Conditions:

Wind: Winds should be less than 12 mph and should not have exceeded that velocity during the prior 12 hours.

Waves: The seas should be relatively calm (< 2 foot) on the 12 hours prior to and during sampling. Wave action can create a hazardous situation while surveying the near shore data point (pt. 1). Wave action and swells can present a potentially damaging environment for the equipment (esp. the TOV). Wave action also tends to re-suspend sediments which reduces the quality of the underwater photography and viewing.

Boat Equipment/Handling:

Boat: Boat needs to be a minimum of 18 feet with a shallow draft (,12 inches).. Outboard needs to have a power tilt to maneuver in the shallow and rocky areas.
Handling: The boat needs to be operated with caution when moving within the eelgrass resource area. During low tide conditions, the inner edge of the transect (pt. 1) will not able to be included in the GPS survey (data dictionary will indicate whether the inner edge is recorded).

DATA MANAGEMENT

The transect and point survey data will be collected digitally. The following is a description of the data to be collected and the final digital map/data base of the results:

1. Total collection of possible sampling sites and attribute information will be recorded in spreadsheet format.
2. Grid sampling data collected will be recorded in a digital attribute table coordinated with GPS –derived location information. This data is compatible with GIS software (ArcVew) which will be used for the development of the final digital base map.
3. Captured digital imagery will be stored on an external hard drive it will be encoded with the GPS location and will be geo-referenced to the database and will be included as part of the final project report.

Massachusetts Estuaries Project QAPP

Appendix B-2 Data Review and Acceptance Criteria

Massachusetts Estuaries Project

Data Review and Acceptance Criteria

Estuaries Project Technical Team
May 24, 2002

Overview: The Massachusetts Estuaries Project was initiated in December 2001 to provide the scientific foundation for the management and restoration of 89 estuarine systems throughout southeastern Massachusetts. Since regulatory agencies and communities have been concerned over the declining habitat quality of these systems for over a decade, there have been numerous individual data collection efforts to address specific issues, such as NPDES permits, dredging, wetland restoration, etc. It is the intent of the Estuaries Project to incorporate as much of this previously collected data as possible, both for efficiency and to provide historical perspective. However, since these previous studies are not part of the present QAPP, strict review is required before incorporating their results in order to ensure data quality and comparability.

SMAST will be responsible for review of existing monitoring data and estuarine process data to determine suitability for inclusion into the water quality modeling, synthesis and development of site specific thresholds. Decisions regarding data incorporation will be made by the Estuaries Project Technical Team (which includes DEP Project Manager). There will be 4 classes of data and process for inclusion:

- gathered with a QAPP, with limits meeting the requirements of the Estuaries Project QAPP – data accepted;
- gathered with a QAPP, with limits not meeting the requirements of the Estuaries Project QAPP – data unacceptable unless further review by Technical Team deems any special considerations to allow use;
- gathered without a QAPP, but with traceable and documentable sampling and analysis which indicates data limits that meet the requirements of the Estuaries Project QAPP -- data likely acceptable after review by Technical Team;
- gathered without a QAPP and without traceable and documentable sampling and analysis related to the requirements of the Estuaries Project QAPP -- data almost certainly will be unacceptable after review by Technical Team. These data will be treated as anecdotal information.

Process: The Massachusetts Estuaries Project Technical Team will review all project data prior to its use in water quality modeling, system synthesis or thresholds development. The team will render an opinion and judgement regarding data acceptability, generally using the criteria in the 4 data classes given above. Data will be deemed to be:

- Fully useable, to be fully incorporated into the Project database;
- Useable only as supporting data, requiring Project data collection;
- Useable only as qualitative supporting information (anecdotal);
- Not useable in any fashion for this Project.

Data used in the Massachusetts Estuaries Project must, at a minimum, be traceable back to its source. The source of the data may be a specific person who was responsible for the actual data collection or it may be an organization. If a source can not be determined for any given data set, the data set under consideration will be brought to the attention of the technical team and a recommendation will be made to not accept the data for inclusion into the program. If the source of a data set can be identified with certainty, than the data set will be considered for verification of the data quality.

Verification of a data set can occur in several different ways. Ideally, the data set being considered for inclusion into the Massachusetts Estuaries Project will have been collected under an approved Quality Assurance Project Plan (QAPP), with limits meeting the requirements of the Estuaries Project QAPP. Approval of QAPPs would typically be rendered by the Massachusetts Department of Environmental Protection (DEP) or the U.S. Environmental Protection Agency (EPA). Attempts will be made by the Estuaries Project to collect QAPPs for each data set which could provide useable data to the Project. These QAPPs will be kept in the Estuaries Project library for future reference should the need arise. Should this scenario be the case, it will be recommended to the Technical Team that the data set be included into the Estuaries Project. If it is determined that the data was collected with an approved QAPP but detection limits do not meet the requirements of the Estuaries Project QAPP, data will be considered unacceptable unless further review by Technical Team deems any special considerations to allow use.

In the absence of a DEP or EPA approved QAPP, the person or organization responsible for collecting the data and the lab that was responsible for analysis of samples will be sought out for specific information regarding data collection practice and analysis. Collection of samples or measurement data, in addition to the analysis of samples by a lab, at a minimum must have been performed in accordance to a set of standard operating procedures specific to the parameter measurement or sample type being collected.

Should a data set under consideration be collected in the absence of a DEP or EPA approved QAPP and the data is not traceable back to the person or organization responsible for the collection of the data, data almost certainly will be unacceptable after review by Technical Team. These data will be treated as anecdotal information.

Verification of the quality of a data set can also be achieved should the data have been peer reviewed or published in a scientific journal. In these cases, the protocols are available in the “Methods” section of the paper. However, the data collection and analysis still needs to be reviewed by the Technical Team to determine if it satisfies the criteria detailed in the Project QAPP. Data presented in the context of “grey” literature (e.g. an organization newsletter, reports proceedings etc.) will be considered in a similar manner to journal articles, except without the imprimatur of the peer review. Should a data set be presented in a technical report and be deemed appropriate for consideration for the Estuaries Project, the Technical Team will be convened for review of the evidence for data inclusion. If the source can be identified and the data was collected according to an established SOP, the technical team may judge the data to be acceptable to the project. In all cases, the criteria used for data inclusion will be that the data meets the requirements of the Estuaries Project QAPP.

Verification of data to be included in the Massachusetts Estuaries Project will help determine that the data set is either of insufficient quality based on above mentioned criteria and therefore should not be included in the Estuaries Project or satisfactory for use by the project. Having determined that the data set under consideration is of sufficient quality, the Technical Team will evaluate whether or not the data set is comparable to the needs of the Estuaries Project. For example, dissolved oxygen measurements may have been collected appropriately and with proper QA under an approved QAPP, but the measurements were made outside of the needed July-August window or may have been collected at the wrong depths.

In addition to satisfying an Estuaries Project need/objective, it will be necessary that the data set be sufficient in quantity in order for it to be worth considering for the project. A primary consideration is that data meet the Data Quality Objectives detailed in the Estuaries Project QAPP. The technical team will determine the degree of sufficiency based on the parameter being considered. Both temporal and spatial criteria will be applied to the determination of sufficiency.

Depending on the parameter being considered for inclusion into the project, consideration will be given as to whether or not the parameter of interest needs to be supported by additional Project data collection in order to be of value to the Project. In the absence of appropriate supporting data, the parameter under consideration may be of little value and therefore a Technical Team recommendation would be made to not include the specific data set into the project.

Ultimately, all data being considered for use in the Massachusetts Estuaries Project will be judged worthy relative to quality control criteria set forth in the overall umbrella QAPP for the project. Criteria for acceptance of data in each of the Estuaries Project elements (hydrodynamic modeling, watershed nitrogen loading, nitrogen regeneration, linked watershed embayment nitrogen model, habitat assessment, synthesis of modeling and habitat assessments) are presented in respective sections of the overall project QAPP. Additionally, data being considered for inclusion in the estuaries project must meet the criteria for precision, accuracy, and sensitivity (including instrument detection limits) as defined in the overall project QAPP.

Massachusetts Estuaries Project QAPP

Appendix B-3 Embayment Specific Bacterial Assessments

A) Bacterial Sampling Approach

B) Technical Memorandum: Analysis of Yr 1 Priority Estuaries for inclusion on 303(d) List for Bacterial Contamination

C) Top 20 vs. DRAFT Cape Cod Watershed Water Quality Assessment Report Estuary Segments Evaluation Matrix

Bacterial Assessments:
Massachusetts Estuaries Project Priority Embayments 1-20.

PART A:

Embayments for Bacterial Assessment:

Based upon the review of existing data relative to bacterial contamination within the Yr. 1 Priority Embayments, 1-20 (Howes and Samimy 2002, see Part B this Appendix), 7 estuaries were selected for further evaluation of contamination and field data collection. The 7 embayments are:

- Muddy Creek, Chatham (Appendix III)
- Frost Fish Creek in Bassing Harbor System, Chatham (Appendix IV)
- Acushnet River Estuary, New Bedford/Fairhaven/Acushnet (Appendix IX)
- Nantucket Harbor, Nantucket (Appendix XIII)
- Three Bays, Barnstable (Appendix XV)
- Oyster Pond, Falmouth (Appendix XVII)
- Sesechacha Pond, Nantucket (Appendix XVIII)

Assessment of Bacterial Contamination:
Assessment of bacterial contamination by the Estuaries Project within each of the 7 target embayments will consist of:

- Review of existing bacterial data within and in freshwater discharges to each embayment;
- Field sampling of bacterial contaminants (Fecal coliforms, *E. coli* and *Enterococcus*) in freshwater inflows under wet and dry weather conditions[1];
- Field sampling of distribution of bacterial contaminants (Fecal coliforms, *Enterococcus*) within the estuarine waters under wet and dry weather conditions.
- Synthesis of all bacterial information with circulation information to target embayment regions requiring source identification for remediation.

[1] Dry Weather = <0.1" of rain in previous 72 hrs; Wet Weather = >0.30" rain in previous 48 hrs.

The review of existing bacterial contamination data will focus primarily upon data from the Division of Marine Fisheries shellfish monitoring program and secondarily upon data collected by water quality monitoring programs and beach monitoring programs (DPH) and any site specific survey data which might be available. Although information on Fecal coliforms, *E. coli* and *Enterococcus* are desired, the bulk of the existing information relates only to Fecal coliform sampling.

The surface freshwater input and estuarine survey samplings will be conducted under both wet and dry weather conditions. The purpose of these paired surveys is to identify major regions of each estuary that need further investigation for remediation and to determine

the role of stormwater versus chronic inputs (septic systems, fauna, etc.) in the levels of contamination.

The embayment sampling program is to determine the distribution of bacterial contaminants within each of the 7 estuaries and to determine changes from dry to wet weather conditions. Coupling the freshwater inflow data to the estuarine response surveys will be used to identify the focus studies required for implementation of bacterial remediation alternatives. However, as the focus of the Estuaries Project is not on the management of bacteria in the coastal zone, sampling efforts will not be designed to pin point individual sources of bacteria within a watershed. For the purpose of the Estuaries Project, bacterial assessment in an embayment will stop at the tributary level of the aquatic system. The output of the hydrodynamic model showing the circulation of the embayment under study will be used in the synthesis and interpretation of the historic and sampling data.

Findings on bacterial counts in an embayment will be presented in each embayment report. Suggestions will be made based on the data generated that can help steer a town's efforts (e.g. sanitary sewer / septic tank surveys) towards identifying and managing sources of bacteria in a watershed.

Stream Sampling: In addition to stream nutrient sampling, SMAST will conduct bacterial sampling in each of the major surface water inflows to each of the 7 embayments where bacterial contamination is an identified issue. Sampling will consist of routine collection of stream water samples for (Fecal coliforms, *E. coli* and *Enterococcus*) following the field protocol in B-I. Additional stormwater pipes/discharge points may be assayed during wet weather sampling, to the extent that these flows can be identified by site survey or Town records. These freshwater samples will be assayed by the Barnstable County Department of Health and the Environment Laboratory. Focus will be placed on fecal coliform as the majority of currently available bacterial data is for that organism. Bacterial assays will be performed by a DEP certified laboratory (generally Barnstable County Health Laboratory (Dr. Tom Bourne, director, 508-375-6608). In the event that historic data or field sampling shows a high fecal coliform count for a specific stream (>50 CFU/100 mL), additional assays will be routinely performed to determine counts for *Enterococcus* and *E. coli*. The analytical methods are discussed in Section B.3 in the Estuaries Project QAPP.

Bacterial samples will be obtained at the same time that the stream is being sampled for nutrients, gauged, and measured for flow velocity. The identified major freshwater inflow sampling sites are shown in Figure 3 within the 7 specific embayment Appendices I - XX. Based on the bacteria data generated for each stream discharging to an embayment, determinations can be made as to possible regions of an embayment watershed that are most likely bacterial contributors to the aquatic system.

Estuarine Sampling: Sampling of surface water within each of the 7 priority embayments determined to have bacterial contamination issues (see Part B this B-III) will be conducted as an "independent event (i.e. will be a focused sampling for bacterial contaminants). Sampling will be conducted from a boat with all of the samples collected within an embayment within an interval of 2 hours, but more likely within a 1 hour interval.

Sampling will be at each of the sites used for the Benthic Regeneration and Stream sampling (see Figure 3 within the 7 specific embayment Appendices). These sites are distributed throughout the each estuary and will be geographically referenced (Garmin GPS) prior to the first bacterial surveys. The high density of survey sites is needed for resolution of the distribution of bacterial contaminants.

Samples will be collected directly into the 250 mL sterile bottle provided by the analytical laboratory at a depth of 0.15 m, following the protocol in B-I. Estuarine survey samples will be assayed for fecal coliform and *Enterococcus* by the Barnstable County Health Laboratory (Dr. Tom Bourne, director, 508-375-6608). Samples will be transported to the laboratory within 6 hours of collection. Analysis and transport procedures are detailed in Section B.3 and B-I of this QAPP.

The Estuarine Survey samplings will focus on collected paired dry and wet samples at the same tidal stage (generally mid-ebb). The rainfall determinations will be based upon the closest meteorological station (see Section B.3). However, the Estuary Project may establish rain gauges within the watersheds of some of the 7 estuaries for confirmation purposes. At present Project gauges are proposed for 2 sites: the Chatham Water Quality Laboratory, Three Bays on Grand Island. These gauges will be graduated cylinder models with an accuracy of 0.01". They will be sited based upon manufacturers recommendations. These gauges will be read daily by scientists collaborating with the Estuaries Project. They will be fully trained as to the operation and maintenance of the gauges. The gauges may be upgraded to tipping bucket rain gauges which have a digital readout and 0.01" accuracy (Forestry Suppliers).

Dry weather sampling will be conducted when a rain event is anticipated within the next several days. The paired wet weather sampling will be launched only after 0.3" of rain have fallen within the previous 48 hours. Ideally, the wet weather sampling will be conducted on the first mid-ebb tide following the 0.3" of rain (i.e. within 12 hrs). For very large rain events (>1" in 24 hours) a second estuarine survey may be conducted (if feasible) on the first mid-ebb tide following the end of the rainfall.

Part B:

********** **MEP Technical Memorandum** **********

To: Massachusetts DEP
From: SMAST-UMD, Massachusetts Estuaries Project (Howes/Samimy)
RE: Analysis of Yr 1 Priority Estuaries for inclusion on 303(d) List for Bacterial Contamination
Date: June 26, 2002

The Estuaries Project Technical Team has analyzed available bacteriological data for the Year 1 Priority Estuaries to support an evaluation relative to their inclusion on the revised 303(d) list for Pathogens. We will soon be forwarding to you a comprehensive Technical Report further detailing this issue. We await a transfer of maps from vacationing DMF personnel. We consider all other aspects of this research and analysis exercise to be complete for the 20 estuaries in question.

The analysis required the following sub-tasks:

- Review of the DEP Cape Cod Watershed Water Quality Assessment Report
- Review of the DMF Shellfish Area Classification Report, Appendix E in the above DEP Cape Cod Watershed Water Quality Assessment Report
- Review of the DMF – Designated Shellfish Growing Area Maps for the 1-20 embayments not in the DEP Cape Cod Watershed Water Quality Assessment Report
- Analysis of the DMF bacterial data, assembled by DEP.

Please note that this memo is in response to DEP's request that we review the DEP Watershed Water Quality Assessment Report for Cape Cod embayments and compare their listed segments with the Massachusetts Estuaries Project (MEP) list of Top 20 Priority Embayments. This review and comparison process has prompted us to make an integrated assessment of the spectrum of bacterial data available using all of the data sources above. The attached summary table will be revised with additional information but we feel it is important to provide a summary at this time.

It should be noted that the approach used in both the DEP Cape Cod Watershed Water Quality Assessment Report and in the DMF data assembled by DEP, generally had multiple sub-regions within an embayment "rolled-up" into their larger block designations. In many cases where the DMF breakdowns were independently obtained, it was clear that only a small area within the total block was Provisionally Closed or Prohibited. Sometimes the closure of this small area resulted from harbor or marina activities only. In one case an area was referred to as being open, despite a bacterial contamination problem within large sections of the embayment. These issues will be discussed in the more comprehensive Technical Memorandum.

Based upon information from the above sources, the following analysis evolved as we proceeded:

(1) Review of the DEP Assessment Report determined that the DMF source data was also required. The reworked data in the Assessment Report was not sufficient for the Projects needs. One problem is that no maps of the DMF collection sites were available which is important if a whole embayment is to be considered for 303(d) listing. In addition, only 5 of the 20 MEP estuaries were in the report.

(2) DMF has been contacted and have been very helpful in providing information on area classifications for the initial 20 MEP embayments. This data will be provided in the full technical document.

(3) Bringing together the available data into Table 1 provides an overview of the relationship of the existing 303(d) listed embayments and those with significant closures. The information presented in the Table supports recommendations for revised 303d listings for pathogens.

Evaluation for 303(d) List:

Based upon the data in Table 1, there are 7 embayments sufficiently contaminated for potential inclusion on the 303d List. The sole criterion for this statement is the exceedance of fecal coliform levels of the shellfish standard of 14 colony forming units per 100ml as collected and assayed (by MPN) by the Massachusetts Division of Marine Fisheries. Evaluation of these systems follows:

1) *Muddy Creek, Town of Chatham:* DMF has designated the 2 sections of this system (SC58.1, SC58.2) Conditionally Approved and Prohibited. There seems to be a clear bacterial problem in this system. *Evaluation - 303d Listing Appropriate.*

2) *Bassing Harbor System, Town of Chatham:* This system includes Bassing Harbor, Crows Pond, Ryders Cove and Frost Fish Creek. Bassing Harbor, Crows Pond and Ryders Cove are real embayments. Frost Fish Creek is a salt marsh with a tidal basin and is a tidally restricted wetland. Only Frost Fish Creek has a bacterial problem. It is almost certain that this problem stems from its wetland status. In addition, it is tidally restricted and a relatively isolated sub-component of Ryders Cove. Therefore, while there is support for adding Frost Fish Creek to the 303d List, it should not bring all of the Bassing Harbor System to the 303d List. *Evaluation – Uncertain, but at most only Frost Fish Creek should be considered.*

3) *Nantucket Harbor, Town of Nantucket:* This system is already on the 303d List. It appears that there are 2 Prohibited areas. Polpis Harbor and in the boat basin in Nantucket Harbor. The boat basin is the primary marina area and where the Steamship Authority docks are located. It should be confirmed as whether this area may be closed as a result of harbor activities. It would seem reasonable to restrict the 303(d) assessment to Polpis Harbor, rather than the full extent of Nantucket Harbor. Polpis Harbor functions as a major sub-embayment to Nantucket Harbor and only a

small fraction of one of its two lobes shows bacterial contamination. This latter lobe supports the major stream input to the entire Nantucket Harbor System and drains a major wetland and cranberry bog area. *Evaluation – Focus 303d Listing efforts on Polpis Harbor.*

4) *Three Bays, Town of Barnstable:* Princes Cove, the relatively small sub-embayment to upper Three Bays, is currently on the 303d List. DMF data indicates that Princes Cove and associated North Bay are Conditionally Approved. There are other sources of fecal bacterial data for the Three Bays System so perhaps a modest system-wide analysis with a more detailed upper system analysis would be in order. *Evaluation – Continue 303d Listing.*

5) *Oyster Pond, Town of Falmouth:* This system is currently classified as Prohibited by DMF. There is an extensive set of fecal coliform data available for this system. It should be noted however that this system has been reconfigured as a brackish water system with a salinity range of 2-4 ppt. It is unclear whether there is a shellfish resource to protect. *Evaluation – Uncertain.*

6) *Sesechacha Pond, Town of Nantucket:* This system is currently on the 303d List. In addition, DMF has this system classified as Prohibited. *Evaluation – Continue 303d Listing.*

7) *New Bedford Inner Harbor (Acushnet River Estuary), Towns of Acushnet and Fairhaven and the City of New Bedford:* This system is currently on the 303d List. In addition, DMF has this system classified as Prohibited. Major issues within this system stem from the fact that it is fully enclosed and (a) has a significant river input, (b) has a number of operational CSO's, (c) contains the outfall from Fairhaven's WWTF, and (d) is the primary commercial harbor in southeastern Massachusetts. *Evaluation – Continue 303d Listing, but many of the TMDL implementation options are already clear.*

Habitat Quality: In addition to considering bacterial contamination the review of the DEP Cape Cod Watershed Water Quality Assessment Report included nutrient related assessments. The Report does consider habitat under an "Aquatic Life" category. From the description provided, we interpreted this category as being analogous to habitat health, which in these embayments can be a good indictor of "nutrient related habitat quality" or trophic status. Unfortunately, and without explanation, none of the Estuaries Project (1-20) embayment segments listed in the Assessment Report had been assessed for "Aquatic Life".

We are finalizing the comprehensive fecal coliform review that includes issues presented in this Technical Memorandum. The full report will have the source data and graphical representation of the DMF field data and will be used as a reference document for the MEP. This reference document will be upgraded to include all 89 embayments of southeastern Massachusetts when we obtain the tabular data for MEP embayments 21-89 from DEP/DMF and from the DMF field sampling program.

MASSACHUSETTS ESTUARIES PROJECT
Shellfish Classification Areas and Classification Types in Top 20

TOP 20 vs. DRAFT Cape Cod Watershed Water Quality Assessment Report Estuary Segments

MEP RANKING Top 20 (mep)	MEP TOWN (mep)	MEP EMBAYMENT SYSTEM (mep)	DEP ESTUARY SEGMENT CAPE COD WATERSHED	DEP SEGMENT NUMBER	DEP AQUATIC LIFE	DMF EMBAYMENT CLASSIFICATION AREA CODE	DMF EMBAYMENT CLASSIFICATION TYPE	EPA 303(d) LIST
1	Mashpee/Barnstable	Popponesset Bay	Mashpee River Shoestring Bay	MA96-24 MA96-08	NA	Popponesset Bay(SC19)	A	
2	Chatham	Sulfur Springs Bucks Creek	NOT APPLICABLE			Sulfur Springs (SC46) Bucks Creek (SC46)	CA CA	
3	Chatham	Muddy Creek	NOT APPLICABLE			SC58.1 SC58.2	CA **P**	ADD
4	Chatham	Bassing Harbor Ryders Cove Frost Fish Creek	Chatham Harbor *	MA96-10	NA	Bassing Harbor (SC54) Frost Fish Creek (SC57)	A **P**	ADD
5	Chatham	Stage Harbor	Stage Harbor	MA96-11	NA	SC48.0 SC48.4	A CA	
6	Chatham	Taylors Pond	NOT APPLICABLE			SC45	CA	
7	Falmouth	Bournes Pond	NOT APPLICABLE			SC13.0 SC13.1 SC13.2	A CA A	
8	Falmouth/Mashpee	Hamblin Pond Jehu Pond Quashnet River	Waquoit Bay Quashnet River Red Brook	MA96-21 MA96-20 MA96-25	NA	Hamblin / Jehu (SC16)	A	
9	Falmouth	Great/Perch Ponds	NOT APPLICABLE			SC11.0 SC11.20 SC11.21 SC11.22	 CA A A CA	
10	Falmouth	Green Pond	NOT APPLICABLE			SC12	CA	
11	Wareham	Agawam Wareham Broad Marsh Rivers	NOT APPLICABLE			BB36	Not in DMF Report	
12	Falmouth	Little Pond	NOT APPLICABLE			SC10	MC	
13	**Nantucket**	**Nantucket Harbor**	**NOT APPLICABLE**			**NT2.1** **NT2.2** **NT3** **NT4.0** **NT4.1** **NT5**	**A** **P** **A** **A** **P** **A**	**ON**
14	Falmouth	West Falmouth Harbor	NOT APPLICABLE			BB54.0 BB54.1 BB54.2 BB54.20	CA P R A	
15	**Barnstable**	**Three Bays**	**Prince Cove**	**MA96-07**	**NA**	**(North) SC23** **Prince SC23.1,2,3** **(West) SC22** **(Cotuit) SC21**	**CA** **CA** **A** **CA/A**	**ON**
16	Marthas Vineyard	Edgartown Great Pond	NOT APPLICABLE			V26	CA	
17	Falmouth	Oyster Pond	NOT APPLICABLE			SC6	P	
18	**Nantucket**	**Sesachacha Pond**	**NOT APPLICABLE**			**NT9**	**P**	**ON**
19	**New Bedford**	**Acushnet River, New Bedford Inner Harbor**	**NOT APPLICABLE**			**BB15**	**P**	**ON**
20	Bourne	Eel Pond, Back River	NOT APPLICABLE			BB47.1 BB47.2 BB47.3	CA CA CA	

MEP = Massachusetts Estuaries Project
DEP = Massachusetts Department of Environmental Protection
DMF = Massachusetts Department of Marine Fisheries

* Chatham Harbor, though listed as in the Top 20 is really source water to the Bassing Harbor System
Not Applicable = Cape Cod Watershed Water Quality Assessment Report Estuary Segment not present in Top 20

NA = Not Assessed
A = Approved for shellfishing
CA = Conditionally Approved for shellfishing

SMAST University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project QAPP

Appendix B-4 Response to Comments on Final QAPP (7/24/2002)

A. Laboratory QA Plans
   SMAST and Barnstable County Health Department Laboratory
   Previously submitted to DEP under separate cover (January 2003)
   Not for general distribution

B. SOP for Bathymetry

C. Role of Volunteer Monitors in Coastal Water Quality Programs

D. Applicability of Blue Ice Packs for Cooling Bacteriological Samples

E. Revised Table B.1-1 found in Section B.1.1 of the MEP QAPP

F. Addendum to Section B.3.3 (Phosphorous Loading)

G. Tabulations of samples collected in 2002

MASSACHUSETTS ESTUARIES PROJECT
Bathymetric Standard Operating Procedure

Introduction:

Accurate hydrodynamic modeling requires accurate mapping of water depths throughout the tidal reach of the embayment. This requires simultaneous location and depth data gathering. In addition, since the systems are tidal, a correction for tidal elevation is also required.

Equipment:

Leica DGPS and Leica Beacon
Odum Single beam transducer and fathometer
Lap Top computer with HYPAK Oceanographic Software
Meter stick
Tide Gauge
Field data sheets
Batteries (2 – 12V Batteries)

Instrument Calibration:

1. DGPS

Check instrument against local USGS benchmark before and after survey.

2. Transducer/Fathometer

After mounting transducer on the side of the boat, measure depth below surface with meter stick and record.

3. Tide Gauges

Use gauges that have been pre-calibrated in SMAST seawater tank at multiple depths. In field, after mounting gauge on piling (or other fixed structure), record depth of water over gauge with meter stick.. Note: in complex embayments multiple gauges may have to be placed for a survey.

Field Procedure:

1. Connect transducer to the bottom of the swivel mount.
2. The DGPS beacon is fixed to the top of the swivel mount directly above the transducer.
3. Turn on instruments and allow 30 minutes for warm up before pre-survey calibration is performed.
4. Connect Fathometer and DGPS to laptop computer.

5. Check accuracy of transducer read out on computer by comparing read out to actual measured depth. Record on data sheet.
6. Follow transects set up prior to arrival at the field site on aerial photo. Transect lines are established perpendicular to the long axis of the embayment starting from the head of the embayment to the mouth. Transects are established to allow for 250-500 feet between transect lines.
7. Record start and stop times of each transect on data sheet

Post Survey:

Repeat calibration checks for transducer, tide gauge and DGPS.
Disconnect DGPS from swivel mount.
Disconnect transducer from swivel mount.
Disconnect Batteries.

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Massachusetts Estuaries Project
Bathymetric Survey Data Sheet

[Telephone: (508) 910-6352]

Embayment: _____ Date: _____

Personnel: _____

Weather: _____

Time on site: _____ Time off site: _____

	Pre-Calibration		Post-Calibration	
Measured Depth of Transducer				
Transducer Read Out				
DGPS Benchmark (Lat/Lon)				
DGPS Measurement (Lat/Lon)				

Run No.	Transect Start Time	Transect Stop Time	Run No.	Transect Start Time	Transect Stop Time
1			27		
2			28		
3			29		
4			30		
5			31		
6			32		
7			33		
8			34		
9			35		
10			36		
11			37		
12			38		
13			39		
14			40		
15			41		
16			42		
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21			47		
22			48		
23			49		
24			50		
25			51		
26			52		

MASSACHUSETTS ESTUARIES PROJECT
Role of Volunteer Monitors in Coastal Water Quality Programs

Regarding USEPA Memorandum dated August 19, 2002, Section C, Item number 1 (***Training and Assessments [Sec.B.1.2 and C.1])***

Overview:
The Estuaries Project requires three years of baseline nutrient related water quality data on an embayment prior to the implementation of its full field data collection, modeling and thresholds development program. These data are needed both to guide field sampling and to validate the water quality model.

At present, the SMAST Team has reviewed coastal monitoring programs throughout southeastern Massachusetts as to applicability of data to the Estuaries Project. Programs typically consist of trained volunteer monitors, although some are fully conducted by professional staff. Almost all of the present programs are associated with the SMAST Coastal Systems Program for technical guidance and sample analysis. In almost all cases nutrient analyses have been conducted within the Coastal Systems Analytical Facility at SMAST and all potentially acceptable bacterial analyses have been conducted in DEP certified laboratories (primarily the Barnstable County Health Laboratory).

In almost all programs, SMAST has been responsible for training guidance, development of sampling methodologies, preparation of field sampling gear, and database preparation. In many of the programs, SMAST also conducts the assessments and prepares the monitoring reports. This existing association will facilitate the evaluation and incorporation of monitoring data by the Estuaries Project Technical Team.

The review and evaluation criteria for monitoring data (and all other data) is detailed in B-II of the Massachusetts Estuaries Project Quality Assurance Project Plan (QAPP).

Background:
Long-term population growth and associated increases in nitrogen loads has resulted in the increased eutrophication of estuaries, not only along the Southeastern Massachusetts shoreline, but along many of the world's coastlines. To address the ecological problems associated with this increase in nutrient loads, new TMDL methodologies have been developed to provide the quantitative approaches needed to model current and future nitrogen loads and their environmental impacts. Fundamental to these models is the availability of long-term high quality monitoring data that takes into account year to year variations in key environmental variables, and on a time scale suitable to identify any trends that may follow changes in land use and/or discharge along the coastline. This baseline data is therefore essential to the development of appropriate nitrogen management and land use strategies for coastal ecosystems.

One of the numerous tasks that must be undertaken in the execution of the Estuaries Project is the assemblage and review of all available long-term water quality monitoring data suitable for incorporation into the Estuaries Project. In many cases, this data has become available in recent years through the use of citizen-based water quality monitoring programs operating in Southeastern Massachusetts under the technical guidance of the Coastal Systems Program at SMAST. These water quality monitoring programs are staffed with trained volunteers, given both technical hands-on training of equipment use and sample collection, as well as fundamental information on ecological processes upon which sampling techniques were based. The goal of these programs is to collect research quality data using techniques appropriate for use by trained citizens; the techniques were developed to answer basic research questions and have been tested against more sophisticated (and expensive) approaches utilizing the tools of basic ecological research (Taylor, C.T. and B.L. Howes, 1994).

Each individual monitoring program within southeastern Massachusetts generally maintains the same goals of providing reliable water quality data to assist environmental managers to:

- Establish baseline water quality,
- Evaluate nitrogen loading inputs,
- Characterize and identifying sources of pollution,
- Document long-term environmental trends in water quality,
- Evaluate the relative success of clean-up efforts,
- Facilitate implementation of management recommendations

Data Sought from Water Quality Monitoring Programs:
This focus is also driven by the Regulatory Agencies, including EOEA's Watershed Initiative, as well as the Public's concern relating to nutrient issues. Regulation of nutrients is changing relative to watershed-based water quality management and the public interest in clean water. As well, management of nutrients continues to be at the top of the US EPA's Agenda.

In addition to nutrient measurements some of the monitoring programs collect parallel measurements of fecal coliform levels. Almost all of this bacterial data has been collected by Division of Marine Fisheries (DMF) and will be assembled with their help for use by the Estuaries Project. Limited additional bacterial data has been collected by water quality monitoring programs. Bacterial contamination is the primary cause of embayment closures to shell fishing and swimming. Review of existing coliform data from state and local programs as well as ongoing monitoring programs will determine the need for additional measurements of fecal bacteria within specific estuaries within the Estuary Project study area. As available (and appropriate) this information will be evaluated for incorporation into Estuaries Project database.

The goals of the monitoring programs are to provide data needed to evaluate overall water quality conditions throughout the sub-embayments and to determine changes over the long-term. Through the use of trained volunteers, we can effectively collect the

substantial amount of spatial and temporal water quality data. The number and locations of sample stations is specific to each embayment and depends in part upon the embayment's size and shape, access, and navigational passages. Sampling is to be conducted throughout each estuary from its headwaters to its mouth under the same conditions of tide and weather. This is possible due to the coordinated efforts of a large number of volunteers. The data collected by the volunteers is of sufficient quality to represent environmental conditions since (1) volunteers are trained each year and are constantly checked by the Coordinator, (2) volunteers collect physical data and D.O. which are performed in the field and (3) all nutrient assays are conducted at the SMAST laboratory.

Training of Volunteer Monitors:
Volunteer monitors will not be directly involved in collecting samples for MEP-related activities. Previous data collected by volunteer monitoring programs will be reviewed and evaluated for acceptance for use by MEP or rejection according to the criteria outlined in B-II of the QAPP. Data reviewed in this manner will be classified as:

1. Fully useable
2. Useable only as supporting data
3. Useable only as qualitative or anecdotal information
4. Not useable

The criteria detailed in B-II will ensure that the only data accepted for MEP use are collected using QAPPs previously approved by the DEP or EPA.

Monitoring Program coordinators for past sample collection efforts are volunteers who have been fully trained and evaluated by SMAST personnel before field sampling begins. They need to provide the Technical Team with sampling techniques and training materials. Volunteers should be taught the monitoring program's objectives and their role and responsibilities. The seriousness of the enterprise and the need for completeness of sample collection should be emphasized. Volunteers need to have received a formal hands-on training session prior to each field season. Specifically, volunteers need to be instructed in the importance of taking accurate and timely measurements and following the written field protocols provided. They should have been given a demonstration of the protocol and been observed collecting the samples and performing the tests. Retraining sessions should be held at the beginning of each sampling season. Ideally coordinators conduct individual follow up with field checks on new volunteers and seasoned volunteers are teamed with newly trained volunteers to assure consistent sampling technique. Volunteer assessment should be checked by evaluation of data against previous sample data from earlier assessments. The program coordinators should have a contact database for all volunteers. In reviewing data from water quality monitoring programs, the Estuaries Project will ascertain that field and laboratory approaches are related to a formal QAPP or sampling plan.

Applicability of Blue Ice Packs for Cooling Bacteriological Samples Collected by the Massachusetts Estuaries Project

B.L. Howes & R.I. Samimy – SMAST

Background:
During technical discussions between EPA and DEP QAPP reviewers and Estuaries Project Technical Team members, concerns were raised relating to the use of blue ice packs for cooling bacteriological samples. The major concern related to the ability of these re-usable ice packs to cool water samples sufficiently quickly and to the appropriate temperature. Based upon the importance of proper sampling handling for these "live" biological samples, it was prudent to conduct tests of the performance of blue ice relative to bacteriological sampling.

Approach:
Duplicate bacteriological sample containers (150 ml), provided by Barnstable County Department of Health and Environment. A 8 liter container was filled with freshwater. Two temperature loggers (Onset Computer Hobo Loggers) were placed into the container for sufficient time to reach temperature equilibration (~5 min). Duplicate sample bottles were then filled and a logger placed in each (logger vol. ~10 ml). The sample bottle temperature was determined using a thermocouple digital temperature probe/meter (Omega). The bottles were immediately placed into a standard 13 liter Igloo "Playmate" Cooler held at 22^{o}C. In the cooler were blue ice packs which had been frozen in the SMAST walk-in sample freezer (-30^{o}C). The temperature of each bottle was recorded every 3 minutes throughout the holding period. The loggers were calibrated in a stirred ice bath prior to use and the temperature of each bottle was checked by thermocouple temperature probe/meter at the end of each experiment. Three experiments were conducted in which the volume of blue ice was varied, combinations of large (7.5"x 5.8"x 1.5") and small (6.8"x 4"x 1.5") packs were used.

Results:
In all cases the blue ice appeared to rapidly (<0.65 hr) cool the samples to the required sample temperature, <10^{o}C (Standard Methods, 19th Edition, Section 9060B). This cooling rate is considered acceptable given that (a) the sample initial temperatures were between 26^{o}C and 28.6^{o}C and (b) the cooler was held at 22^{o}C during the incubation. In experiment 1, where a maximum number of ice packs (5) were employed, the sample temperature in one of the bottles was brought too low (-0.1^{o}C). The standard field sampling cooler has between 3 and 4 ice packs. In experiments 2 and 3 the samples reached proper temperatures and excessive cooling was not evident. In all cases the blue ice packs gave sustained cooling for 16 hours, much longer than the Estuaries Project holding time of 6 hours (Table 1).

The time-course of cooling for the most rigorous experiment is shown in Figure 1. In this text, only 1 large and 2 small ice packs were used compared to a minimum field cooler of 2 large and 1 small. In addition, the initial sample temperature was high,

28.6°C. However, the data indicates that the appropriate holding temperature was reached in an acceptable period of time, within approximately 30 minutes (0.50 hours).

Table 1
Summary of tests of cooling capacity of blue ice packs for bacteriological samples. All experiments were conducted in a standard 13 liter cooler held at 22°C.

	Rep Btl	# Blue Ice Packs	Start Temp (C)	Time to 10°C (hr)	Time to 4°C (hr)	Temp C @ 6 hr	Temp C @ 16 hr
Expt. 1	A	5 (2 l + 3 s, 4.1L)*	26.0	0.62	1.27	--	-0.1
	B		26.0	0.62	1.52	0.5	0.9
Expt. 2	A	4 (2 l + 2 s, 3.5L)	26.6	--	--	--	0.9
	B		26.6	--	--	--	0.0
Expt. 3	A	3 (1 l + 2 s, 2.4 L)	28.6	0.40	0.65	1.6	--
	B		28.6	0.35	0.55	1.5	--

* The number, type (l=large, s=small) and total volume (liters) of blue ice is presented.

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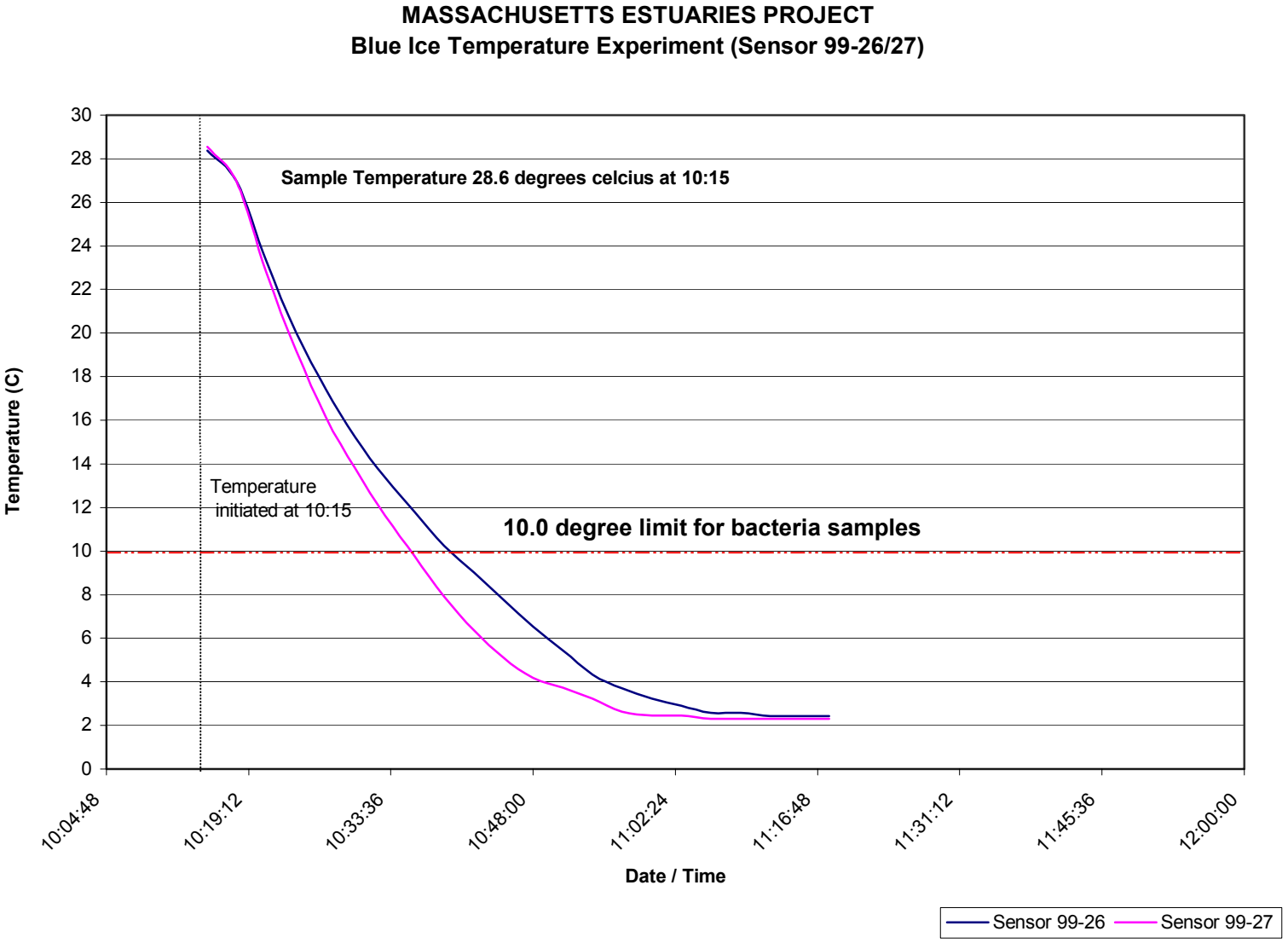


Figure 1 - Time-course of Sample Cooling

MASSACHUSETTS ESTUARIES PROJECT
Revised Table B.1-1 from Section B.1.1 of MEP QAPP

B.1.1 Data Quality Objectives

Data quality objectives have been selected as criteria for the **Review of Nitrogen Related Water Quality Monitoring Data Task** in order to fit with the goals of the Water Quality Monitoring Task and the concentrations and natural variability found within the tidal estuarine environments throughout southeastern Massachusetts. The methods and approaches which render data acceptable for inclusion of data into the Estuaries Project must meet the required levels of precision, accuracy, field blank cleanliness (analyte free), and detection limits. Although site-specific exceptions may be made after review by the Technical Team (B-II), the minimum performance criteria for the basic physical sampling is given in **Table B.1-1 revised below to include footnotes.**

Table B.1-1 Water Quality Program, field parameters measured & data objectives

Parameter	Method	Range	Sensitivity	Precision	Accuracy	Calibration
Temperature[a]	*Thermometer*	*-5℃ to +40℃*	*0.5℃*	*±0.5℃*	*1℃*	*Certified thermometer over temperature range*[b]
Temperature	*Thermister*	*-5℃ to +40℃*	*0.1℃*	*±0.1℃*	*0.2℃*	*Factory calibration & Certified Thermometer*
Salinity	*Conductivity Meter*	*0-35 ppt*	*0.1 ppt*	*±0.1 ppt*	*0.2 ppt*	*Certified Conductivity Standards*
Salinity[c]	*Hydrometer*	*1.000 to 1.050/ Specific Gravity*	*0.5 ppt*	*±1 ppt*	*1-2 ppt*	*Conductivity Meter & Certified Standards*
Dissolved Oxygen	*Modified Winkler Titration Hach OX2P*	*0-16 ppm*	*0.5 ppm*	*±0.5 ppm*	*1 ppm*	*Dissolved gas standards*
Dissolved Oxygen	*Oxygen Meter*	*0-16 ppm*	*0.1 ppm*	*±0.1 ppm*	*0.2 ppm*	*Dissolved gas standards*
Water Clarity	*Secchi Disk disappearance/ meters*	*0-15 m*	*1 cm*	*±10 cm*	*20 cm*	*NA*

[a] Not preferred method for measuring temperature (Thermister Method is preferred). However, this method is acceptable if it is only used for calculating oxygen saturation for monitoring purposes.

[b] Calibration uses regression of field thermometer vs. certified thermometer with 5 temperature points and an $R^2 > 0.99$ and no pair of temperature points should exhibit a difference greater than ±1.0 degree.

[c] Not preferred method for measuring salinity (Specific Conductivity Method preferred). This method should not be used to determine stratification unless differences > 2 ppt.

MASSACHUSETTS ESTUARIES PROJECT
Addendum to Section B.3.3 (Phosphorous Loading)

Phosphorous loading to freshwater systems (ponds/streams) will not be determined as it is not the focus of the Estuaries Project in and of itself. The Estuaries Project focuses primarily upon the sources, sinks, and transfers of nitrogen within the watershed-embayment complex. Nitrogen is the nutrient for managing eutrophication in Massachusetts coastal embayments, while phosphorus is the primary nutrient for management of eutrophication of freshwater systems. In specific cases where it is necessary to determine phosphorous loading in support of other analyses or evaluations, loading may be determined. Some examples of cases where support may be requested:

- NPDES Permiting
- Nitrogen source reduction for embayment restoration, where P load to eutrophic freshwaters will also be effected. Source reduction may be by relocation of discharges or reduction in discharged load.
- Cases where a regulatory agency has a priority

In the event that phosphorus loading determinations are undertaken, a project specific plan will be developed to meet site specific needs. However, the analysis will follow the format of the nitrogen loading analysis for the embayments. This site specific project plan will be appended to the relevant embayment specific Appendix QAPP under this umbrella QAPP for the Estuaries Project.

MASSACHUSETTS ESTUARIES PROJECT
Tabulations of Field Samples

Embayment specific tabulation of field samples to be collected in each of the systems under investigation by the Massachusetts Estuaries Project have been developed and are included in each of the embayment specific appendices.

APPENDIX D: Lonnie's Pond Aquaculture Demonstration Project: Year 2 Monitoring Summer/Fall 2017 Oyster Deployment Report

Technical Report

DRAFT FINAL

Lonnies Pond Shellfish Demonstration Project
Year 2 Monitoring Summer/Fall 2017 Oyster Deployment

To:

Town of Orleans, MA
Water Quality and Wastewater Planning

From:

Brian Howes, Ph.D., David Schlezinger, Ph.D., Roland Samimy, Ph.D. , Micheline Labrie, Jennifer Benson, M.S., Sara Sampieri, M.S.,Amber Unruh, and Paul Mancuso

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New Bedford, MA 02744

September 2018

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Section I. Introduction

Background:

Based on the findings of the Massachusetts Estuaries Project (MEP 2002 – 2017, conducted by SMAST-CSP), it is clear that estuarine water and habitat quality in southeastern Massachusetts estuaries is impaired by nitrogen enrichment. As a result, towns across southeastern Massachusetts are now seeking innovative approaches for lowering estuarine nitrogen levels as these natural systems are integral to the character and quality of life in communities across the southeastern Massachusetts region and citizens want to achieve the MEP set nitrogen thresholds for restoration of their estuarine resources. While traditional sewage treatment is part of the solution for most communities, so too are non-traditional approaches to nitrogen management that have multiple benefits to the community. However, the nitrogen removal efficiency of these non-traditional approaches is still being quantified so that they may be formally considered and credited with nitrogen removal in town specific nitrogen remediation plans.

An *in situ* water quality management approach that is gaining momentum in many communities across southeastern MA (e.g. Westport, Falmouth, Mashpee) is the use of shellfish, particularly oysters, to increase water clarity and remove nitrogen, while also supporting recreational shellfishing and the local economy. CSP has been at the forefront of investigating the use of oyster deployments/reefs as an in-estuary means to improve nitrogen related water quality. CSP scientists have begun quantifying the mass removal of water column nitrogen and quantifying the additional removal via associated enhancement of sediment denitrification (NO3-àN2) to gauge the actual nitrogen removal efficiencies of oyster deployments. Note that oysters are being considered due to their high filtration rates, rapid growth, commercial value and ability to thrive in nutrient rich, warm, shallow waters over a range of estuarine salinities. While oysters are well suited to enhancing water quality for the listed reasons, other filter feeders can be used as well.

In this context, many Massachusetts communities have begun oyster propagation. However, almost none have quantified the integrated nitrogen removal through filtration, deposition and sediment denitrification and harvest. Similarly, water quality improvements associated with oyster deployments have not generally been accurately assessed. As a result, it is difficult to compare the cost/benefit of using shellfish compared to other nitrogen management approaches (e.g. traditional WW treatment, PRBs, floating wetlands, enhanced natural attenuation). In order for Orleans and other towns across the region to be able to implement this soft solution as part of their habitat restoration strategy, it is critical to accurately assess the role oyster filtration plays in estuarine nutrient cycling. This quantitative understanding of the net effect of oyster filtration on nutrient conditions in an estuary will facilitate incorporation of shellfish culture into management and regulatory processes.

The present investigation focuses on quantifying the nitrogen processing and removal by the oyster/sediment complex within Lonnies Pond, a terminal salt pond tributary to Upper Pleasant

Bay, Orleans, MA. The pond was selected due to its high level of nitrogen enrichment, its physical structure, its suitability for oyster culture and appropriateness for measuring nitrogen removal rates. The results are aimed at providing quantitative information to the Town of Orleans as it seeks to implement new nitrogen removal approaches and considers the use of shellfish for remediation of nitrogen related impairment of its coastal resources.

The Nitrogen Loading Problem:

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the greater Pleasant Bay system and Lonnies Pond at a smaller scale, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1996, Weiskel and Howes 1992, Smith et al. 1991). The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). Tidal reaches within Pleasant Bay and Lonnies Pond more specifically, follow this general pattern, where the primary nutrient of eutrophication is nitrogen.

Nutrient related water quality decline, specifically due to excess nitrogen inputs, represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate (process) watershed nitrogen inputs without degradation. As loading increases, a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen as well as identifying both soft and hard solutions for managing nutrient loads to impaired estuarine systems. While this effort is ongoing to varying degrees of effectiveness across the United States (e.g. USEPA TMDL studies), southeastern Massachusetts has been the site of intensive efforts in this area and specifically Pleasant Bay.

Project Need:

Since nitrogen removal is needed to meet estuarine specific TMDLs and restore water and habitat quality in nitrogen impaired estuarine systems, and since traditional approaches are quite costly to communities, less expensive more flexible non-traditional alternatives are needed and are now being considered on a site by site basis by Towns across the southeastern Massachusetts region. The Town of Orleans is investigating a number of these "soft" solutions, including shellfish aquaculture, specifically with oysters. In late 2015, the Town of Orleans initiated a multi-year oyster demonstration project within Lonnies Pond, a eutrophic saltwater basin tributary to Pleasant Bay, in order to test the oyster filtration approach for improving water quality. A small oyster aquaculture system was established in Lonnies Pond in summer 2016 (year 1) to determine: (1) the ability to grow oysters in this basin, (2) oyster survival, (3) the incorporation of nitrogen into oyster tissue and shell, (4) oyster filtration and biodeposition rates and, (5) the fate of nitrogen deposited by oysters to bottom sediments. The initial year 1 results of the multi-year investigation were presented to the Town of Orleans in January 2017 along with conclusions and recommendations for improving the study as the project proceeded into year 2 which captured summer 2017 conditions.

Results presented herein summarize field work completed during the summer/fall 2017 growing season and updates the 2016 data to include spring 2017 “carry over” effects. The focus is mainly on the effect of the oyster deployment on water column particulates (particulate nitrogen and chlorophyll), the amount of nitrogen deposited to the sediments by oysters and the degree to which denitrification is enhanced over background as a result of the oyster deployment. The amount that denitrification is enhanced plus the amount of nitrogen removed by oyster harvest accounts for the total nitrogen removal due to the oyster deployment. While there is a very small potential for nitrogen removal through enhanced sediment burial, the bulk of removal is through enhanced denitrification plus harvest. It is this oyster mediated N removal value that is the critical number for developing nitrogen management plans and designing larger deployments to reach specified nitrogen loading reductions required for restoration under MassDEP/USEPA TMDLs.[1]

Section II. Background Water Quality Monitoring in Lonnies Pond

Sampling Program:

A sampling program was implemented in Lonnies Pond to establish both a pond-wide water quality benchmark and to quantify nitrogen removal by the pilot oyster culture deployment undertaken during the 2016 and 2017 growing seasons. Eight (8) water quality sampling locations were monitored in 2016 (LP1-LP4; M5-M8), building upon pre-existing database of water quality from the same monitoring stations. To better evaluate water column constituent gradients within the pond and how these may be affected by the presence of oyster culture, 6 more sampling locations (LP9-LP13) were added for the 2017 season (Figure II.1). In addition, samples and flow measurements were collected at the outflow from the cranberry bog

[1] The oyster survival and growth analysis and nitrogen removed by harvest was conducted by Science Wares Inc. and is presented in a separate companion report.

upgradient of Lonnies Pond and the herring run (discharge from Pilgrim Lake) when sufficient flow was available for sampling. It should be noted that during the oyster deployment period, flow from the cranberry bogs was episodic during both summer 2016 and 2017, however, there was consistently measurable flow in the herring creek discharging into Lonnies Pond from Pilgrim Lake (summarized in Section VIII). Water sampling occurred bi-weekly during mid-ebb tide conditions and usually in the early morning. Samples were collected at the surface, bottom, and at mid-water column where sufficient depth allowed. Samples were analyzed for: temperature, salinity, total nitrogen (nitrate + nitrite, ammonia, dissolved organic nitrogen, particulate organic nitrogen), chlorophyll-a (Chl-a), pheophytin-*a*, orthophosphate, dissolved oxygen, transparency (secchi depth), and alkalinity. Samples were collected according to protocols outlined for the MEP and which are followed by all other water quality monitoring undertaken by the SMAST-Coastal Systems Program across the southeastern Massachusetts region. Weather, tide-status, and results of water quality monitoring were documented. Quality Assurance samples (field duplicates) were collected (5%-10% of total number of samples collected) with the goal of gaining acceptance of study results by MassDEP and USEPA. Dissolved oxygen and temperature profiles (surface to bottom at 0.5m-1.0m increments) were completed at each sampling location using a YSI-55 handheld DO meter and following protocols developed for the MEP. Winkler samples were collected in triplicate at the DO/CHLA moorings at the sensor depth.

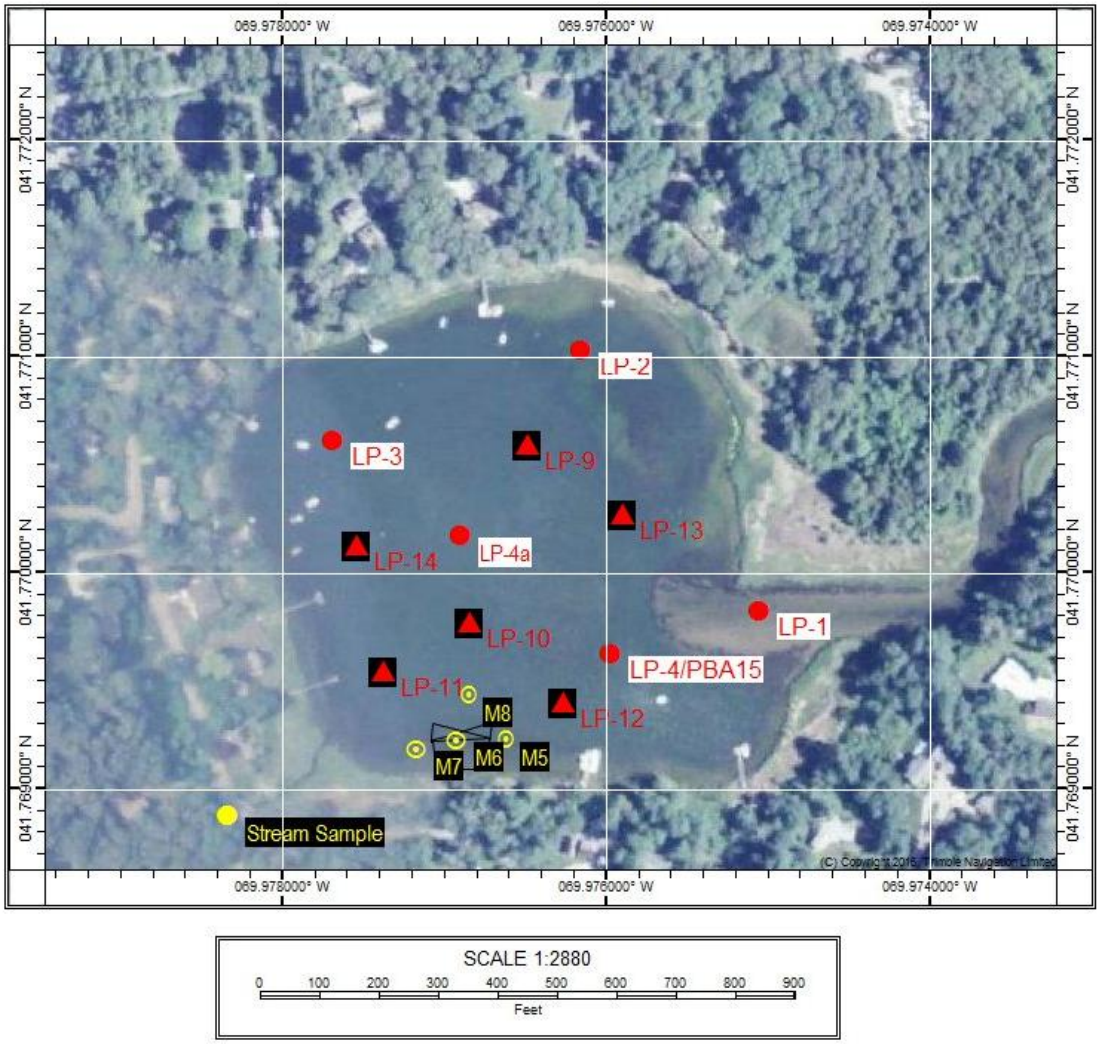


Figure II.1. Locations of water quality stations. Red dots denote stations established in 2016. Red triangles denote water quality stations added in 2017. LP4a was occupied during June 2016 until a permanent buoy was deployed by the harbormaster; hereafter LP4 was used to compliment previous water quality studies. Water quality stations LP5, LP6, LP7 and LP8 were at the mooring locations denoted on the map as M5-M8.

Brief Description of Findings and Conclusions:

The spatial distribution of major water quality constituents was variable over time. During the 2017 sampling period, there was evidence of higher concentrations of constituents along the northern edge of the pond (April samplings), however, spatial gradients (Figures II.2, II.3, II.4, II.5, top panel) were only established after deployment of the oysters (April onward). These gradients were most apparent during periods of high chlorophyll concentrations during which filtration by the oysters was enhanced. During periods of relatively low chlorophyll concentrations, gradients were small or nonexistent. This pattern differs from the 2016

sampling, during which there were drought conditions, when no evidence of point sources (e.g. stream input loads) or large scale gradients was observed (Figures II.2, II.3, II.4, II.5, bottom panel). In both 2016 (year 1) and 2017 (year 2), there was a clear pond-wide temporal trend with higher levels in mid-summer for each constituent (PON, Chlorophyll-*a*, bioactive N[2]). This temporal pattern is consistent with more eutrophic conditions in estuaries in the warmer summer months, with poorest water quality typically in July through mid-September and specifically evidenced by the large August phytoplankton bloom recorded by the time-series chlorophyll sensors (see Section IV). It should be noted that while there were blooms in both years, the chlorophyll-*a* levels in 2016 were significantly higher with a longer bloom in 2016 than 2017. It is possible that this could be related to the drought in 2016, but the specific mechanism is not well defined at this point.

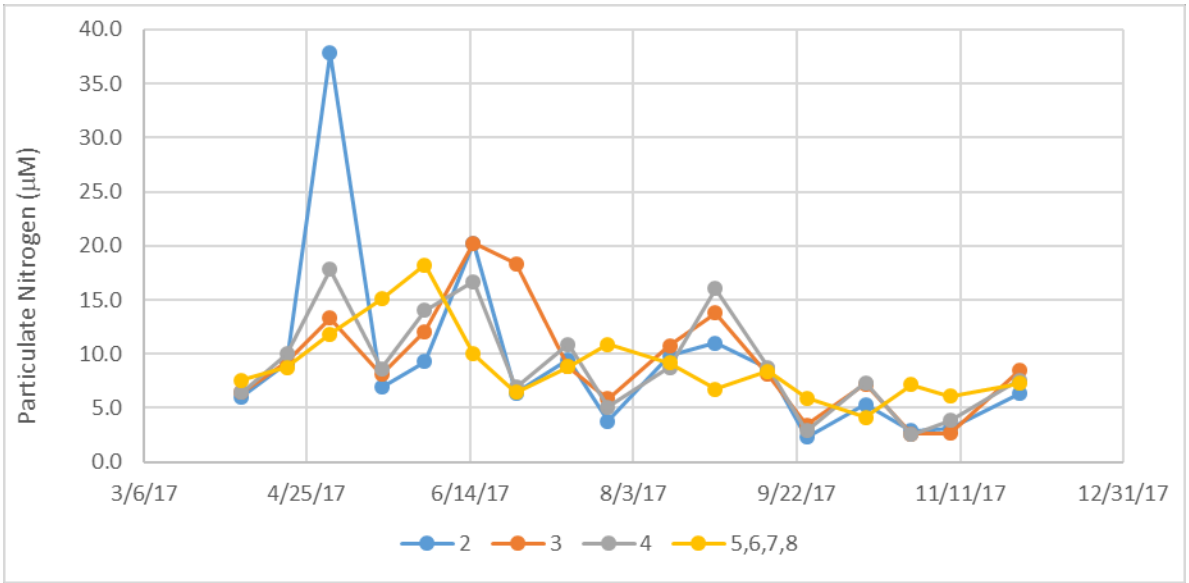
Within the generally homogeneous distribution of the major constituents across Lonnies Pond, there appeared to be lower levels of each constituent within the region of the oyster deployment. Although the magnitude of the constituents varied over time, each of the oyster influenced stations (M5-M8, Figure II.1) usually had lower concentrations than each of the far field stations (stations LP1-LP4, Figure II.1). Focusing on the period when the water quality constituent levels were consistently high (July 18-October 6), the spatial pattern is more clearly seen (Figure II.5) during both 2016 and 2017 field seasons. The distribution map of average water column constituent levels indicates lower levels of chlorophyll-*a* and PON are associated with the oyster deployment area compared to the area represented by the far field stations. Stations LP-1,2,3 and 4 showed consistently higher levels, station M8 intermediate levels and the stations directly associated with the oyster deployment showed lowest levels of each constituent. Even comparing the outboard station M8 to the nearby stations (M5, M6, M7) directly within the area of oyster influence, the influence of oyster filtration in removing particulate matter from estuarine waters was apparent (especially for station M6 in the middle of the oyster deployment area and in both 2016 and 2017). However, bioactive nitrogen for the stations within and adjacent to the oyster area was higher in 2017 due to increased dissolved inorganic nitrogen (NH_4 and NO_3). With the higher number of oysters deployed in 2017 the removal of PON by filtration and subsequent release of pseudofeces, labile fecal pellets and ingestion/digestion of filtered material likely results in increases in NH_4 and possibly nitrate (after nitrification) and lowering of water column PON and chlorophyll a.

The water quality surveys were mainly to establish temporal changes in water quality throughout the pond to establish the benchmark (setting) for the overall nitrogen cycling measurements. The surveys indicated that Lonnies Pond tends to be relatively well mixed horizontally as seen in the spatial distribution of chlorophyll-*a* and particulate nitrogen. However, the results did indicate that in the region of the oyster deployment, particulate levels, particularly chlorophyll, are reduced, consistent with the filtering effects of the oysters. This "hole" in the particulate field indicates the high volumes filtered by the oysters as water flows through the deployed bags in minutes not hours. Overall, the results show that the increased

[2] Bioactive nitrogen is ammonium+nitrate/nitrite+particulate nitrogen, the most biologically active portions of the total nitrogen (TN) pool.

oyster deployment in 2017 (year 2) generated a lowering of key eutrophication indicators associated with the oysters held within the southern region of Lonnies Pond as compared to 2016, in part due to the very high phytoplankton levels. Based upon these results, the expanded oyster deployment further improved water quality within this eutrophic estuarine basin.

A clear trend in the spatial distribution of PON and Chlorophyll-*a* was seen only after the oyster deployment (Figures II.6 and II.7), but none was observed with regards to Bioactive N (Figure II.8). The oysters appear to create a sink for PON and Chlorophyll-*a* in surface waters which extends out as far as 100m, thus the water clearing ability of oyster filtration may extend much further than the oyster impact area on the sediments. No such relationship could be seen in NH4 and NOx concentrations which are the precursors to chlorophyll and PON. It appears that the transformation of organic to inorganic forms after filtration by the oysters is lessening the drop in Bioactive N levels associated with the deployment. Interestingly, the oyster deployment area represented a local minimum for chlorophyll in 2016 and in 2017 (Figure II.5), although the average summer chlorophyll levels in 2016 were 2-3 times that of 2017. This suggests that filtration is leading to increased organic matter deposition to the sediments in the area of the oysters.



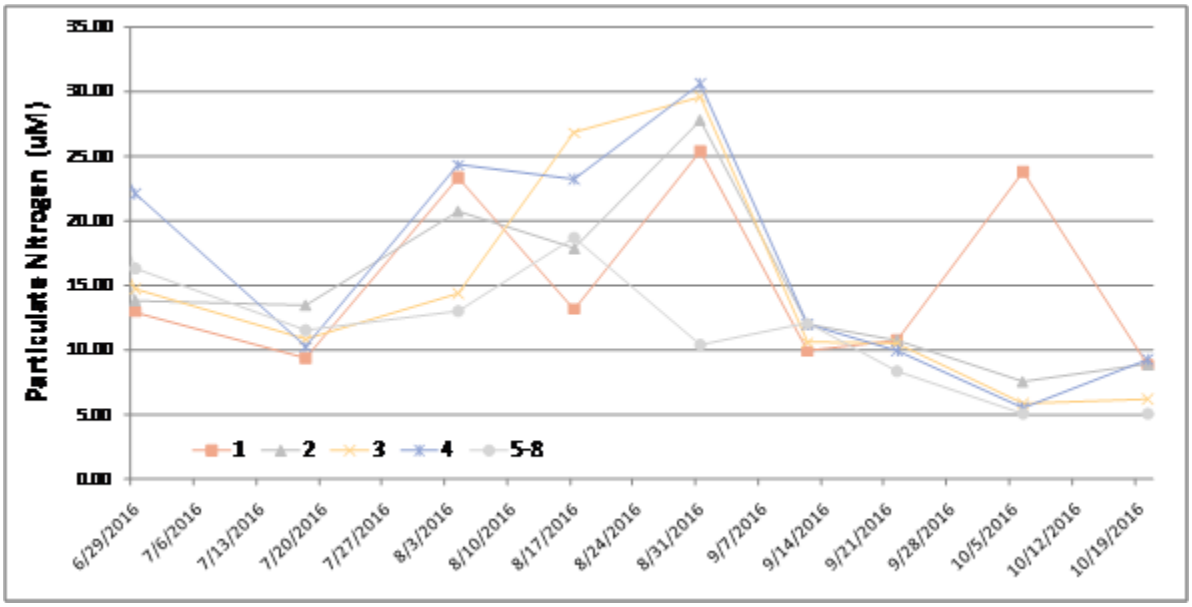
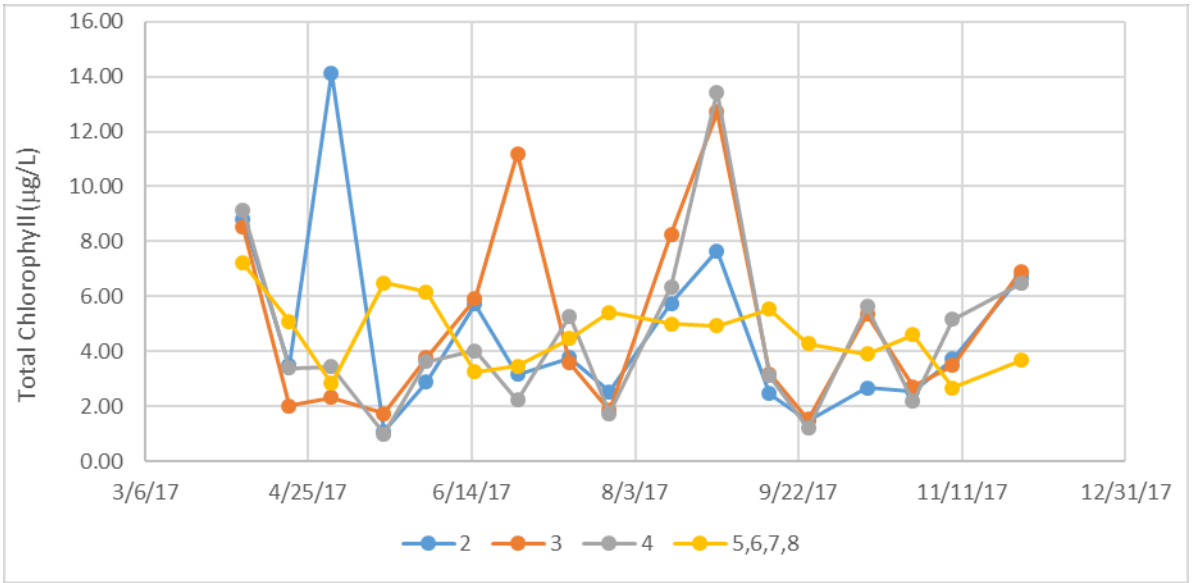


Figure II.2. Top Panel: 2017 time-series of mixed layer average particulate nitrogen at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.



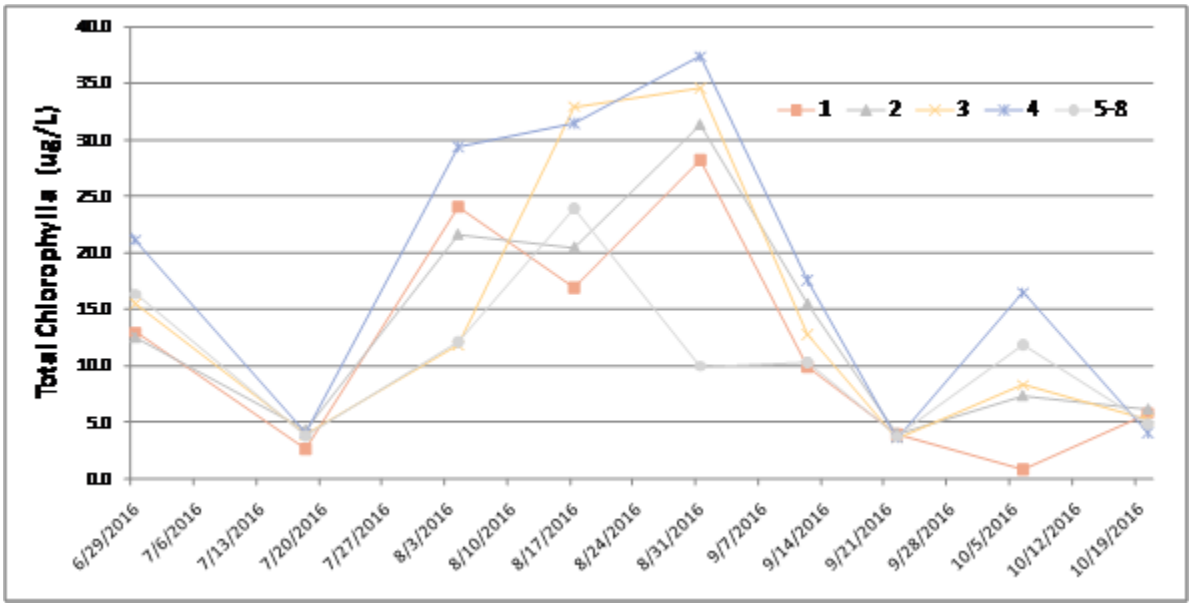
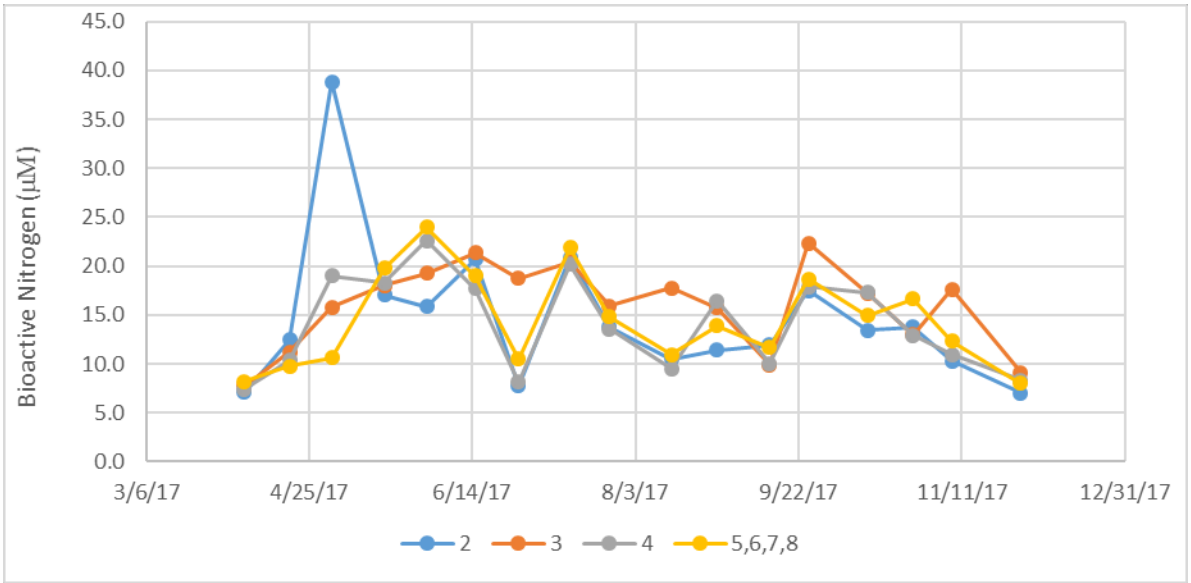


Figure II.3. Top Panel: 2017 time-series of mixed layer average total chlorophyll a at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.



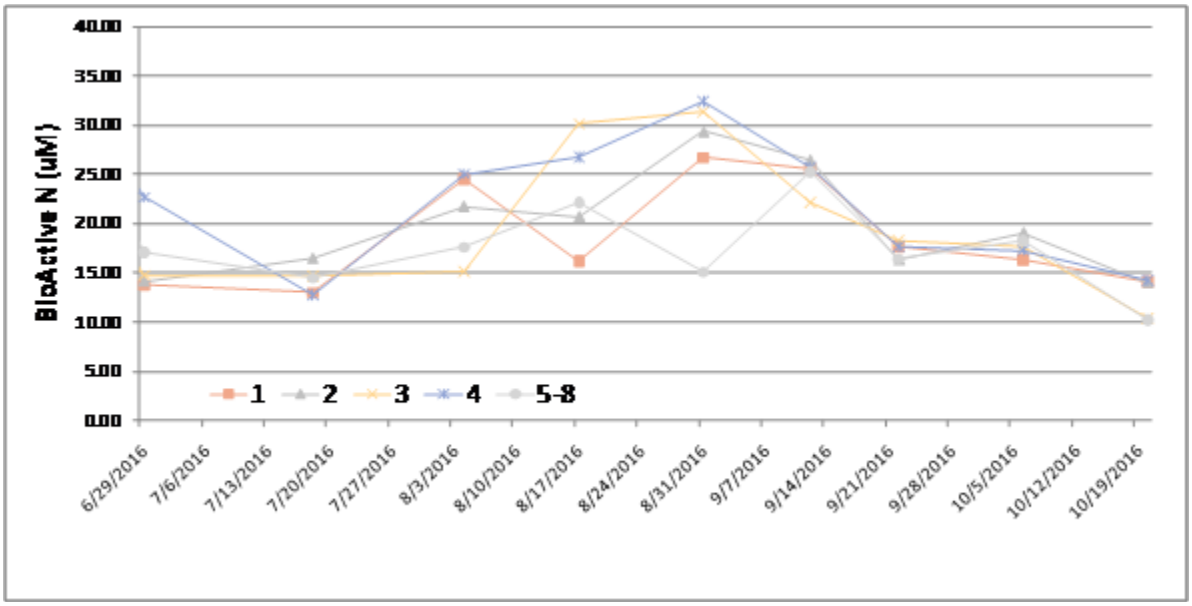


Figure II.4. Top Panel: 2017 time-series of mixed layer average bioactive nitrogen concentration at each individual sampling station and the average of the stations (5-8) associated with the oyster deployment. Bottom Panel: 2016 data shown for comparison. Station numbers refer to locations in station map above.

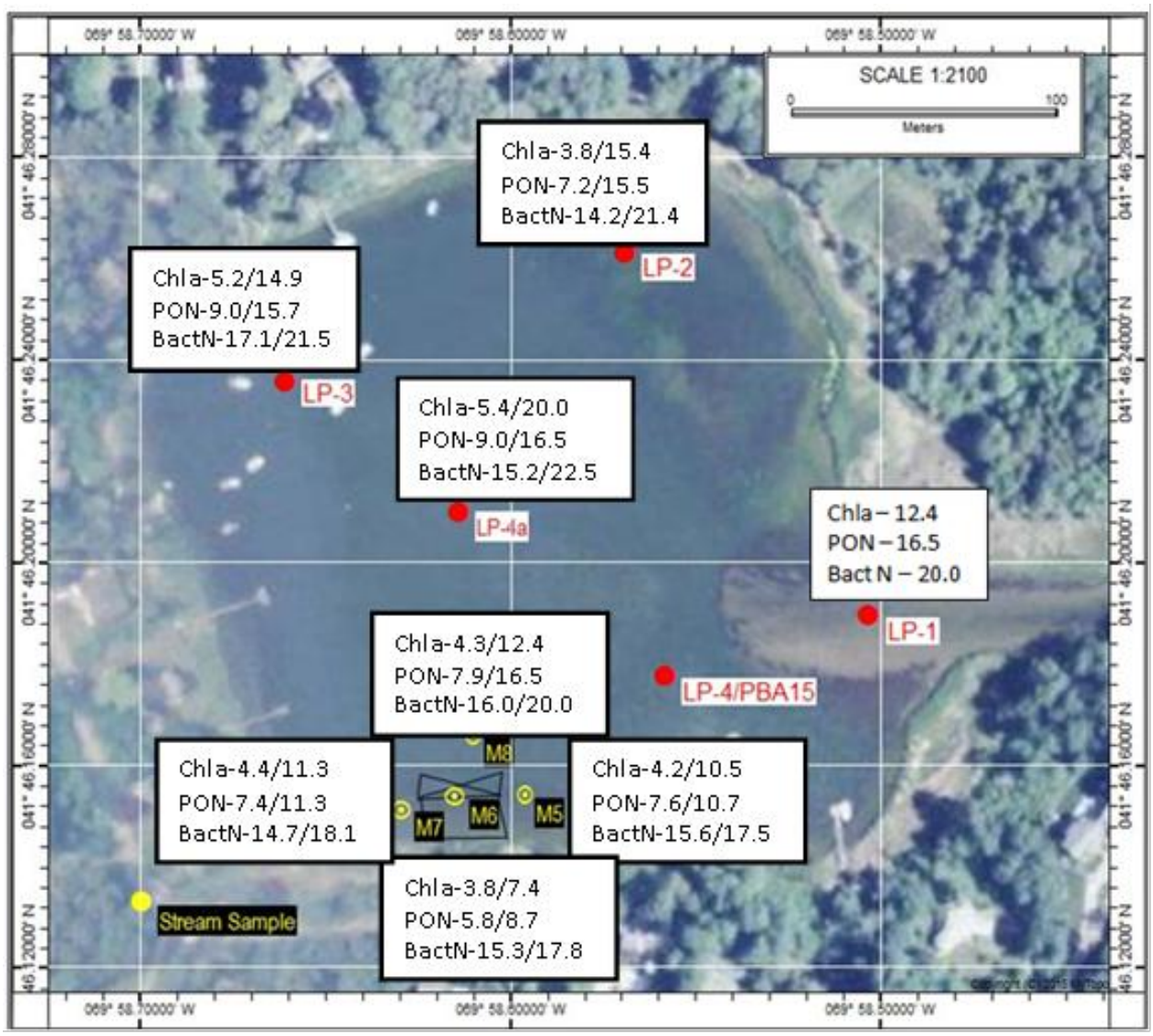


Figure II.5. Mixed layer average concentrations of total chlorophyll a (μg L^{-1}), particulate organic nitrogen (μM), and bioactive nitrogen (μM). Values represent average of samples collected from July 18 through October 6, 2016. Note the lower concentrations of each constituent in the region of the oyster deployment (stations 5,6,7,8) versus farther away (stations 1,2,3,4). 2017 values are shown first with 2016 values shown for reference (2017/2016). Values presented for station LP-1 are only from 2016.

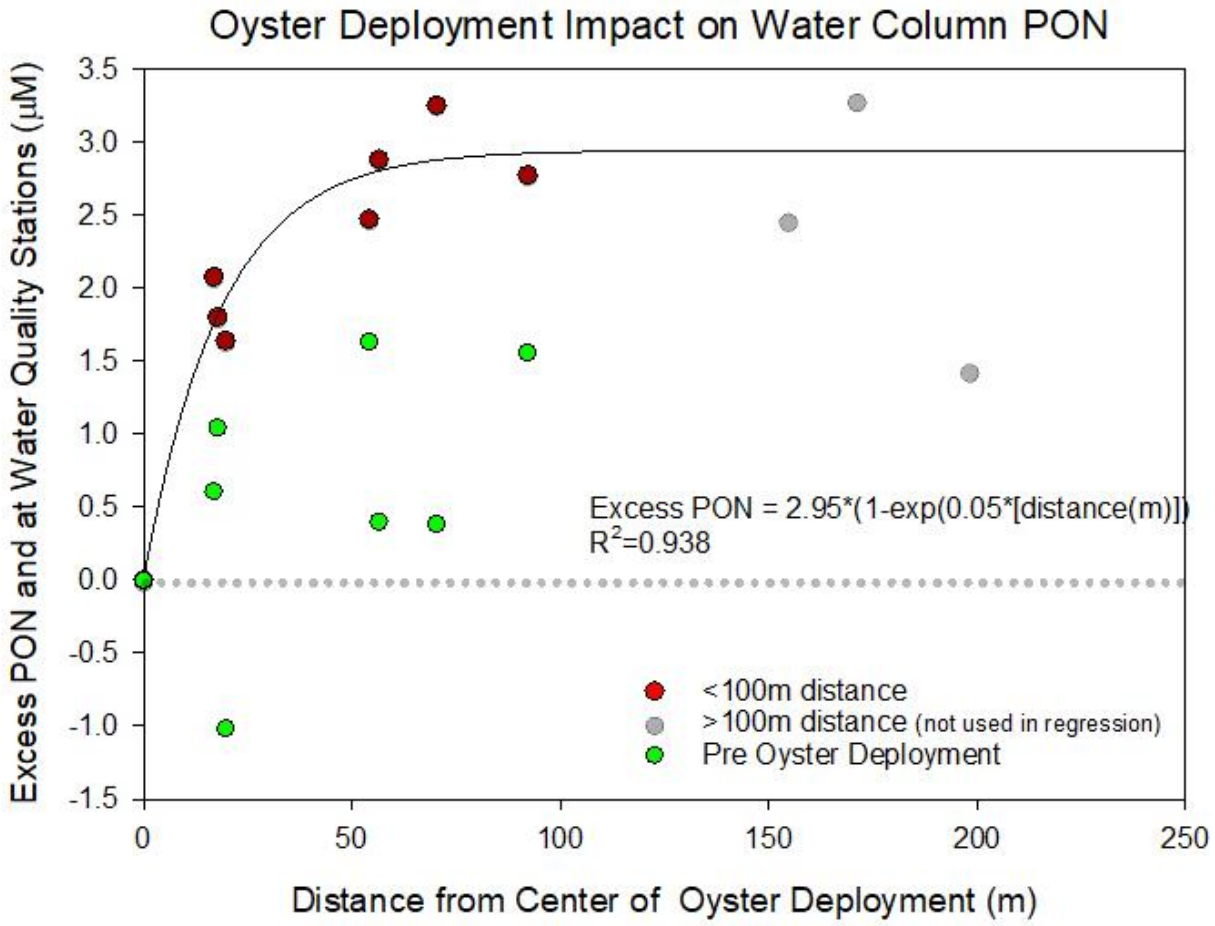


Figure II.6. Mixed layer average concentrations of particulate organic nitrogen (µM) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note the concentrations of excess PON within 100m of oyster deployment increase exponentially with distance only after oysters were deployed.

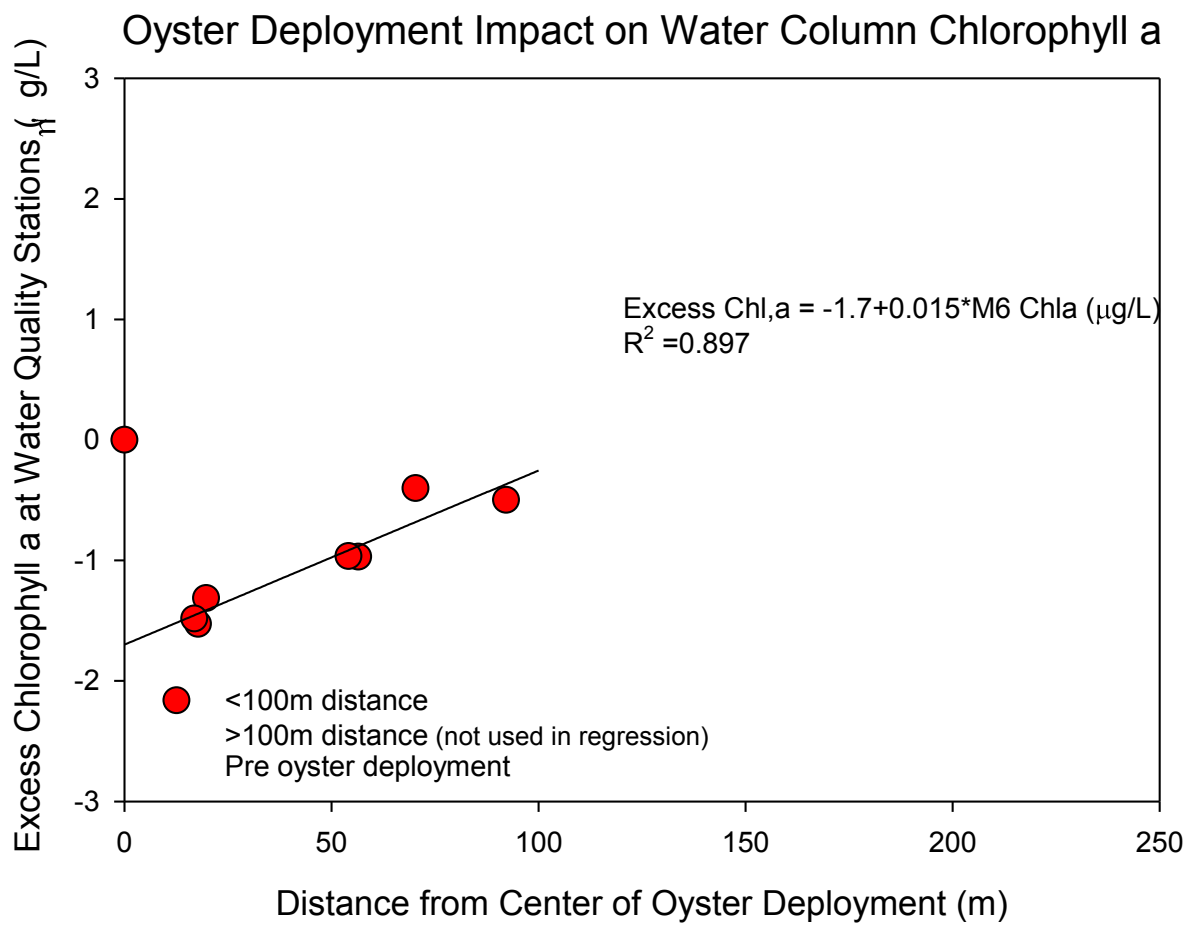


Figure II.7. Mixed layer average concentrations of chlorophyll a (μg/L) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note the concentrations of excess Chla within 100m of oyster deployment increase linearly with distance from the oyster site only after oysters were deployed and that the oysters create a local chlorophyll minimum.

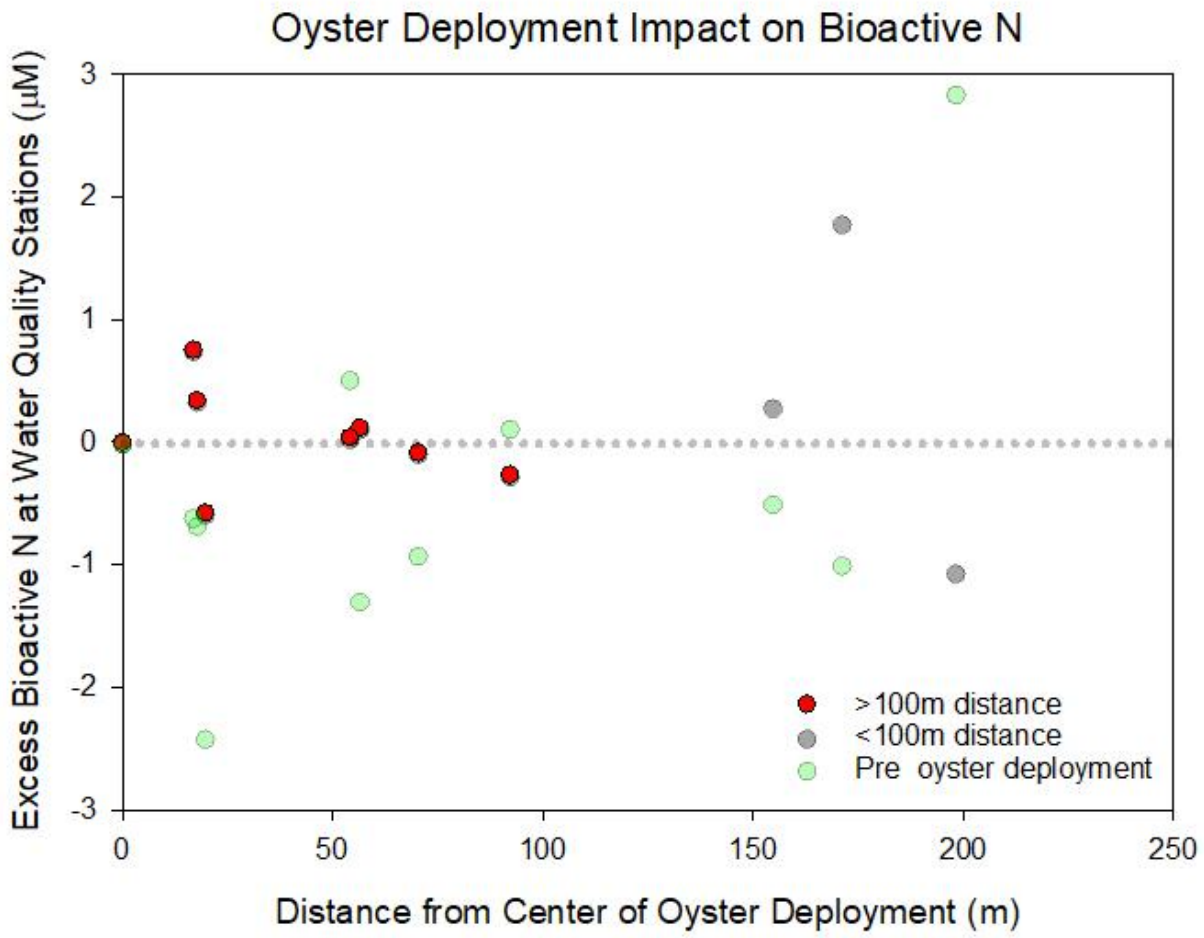


Figure II.8. Mixed layer average concentrations of bioactive N (μM) in excess of that observed at M6 prior to oyster deployment (April –June 2017) and following oyster deployment (July-October). Note that unlike PON and chlorophyll there is no obvious trend with increasing distance from the oyster deployment area, possibly due to it being a composite parameter.

Recommendations based on water quality sampling results:

Sampling should commence earlier in the season to capture any gradients not due to the activities of the deployed oysters. Sampling should focus on the oyster deployment area versus stations farther away, although it may be possible to sample station LP-2 less frequently or not at all. Lastly, it is important to monitor the surface water inflows (herring creek and cranberry bog) during subsequent oyster deployments as these sources of flow and load may figure more prominently under more average or above average precipitation conditions (summer 2016 was considered a particularly dry summer).

Section III. Time Varying Water Quality Assessment Post Oyster Deployment (2016)

Approach:

Water column surveys were conducted as water flowed through the oyster deployment area during complete tidal cycles on 4 dates in Summer 2016 (August 10 and 24, September 13, and October 12). This type of time varying survey (commonly referred to as a tidal flux survey) was not undertaken during the summer 2017 oyster growing season. During the 2016 surveys, samples were collected at nominal hourly intervals over consecutive flooding and ebbing tides. The sample sites included the long-term Lonnies Pond water quality station (PB-15) as background, and 2 sites associated with the oyster deployment itself, one to the west and one to the east. Samples were collected at 0.3 m depth at about 1 m from the edge of the aquaculture footprint. Samples were assayed in a similar manner as for the background water quality surveys (see Section II). In parallel with the water column sampling, an acoustic doppler current profiler (ADCP) was deployed to measure current direction through the aquaculture area relative to the sampling points. The concept was to quantify changes in water column constituents, most importantly particulate organic nitrogen, total chlorophyll-*a* and bioactive N, although the complete suite of nitrogen components, orthophosphate and dissolved oxygen were assessed.

Results:

Although 4 sampling events were conducted during the 2016 sampling season (year 1), the first event (August 10, 2016) was halted midway through the survey due to an extreme rain event which resulted in aberrant water column conditions and un-interpretable flow through the oyster area. Fortunately, the other 3 events yielded usable/interpretable results.

For the three subsequent valid events, the flow through the aquaculture area was NE to SW (8/24 and 9/13) and W to E (10/12) with generally low velocities. Given uncertainties in the amount of contact that a parcel of water had with the aquaculture bags and resulting turbulence, it was not possible to calculate rates of particulate removal. However, it was possible to examine removals on a concentration basis from up-gradient to down-gradient. Since the samples were collected in parallel at the eastern and western sampling points, a paired analysis was possible. It should be noted that on each date, there was a constant wind direction. The constant wind effect resulted in a water flow direction that also did not change between flooding and ebbing tides even as water entered and left the basin (i.e. the circulation was mainly wind driven). Changes in the paired samples over flooding and ebbing tide showed no significant differences in any of the water column constituents in water flooding through the aquaculture system on any of the 3 dates. In contrast, for each survey, constituents showed higher values on the ebb tide in the water before it passed through the aquaculture system than after it had passed through (Table III.1). On ebbing tides over the 3 events, average reductions of 19%-37% in PON, 23%-48% in total chlorophyll-*a*, 12%-20% in bioactive nitrogen were observed. In the October survey, flows approximated the long axis of the aquaculture system and the highest particulate removals were seen (37% in PON, 48% in total chlorophyll-

a). This result likely is related to the water parcels moving along the full length of the oysters in this event, maximizing the opportunity for filtration. This helps to explain the lower observed uptake when water passes obliquely through the system. It should be noted that variation in observed uptake is due to the position of the sampling points relative to the flow direction, as measured uptake will vary with flow direction even if oysters are taking up the same mass in each survey. Nonetheless the results clearly indicate that the oysters filtered out sufficient amounts of particles to significantly lower PON and chlorophyll-*a* levels, which was also seen in the time-series measurements (Section IV). Equally important, the observed reduction in bioactive N indicates that the removal of PON resulted in a net N loss to the water column of 12%-20%, as only about half of the PON removed was returned as regenerated nitrogen from the sediments or excretion nitrogen by the oysters.

Conclusions:

The oyster deployment in Lonnies Pond removed significant amounts of PON and total chlorophyll-*a* in ebbing waters. Particulate nitrogen removal resulted in a net lowering of water column bioactive nitrogen as the amount filtered out was not returned via oyster excretion or sediment regenerated nitrogen. Bioactive N levels declined by 12%-20% during passage through the aquaculture systems. Observed removals are conservative estimates due to the oblique patterns of flow through the oyster area in the surveys, which biases the uptake estimate low in these experiments.

Year 1 Recommendations (2016):

The tidal surveys yielded useful results, but were confounded by the flow pattern at the specific location in Lonnies Pond. While the flow pattern was not ideal, the results are unequivocal and understandable, which increases their value. Future surveys should include a real-time determination of flow direction and associated adjustment of sampling points. Moving sampling points to maximize the contact of a parcel of water with the oyster system would greatly improve accuracy and should support rate estimates. However, it is clear that placement of future demonstration deployments should account for flow direction if these types of measurements are to be undertaken. None-the-less, the tidal surveys clearly indicated that partical removal is sufficiently rapid with the result that there are quantifiable changes in water quality during individual tidal cycles. This supports the contention that shellfish should be able to make a positive change in Lonnies Pond water quality during the critical management period.

Table III.1. Water column constituents up gradient and down gradient stations during tidal flow through the aquaculture system in Lonnies Pond, Summer 2016. Highlighted pairs of means have significantly different levels after passing through the oyster deployment area.

	Flow Direction	PON (uM)	PON (uM)	PON (uM)	T-pig (ug/L)	T-pig (ug/L)	T-pig (ug/L)	TN (uM)	TN (uM)	TN (uM)	BioAvailN (uM)	BioAvailN (uM)	BioAvailN (uM)
Title		East	West	PB-15	East	West	PB-15	East	West	PB-15	East	West	PB-15
	Survey 8/24/2016												
Flood	E to W	15.31	15.80	19.50	22.9	21.3	25.6	47.68	49.29	50.83	16.50	12.07	20.14
Ebb	E to W	11.05	8.94	15.10	12.6	9.8	19.1	47.22	44.16	48.19	14.89	13.05	16.12
	Survey 9/13/2016												
Flood	E to W	8.32	11.93	11.29	7.04	8.03	7.43	51.71	52.55	52.40	22.11	24.38	22.38
Ebb	E to W	13.17	8.86	19.16	9.90	7.03	14.33	50.72	46.20	47.05	22.60	18.09	24.00
	Survey 10/12/2016												
Flood	W to E	8.97	7.95	11.67	7.8	8.9	14.5	47.7	48.9	48.5	25.1	28.9	25.3
Ebb	W to E	7.03	11.21	9.19	3.0	5.8	5.3	42.2	49.4	47.2	20.2	23.0	20.8
	statistical significant p<0.05												

Highlighted pairs of means are statistically significant (paired T-test). The flow did not go down the long axis of the oyster deployment, but did pass through the bags on the ebbing tide either in a East to West (events 1 and 2)or West to East (event 3) fashion. Removal can be seen as lower values at the downgradient station.

Section IV. 2016 and 2017 Time-Series Dissolved Oxygen (DO)/Chl-a Moorings (High Frequency Sampling)

Time-series Mooring Deployment and Sampling:

SMAST scientists conducted continuous monitoring of key water column parameters, dissolved oxygen and chlorophyll-a, at 15 minute intervals to assess the impact of oyster aquaculture on the ambient water column. This high frequency autonomous monitoring was completed in parallel with the traditional water grab sampling effort. The bottom moored sondes also collected measurements of temperature and tide height/depth. The mooring program undertaken in Lonnies Pond during the 2016 and 2017 field seasons followed the same protocols and procedures developed for the Massachusetts Estuaries Project (MEP) analysis of the Pleasant Bay Estuarine System and for the Towns of Falmouth and Mashpee Oyster Demonstration Projects. The consistency of protocols allows cross comparability of data sets collected in years past and from other estuarine locations where oyster deployments have been undertaken.

A total of five YSI-6600 moored sondes were deployed at four locations in both 2016 and 2017. Moored sondes were deployed on the bottom (30 cm above the sediment surface) within the footprint of the oyster deployment area as well as to the east and west of the oyster deployment (Figure IV.1). A fourth mooring was placed to the north of the oyster deployment footprint in approximately 2.5 m of water to monitor water quality outside the influence of the oysters. Two sondes were deployed at this fourth location: 1) at the surface and 2) 30 cm above the bottom. While the moorings provided good oxygen and chlorophyll-a data during the 2016

deployment period, oxygen sensors in 2017 suffered periodic failure of their Teflon membranes. Chlorophyll-a records in 2017 and 2016 provided adequate data for comparison of the respective oyster deployment periods. It remains unclear how the sensors were damaged in situ in 2017, however, thicker membranes and better protection that does not interfere with water movement around the sensors was instituted in the 2018 field season. Bi-weekly oxygen values obtained via winkler titration were collected for sonde calibration. These data are presented as instantaneous measurements for each of the mooring locations. In addition, continuous air equilibration values were calculated from salinity and temperature data.

The moorings were maintained April – November in both 2016 and 2017 to provide information during three critical periods: 1) prior to the deployment of the oysters, 2) when the oysters were most actively filtering pond water (i.e. maximum "oyster effect") and the pond water quality is lowest, and 3) through the autumn months when oyster activity was decreased by colder water temperatures. Moorings were calibrated bi-weekly by collection of samples at the specific depth and location of each sensor. At the time of calibration, each sonde was inspected, cleaned and then downloaded. Sondes were then returned to the moorings and secured. Calibration sampling included triplicate Winkler samples for dissolved oxygen (DO) determination as well as collection of whole water for chlorophyll extraction. The sondes recorded DO, Chl-*a* (via fluorescence), salinity, and water temperature and depth at 15-minute intervals.

Time-series Sensor and Sonde Data Results and Discussion:

The dissolved oxygen (DO) records (Figures IV.1a, IV.2, IV.4, IV.6 and IV.8) all show large diurnal variation in response to water column and sediment respiration at night and photosynthesis during the daylight hours. The levels of oxygen depletion (to 2 mg/L) and large diurnal changes indicate a system that has been organically enriched due to nitrogen enrichment and impairment was seen in the summer of both 2016 to 2017. Close examination revealed lower oxygen minima in 2016 than 2017, even with consideration of the diurnal variability. In 2016 oxygen minima at most sites was ~1 mg/L or even showed periodic anoxia, where as in 2017 oxygen levels generally were above 2 mg/L or even 3 mg/L. These findings were consistent with the measured chlorophyll levels which showed a clear inter-annual difference, with 2016 supporting 2-3 times the phytoplankton biomass than observed in 2017.

A general comparison of oxygen conditions in both 2016 and 2017 was achieved by comparing the overlapping time series data and oxygen levels from the field calibration samples in both years. Calculated air equilibration values which represent the expected DO concentrations of a well-mixed water column in the absence of any biological perturbations were also assessed. The results of the comparison of the available 2016 and 2017 Winkler DO data show generally depressed oxygen concentrations at M8 (north of oysters) due to sensors being rapidly fouled and proximate to the Pond's natural pycnocline for the surface and bottom sensors, respectively. Moorings M5 and M7, located to the east and west of the oyster deployments show slight positive and negative deviations with the exception of a short period beginning June 1 and ending June 15. The extreme excursions from air equilibration were not accompanied by any dramatic change in chlorophyll concentration (e.g. a phytoplankton

bloom) and may have been the result of drift macroalgae periodically interacting with the moorings. The most complete DO record was at M6 in the middle of the oyster deployment. Diurnal excursions in DO were large (up to 10 mg/L) and oxygen minima reached 3 mg/L, however close examination of the records show these low levels were not persistent; the events did not last for more than 1 hour early in the morning.

The continuous chlorophyll records are of generally high quality and confirm conclusions from the bi-weekly sampling results. Phytoplankton concentrations in Lonnies Pond were significantly lower in 2017 than in 2016. Overall temperatures in the pond (from sonde records) were also slightly lower in 2017 than in 2016 and while there are many other environmental factors (rainfall) which can affect phytoplankton biomass, the observations are potentially due to the larger biomass of oysters acting to improve water quality in 2017 possibly coupled with a larger regional meteorological effect. It was noted that in summer 2017 there were also generally lower chlorophyll levels in Pleasant Bay than in 2016 (Orleans Water Quality Monitoring Program).

Unlike the elevated chlorophyll values seen in 2016, the highest chlorophyll concentrations in 2017 were observed within the oyster deployment area (M6). The continuous record displays consistently higher chlorophyll concentrations in the middle of the deployment area than those observed at moorings either to the east or west. This pattern suggests that filtration of plankton by oysters and resulting deposition was concentrating chlorophyll (biodeposits are high in pheophytin a) and releasing it to the water column where it settled beneath the oyster arrays. This concentration and deposition within the oyster deployment area is seen in the surficial sediments and the stimulation of sediment remineralization of organic matter within the water column and surface sediments. Interestingly, chlorophyll levels at M5 and M6 rarely exceed those observed at nearby monitoring locations suggesting that deposition is mainly within the oyster deployment area.

In some locations of oyster culture and aquaculture, concerns have been raised about potential benthic habitat decline resulting from the concentration of feces on the sediment surface which can lead to increased sediment respiration and by extension depressed dissolved oxygen concentrations within the deployment area. While dissolved oxygen concentrations were observed to be below saturation values, the lowest concentrations observed within the oyster deployment area were also observed at far field stations such as LP2 and LP3, hence attribution to oyster culture is not possible. The apparent increased phytoplankton production within the oyster deployment area warrants continued monitoring, but as long as that increased production remains restricted to the deployment area (balanced by increased oyster filtration) it could be a positive outcome as recycled N is removed by oyster assimilation.

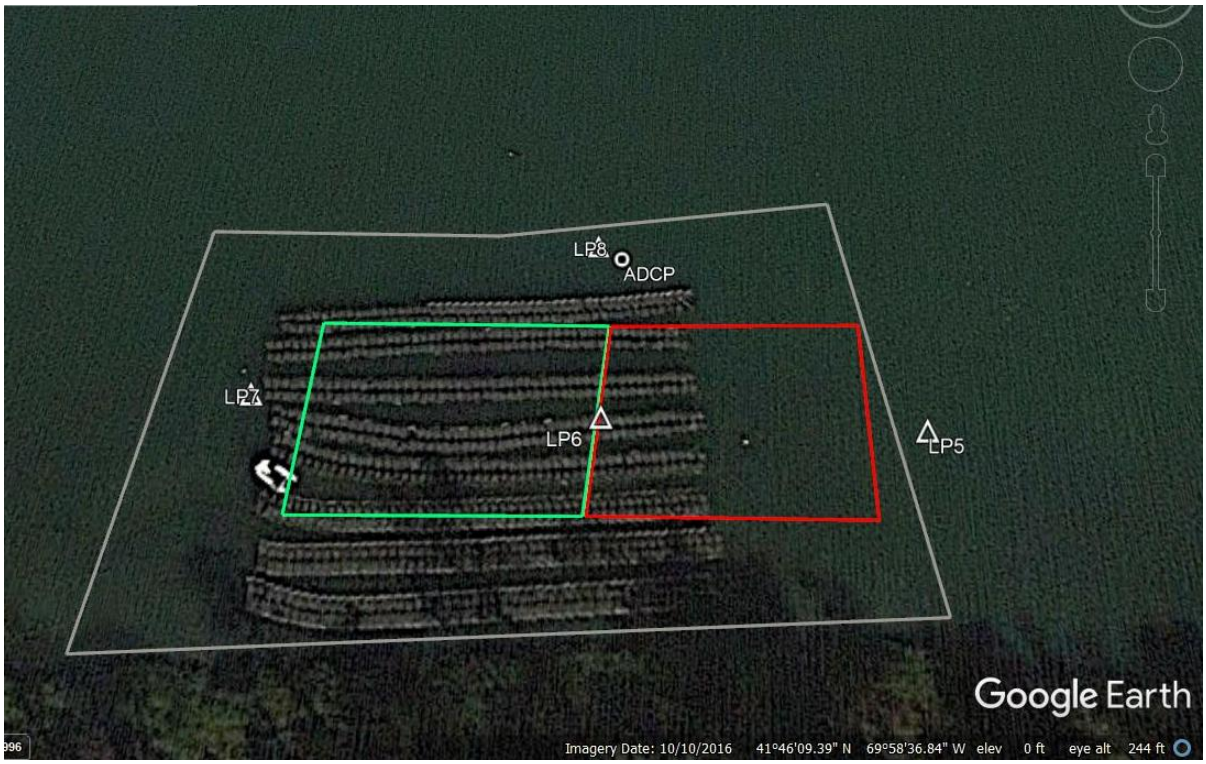


Figure IV.1. Aerial photograph showing the initial 2016 oyster deployment (floating bags) relative to mooring locations at the edges of the oyster deployment footprint (LP5 {bottom}, LP7 {bottom}, LP8 {surface+bottom}). The area defined by the green line is where the first year class oysters (2016) were redeployed in 2017 after over-wintering. The area defined by the red line is were oyster seed was deployed in 2017. The calculated 2016 impact area is denoted by the gray line.

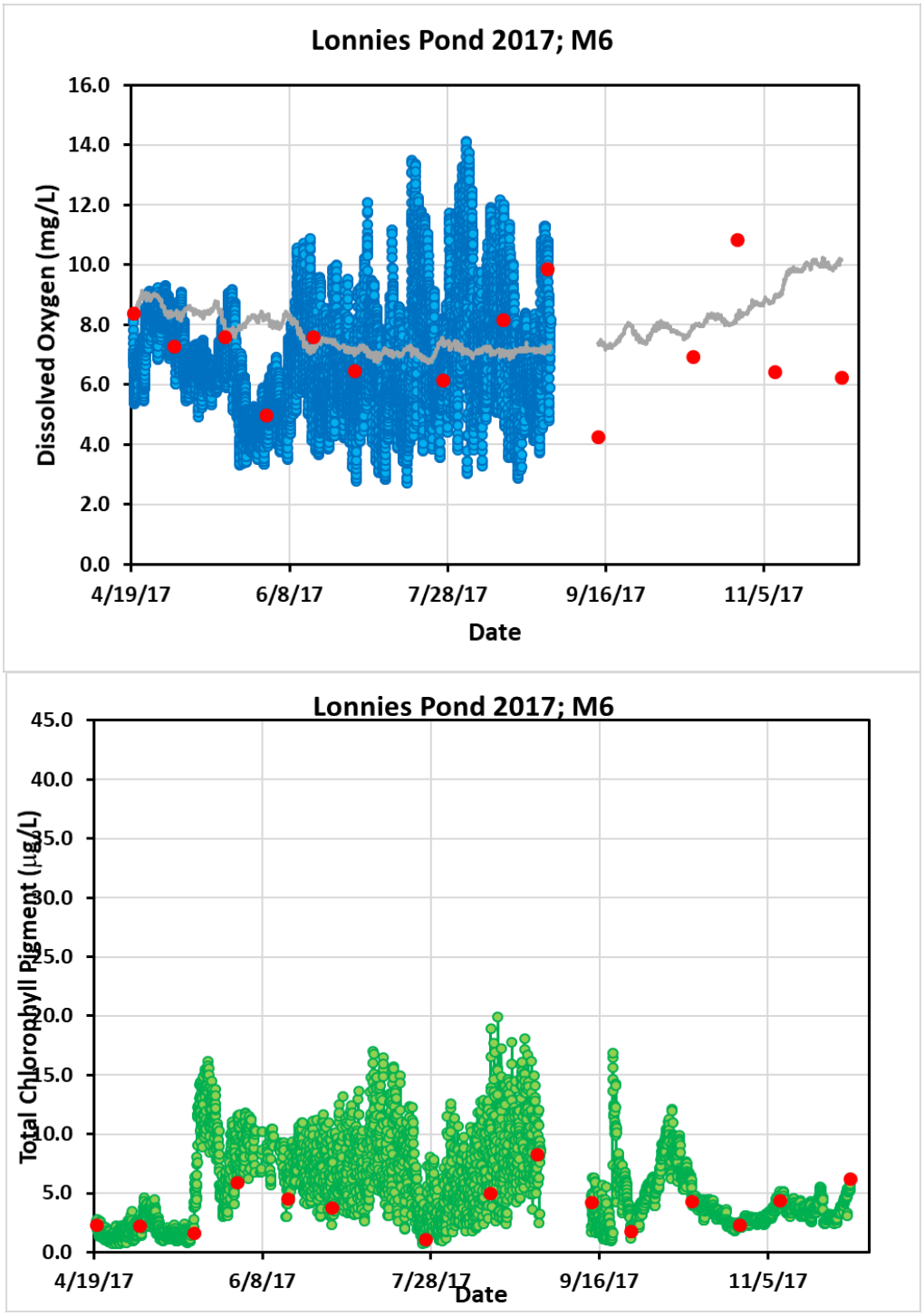
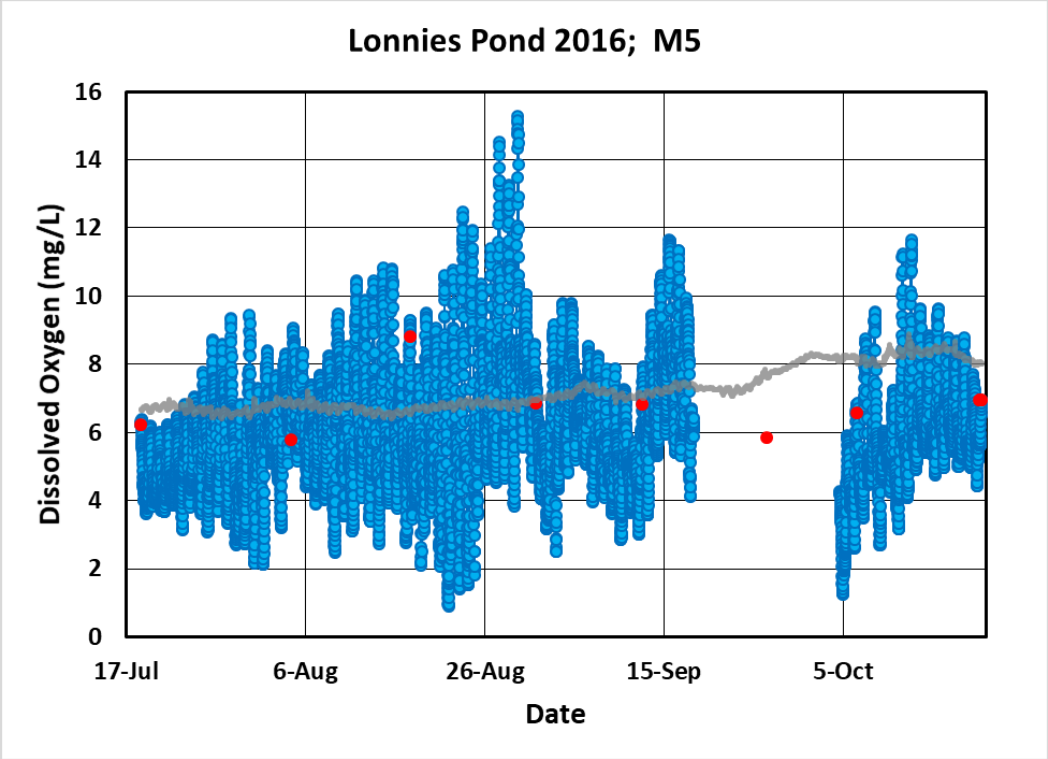


Figure **IV.1a** Time series dissolved oxygen at Lonnies Pond Mooring M6 located in the center of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top). Time series chlorophyll measurements at Lonnies Pond Mooring M6 located in the of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points.



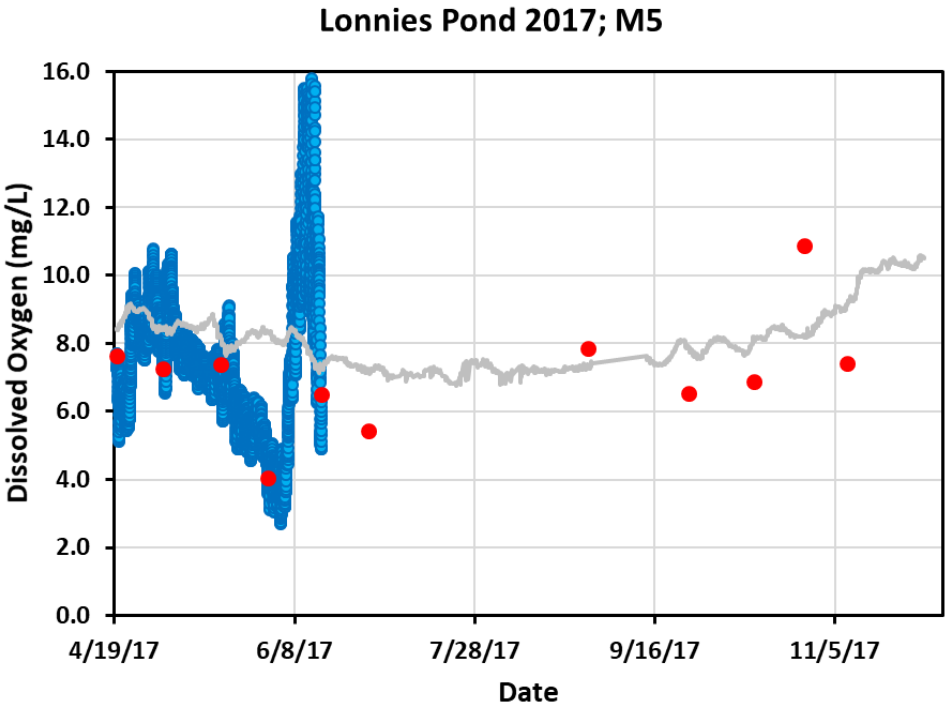


Figure IV.2. Time series dissolved oxygen at Lonnies Pond Mooring M5 located due east of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

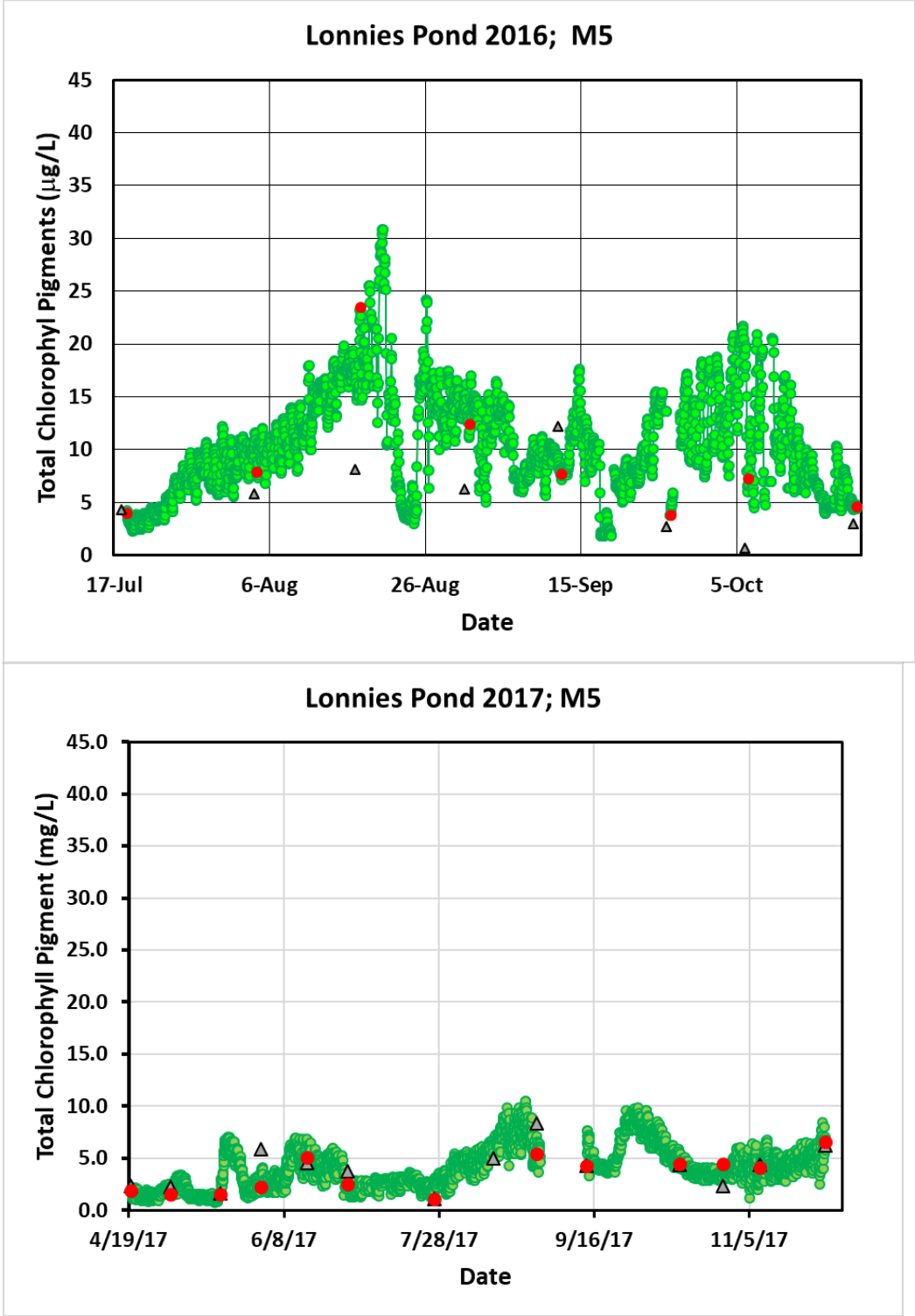


Figure IV.3. Time series chlorophyll measurements at Lonnies Pond Mooring M5 located due east of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

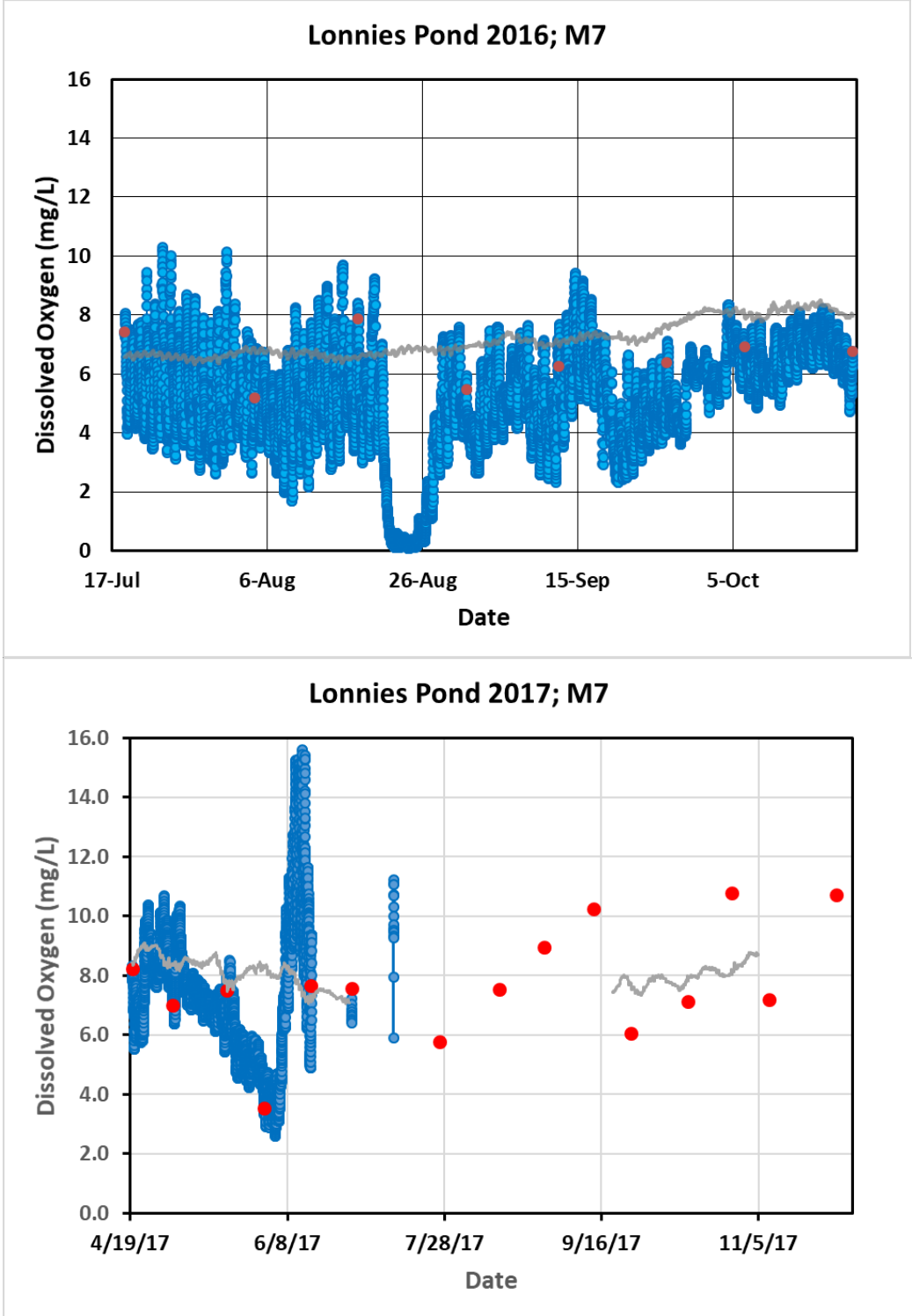


Figure IV.4. Time series dissolved oxygen at Lonnies Pond Mooring M7 located due west of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

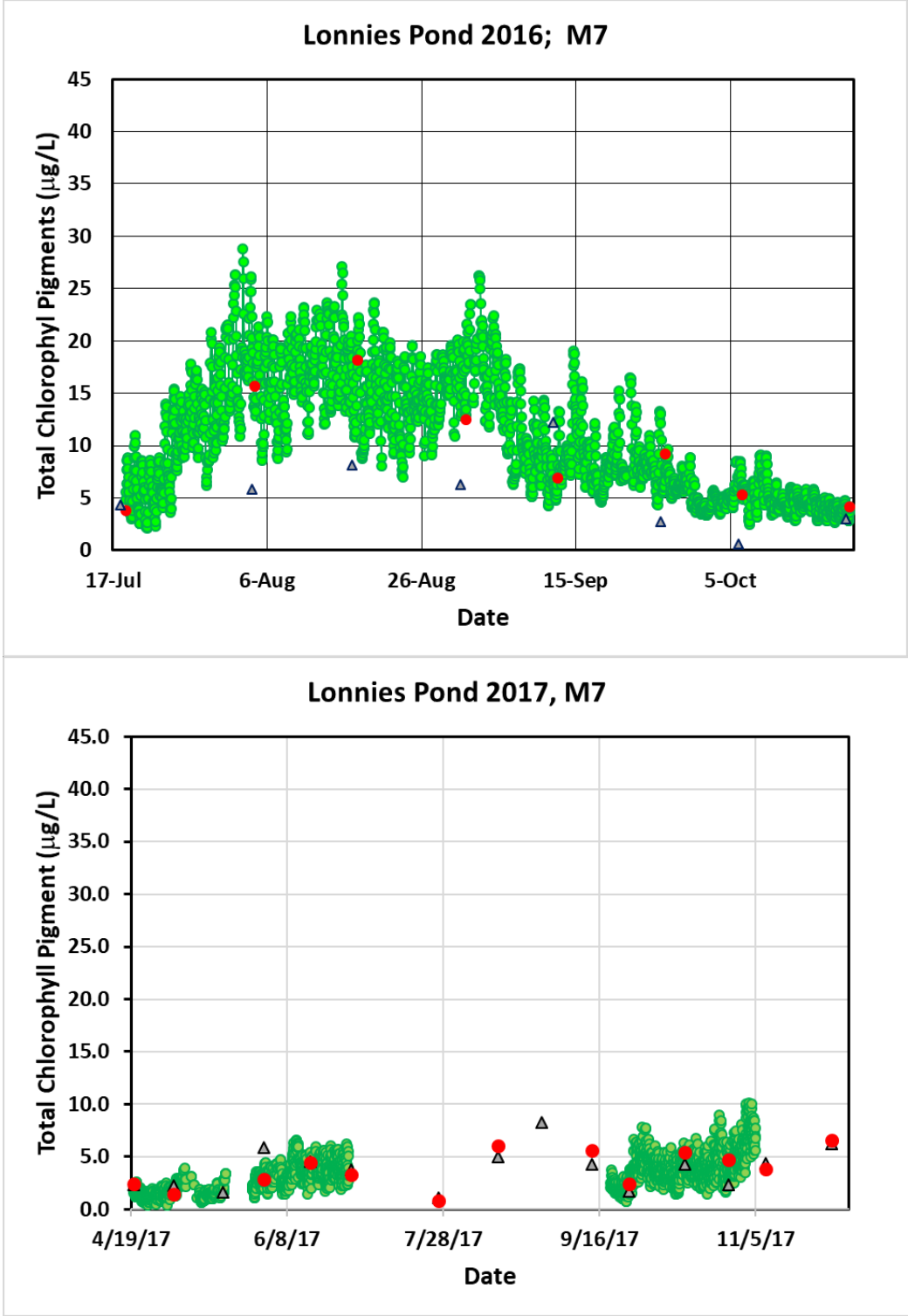


Figure IV.5. Time series chlorophyll measurements at Lonnies Pond Mooring M7 located due west of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

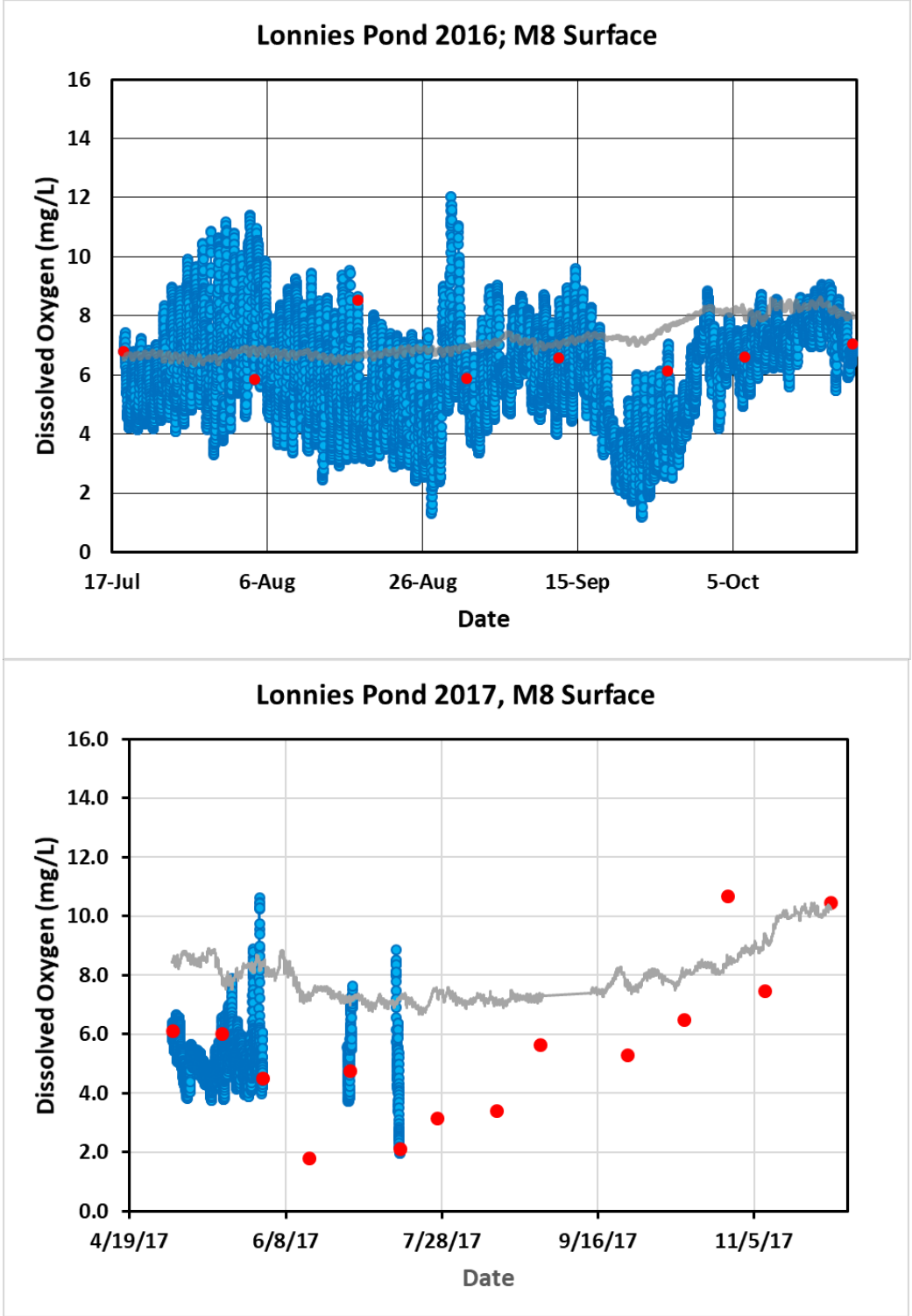


Figure IV.6. Time series dissolved oxygen at Lonnies Pond Mooring M8 (Surface) located due north of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

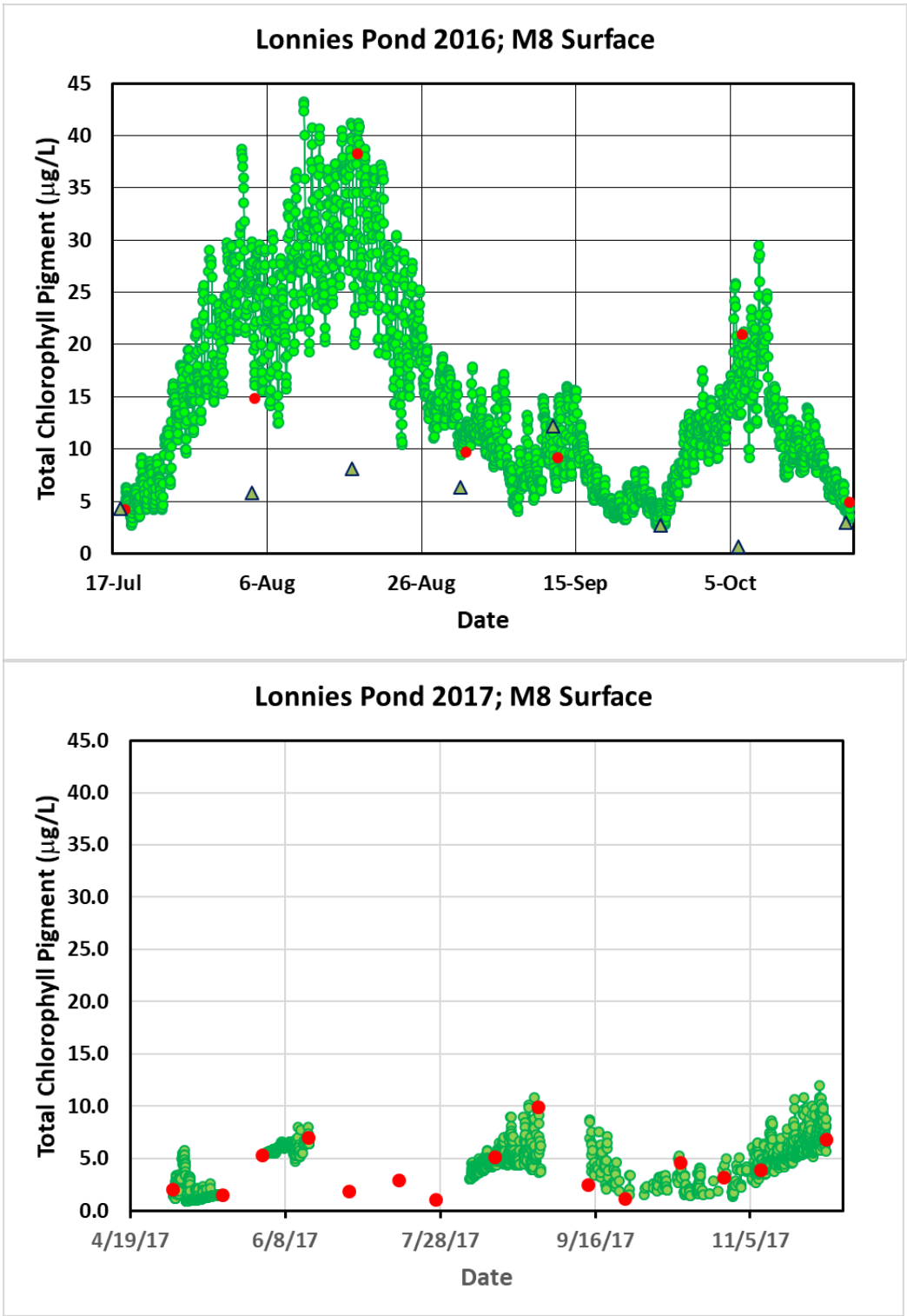


Figure IV.7. Time series chlorophyll measurements at Lonnies Pond Mooring M8 (Surface) located due north of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

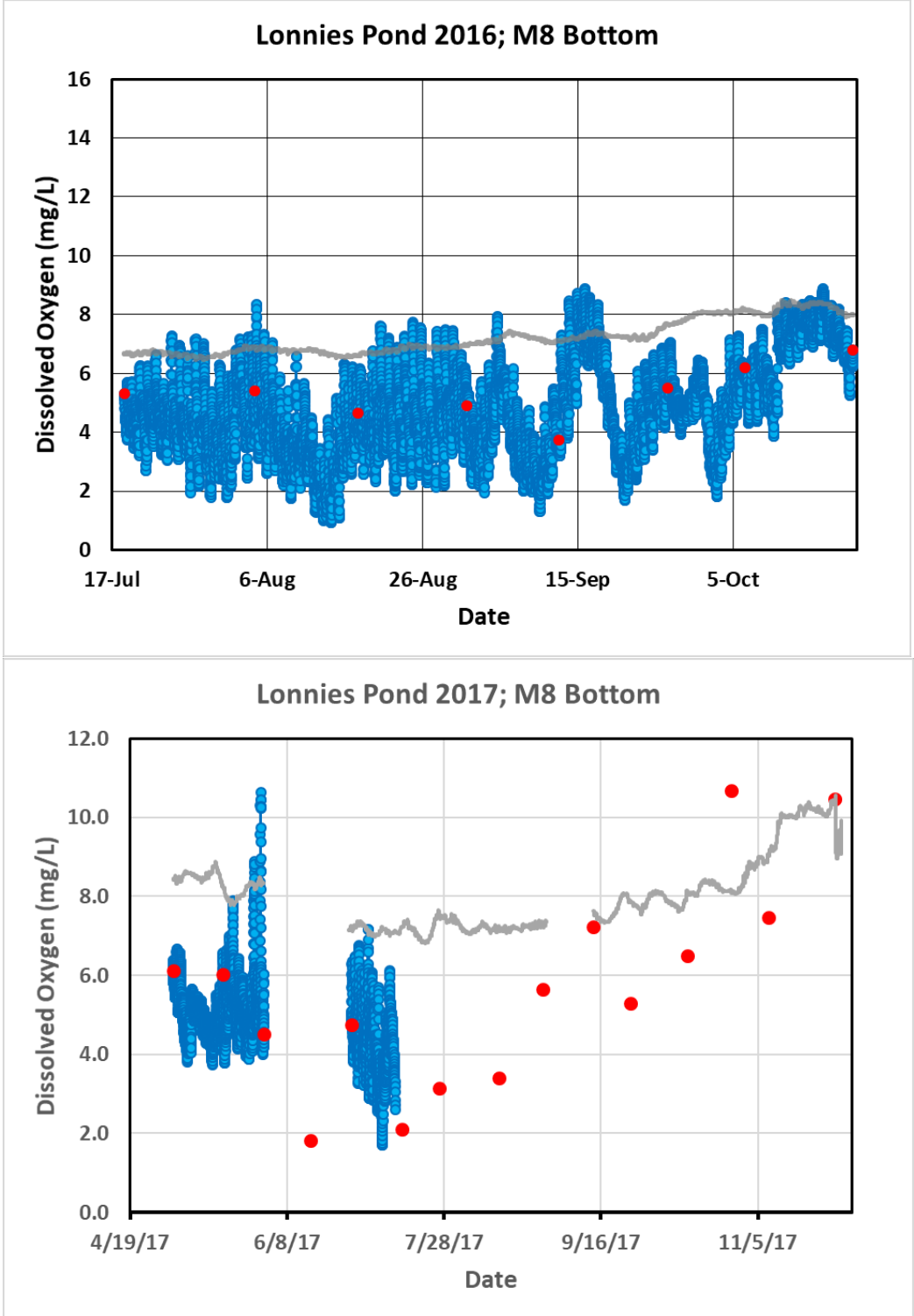


Figure IV.8. Time series dissolved oxygen at Lonnies Pond Mooring M8 (Bottom) located due north of the oyster deployment footprint. Red markers indicate Winkler titration calibration points. The gray line represents the air saturation value (top panel 2016 for comparison).

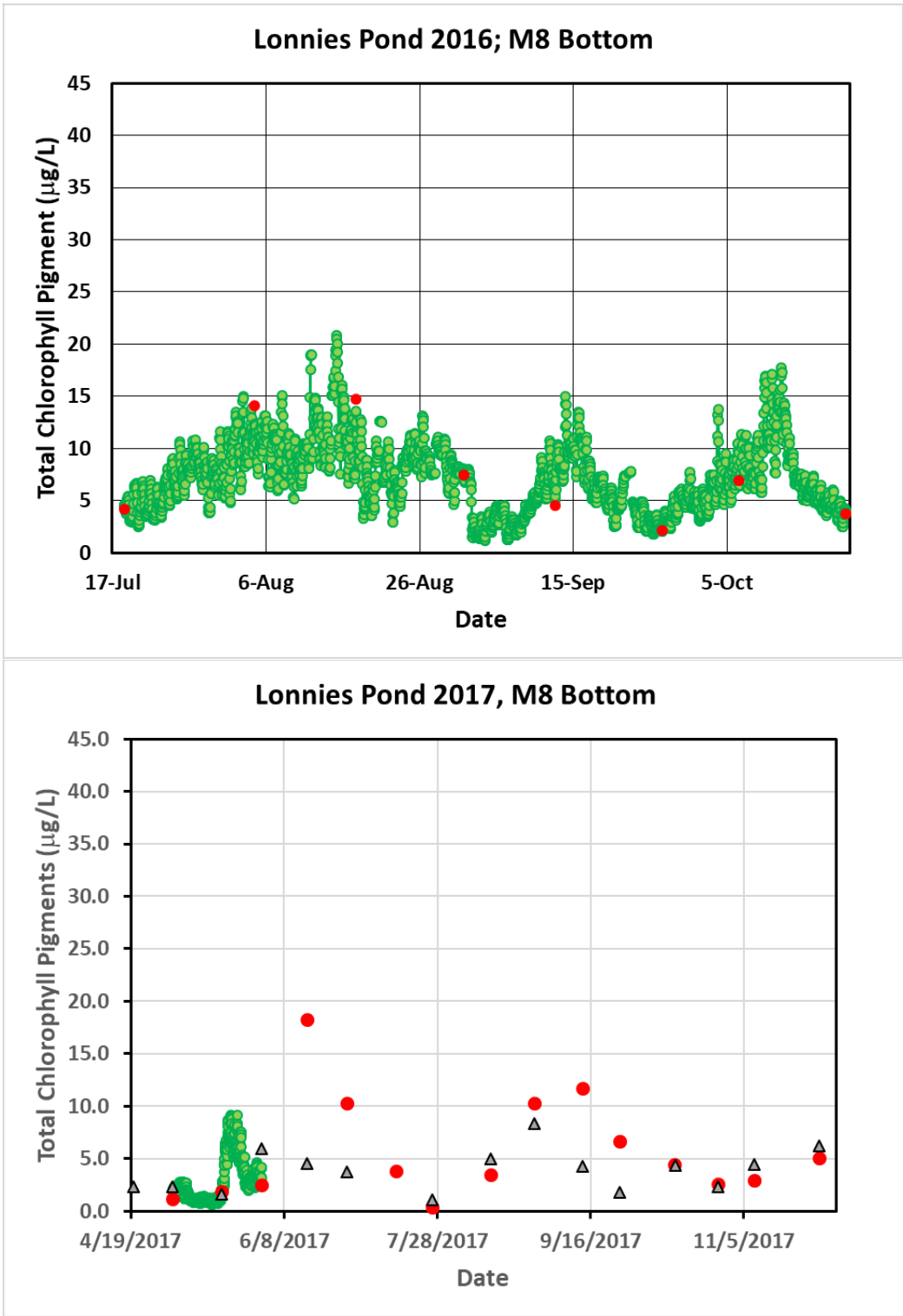


Figure IV.9. Time series chlorophyll measurements at Lonnies Pond Mooring M8 (bottom) located due east of the oyster deployment footprint. Red markers indicate chlorophyll extraction calibration points. Green triangles indicate chlorophyll extractions conducted at Mooring M6 located in the middle of the deployment footprint (top panel 2016 for comparison).

Light pendants were used to measure light intensity in units of μE/m^2/s every 10 minutes and profiles were used to calculate the percent surface irradiance and the light extinction coefficient (k) within the water column associated with the oyster deployment in 2016. The light extinction coefficient, k was calculated using the Beer-Lambert Law which describes the logarithmic decay of light through a medium; the larger the light extinction coefficient, the more rapid the loss of light through the water column and represents a greater degree of turbidity. In contrast, small light extinction coefficients reflect greater light transmission through the water column and less turbidity. The mean daily light intensity was calculated using only the active photoperiod. In addition to the chlorophyll a samples collected for water quality and sonde calibration, total suspended solids (TSS), samples were collected to determine whether inorganic water column constituents could be responsible for changes in water clarity.

The average light characteristics, TSS, and chlorophyll concentrations are shown below (Table IV.1). Stations 5, 6, and 7 were within the oyster area and the bottom TSS values mirror the chlorophyll concentrations of these stations; however, the shallow water and variable shading caused by the moving bags makes light interpretation difficult. The highest light penetration and coinciding lowest light extinction coefficient was located at the site furthest away from the oysters, Lonnies 8, while also having the lowest chlorophyll concentration (Table IV.1). Note that station Lonnies 8 had additional surface samples collected. In contrast, when looking at only the data from stations in the oyster area, Lonnies 5, 6, 7, the lowest chlorophyll and lowest TSS (10.05 μg/L, 9.33 mg/L respectively) were found directly in the middle of the oysters, Lonnies 6. The chemical data represented specially as chlorophyll concentration and total suspeneded solids show these parameters are reduced within the oyster area. It appears that bag shading reduced the utility of the light records, so they were not deployed in 2017. The physical and chemical data support the data from the sondes; however, it was clear that the light data was influenced bag shading. Analysis of wind, rain, and tidal stage did not provide insight into what other factors might be influencing the light data.

Table IV.1: Results from the continuous light profiles measurements from Lonnies Pond showing the mean light intensity, penetration, and the light extinction coefficients along with the total suspended solids (TSS) and total chlorophyll pigments at each station.

Station	Depth	Light Intensity (μE/m2/s)	Mean Penetration	Light Extinction Coefficient, k	TSS (mg/L)	Total Chlorophyll Pigments (μg/L)
Lonnies5 (east)	Surface	249.74				
Lonnies5 (east)	Bottom	88.00	35.21%	1.66	10.99	11.13
Lonnies6 (oysters)	Surface	216.94				
Lonnies6 (oysters)	Bottom	44.42	20.74%	2.41	9.33	10.05
Lonnies7 (west)	Surface	156.47				

Lonnies7 (west)	Bottom	42.95	33.28%	2.39	15.64	15.54
Lonnies8 (mid)	Surface	191.06			10.39	16.62
Lonnies8 (mid)	Bottom	95.53	55.33%	0.92	16.57	9.00

Section V. Particle Capture and Biodeposit Production by Oysters

Oysters, as well as other sessile filter feeders (e.g., barnacles, sponges), increase water column clarity by filtering out particulates which are later released in biodeposition (Newell et al. 2005). The suspended particulate matter consists of photosynthesizing microscopic organisms (phytoplankton), dead particulate organic matter (detritus), and bacteria, which typically colonize the phytoplankton and detritus (Newell et al. 2002). Oysters selectively digest nitrogen-rich particles and reject the less-nutritious and inorganic particles as pseudofeces (Newell et al. 2004; Newell and Jordan 1983). Nutrients from captured foods may be assimilated into biomass (See Figure V.1) (Higgins et al. 2011). The particulates passing through the digestive system are finally deposited as feces and the rejected material deposited as pseudofeces which together are termed biodepositon.

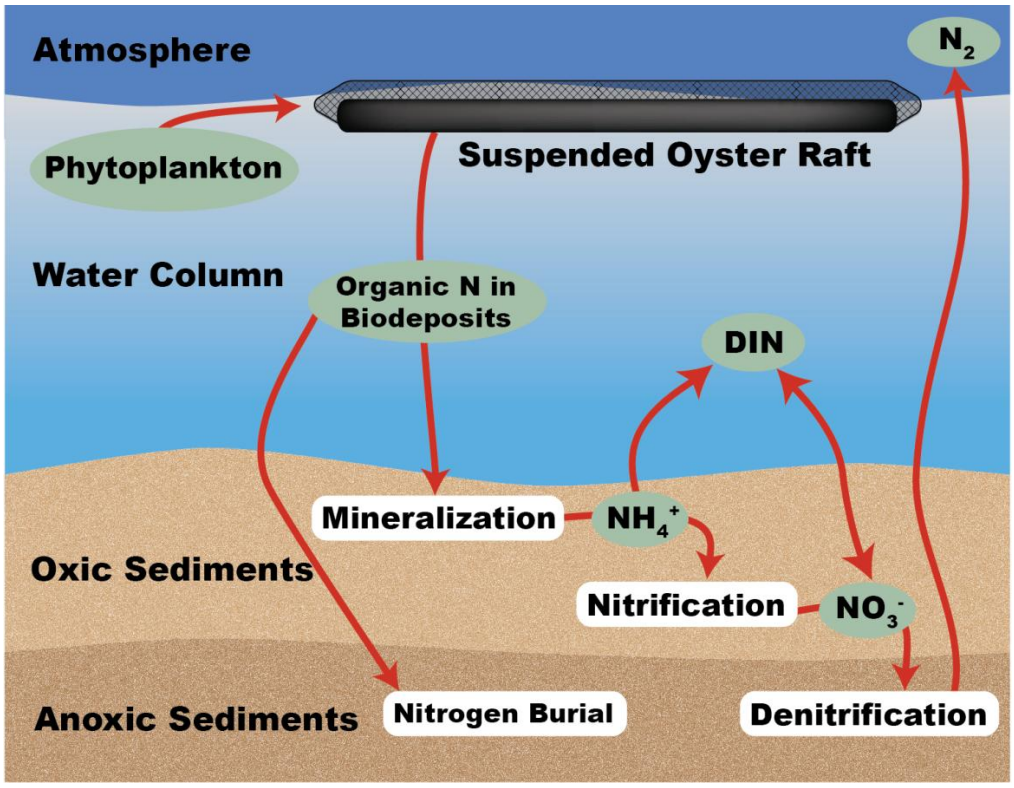


Figure V.1– Diagram of oyster's role in the marine nitrogen cycle in a shallow water estuary with oxygenated (oxic) and non-oxygenated (anoxic) sediments. White rectangles indicate microbial processes; green ovals indicate nitrogen species (Diagram adapted from Kellogg et al 2013).

Particle Capture and Biodeposition by Oysters

In situ biodeposit traps were used to determine individual oyster biodeposition rates during the 2016 and 2017 oyster growing seasons. Oysters used in the biodeposit traps were allowed to acclimate to the environment for a period of three to five days before measurement. The traps were operated for 24 hours to span a full day/night cycle and two tidal cycles. The oysters were positioned in sets of four on a rectangular PVC platform (30 cm x 20 cm; 4 mm thickness). Eight collection containers were installed beneath the platform which are capped with funnels fitted on each side of the oysters to capture and direct feces and pseudofeces into the collection containers (Figure V.2). To account for ambient particle settling into the collection containers, a control apparatus (with oyster shells) was deployed alongside the treatment group. Additionally, small mesh plastic screens were positioned over the biodeposit trap to prevent shrimp and small fish from entering and disturbing or consuming settled biodeposits. The traps were deployed once in October 2016 and on five dates during the 2017 field season. Oysters used in the biodeposit traps were second year oysters from the Lonnies Pond aquaculture oyster population.



Figure V.2. Biodeposit trap deployed in Lonnies Pond, photo by E. Karplus.

Ambient surface water temperature measurements and samples were collected upon trap deployment and removal. These surface water samples were processed for total suspended solids (TSS), particulate organic carbon and nitrogen, total chlorophyll-*a* and salinity. TSS filters were analyzed for particulate organic carbon and nitrogen using a Perkin Elmer 2400 elemental analyzer.

Biodeposit traps collect feces and pseudofeces deposited by each oyster. The collection containers were returned to the laboratory where the biodeposits were given time to settle in the pre-weighed containers, at which point the over lying water layer was siphoned away. Biodeposit samples were weighed, dried to a constant weight, and then processed for particulate organic carbon and nitrogen content. Oysters deployed in the biodeposit traps were collected to measure shell length, whole oyster weight, wet tissue / shell weight, and dry tissue / shell weight. Biodeposition rates were calculated based on the collected mass of feces and pseudofeces minus the mass of ambient particulates collected in the control traps and the deployment duration. The biodeposition rates were standardized to a 1-gram (dry tissue weight) of associated oysters based on the following allometric relationship:

$$Y_s = Y_e\,(1/W_e)^b,$$

where Y_s and Y_e are the standardized and measured biodeposition rates, respectively, W_e is the dry tissue weight of the measured oyster, and b is the allometric exponent 0.58 (Cranford et al. 2011).

By standardizing the individual biodeposition rates it was possible to use the total dry tissue biomass determined for the Lonnies Pond oyster deployment to expand the biodeposition rate to include the total oyster biomass deployed in Lonnies Pond.

The biodeposit measurements (total mass and particulate organic carbon and nitrogen collected per day) and surface water parameters (total suspended solids and particulate organic carbon and nitrogen) were used to determine the mass of particulate organic nitrogen settling from the suspended oyster bags.

Results:

Table V.1. 2017 biodeposition rates, biodeposit characteristics, and surface water column conditions associated with particle trap deployment. Deposition Rates: mean ($\pm$SE) total oyster deployment biodeposition rates and particulate organic nitrogen (PON) deposition. Biodeposit Characteristics: mean ($\pm$SE) particulate organic carbon (POC) and particulate organic nitrogen (PON) content and carbon/nitrogen mass ratio (C:N) of collected biodeposits. Surface Water Column Conditions: mean ($\pm$SE) surface water total suspended solids (TSS), particulate organic carbon (POC), particulate organic nitrogen (PON), carbon/nitrogen mass ratio (C:N), total chlorophyll-*a*, temperature, and salinity at particle trap locations.

	8/1/17	**8/17/17**	**9/14/17**	**10/5/17**	**10/30/17**
Deposition Rates					
Biodeposition (kg dry wt. day^{-1})	18.1 (2.1)	56.0 (9.8)	21.9 (3.2)	24.1 (4.6)	30.6 (1.6)
Biodeposit N deposition (kg N day^{-1})	0.7 (0.2)	2.1 (0.4)	0.8 (0.1)	0.4 (0.1)	0.5 (0.0)

Biodeposit Characteristics					
C content (%C)	21.1 (0.2)	22.8 (0.7)	21.9 (0.1)	11.8 (0.2)	9.8 (0.4)
N content (%N)	4.0 (0.1)	3.9 (< 0.1)	3.9 (0.1)	1.9 (< 0.1)	1.6 (0.3)
C:N	6.2 (< 0.1)	6.9 (< 0.1)	6.6 (< 0.1)	7.3 (< 0.1)	7.1 (0.2)
Surface Water Column Conditions					
TSS (mg dry wt./L seawater)	19.2 (4.7)	6.8 (0.9)	5.7 (0.2)	5.0 (0.5)	5.4 (0.1)
POC (uM C)	138.3 (42.2)	101.3 (9.4)	93.8 (2.1)	47.8 (1.4)	68.9 (10.5)
PON (uM N)	18.3 (5.1)	13.2 (2.1)	13.2 (1.2)	6.8 (0.2)	7.9 (0.9)
C:N	7.3 (0.3)	7.9 (0.6)	7.3 (0.8)	7.1 (0.1)	8.6 (0.4)
Total Chlorophyll-*a* (ug/L seawater)	16.7 (8.6)	15.9 (3.5)	12.9 (0.6)	7.3 (0.1)	8.9 (3.4)
Temperature (Celsius)	23.6 (0.8)	22.5 (0.8)	20.6 (0.6)	15.8 (0.3)	12.8 (0.6)
Salinity	29.5 (0.0)	29.5 (0.2)	28.2 (0.2)	29.0 (0.1)	25.7 (1.3)

Greater seston concentrations and seston organic content were observed in the surface waters during the summer biodeposit trap deployments relative to the fall trap deployments (Table V.1). Greater organic content is associated with higher oyster food quality, but oyster feeding rates appear to stabilize once food concentrations reach ca. 300 μg C/L seawater (Tenore and Dunstan 1973). Observed food concentrations were greater than 300 μg C/L seawater in 2017 with a surface water maximum of 2559 μg C/L during the 8/1/17 biodeposit trap deployment and a minimum of 538 μg C/L seawater during the 10/5/17 biodeposit trap deployment. During periods when particulate organic carbon concentrations are above 300 μg C/L in surface waters, the oysters will reject more and more captured particulate matter as pseudofeces, which is less densely "packaged" than fecal matter/pellets (Tenore and Dunstan 1973). Because the pseudofeces is less dense than fecal pellets it is more likely to be affected by turbulence and lost from the biodeposit trap. Determining *in situ* biodeposition rates means compromising between eliminating environmental factors that interrupt biodeposit collection and maintaining natural environmental conditions. For this reason, biodeposition rates are a conservative estimate of the mass of organic nitrogen transferred from the water column to the sediment through oyster filtration and deposition of feces and pseudofeces.

Table V.2. Full oyster deployment biodeposition summary for the 2017 field season. Full oyster deployment deposition rates and biodeposit carbon and nitrogen content were averaged from May 2017 to December 2017 to determine the season total dry mass of biodeposits impacting the sediments, as well as, the total dry mass of POC and PON contained within the biodeposits.

	Whole Field Season: May 2017 – December 2017
Biodeposit dry mass (kg dry wt.)	4984.8 (163.7)
Biodeposit POC (kg dry wt.)	870.6 (0.5)
Biodeposit PON (kg dry wt.)	151.2 (0.1)

In Table V.2. (above), the whole field season deposition was calculated as follows: 1) determined a dry tissue weight corrected biodeposition rate (mg dry wt. biodeposits/day) for each oyster cohort and month that the oysters were deployed, 2) multiplied the dry tissue weight corrected biodeposition rate by the number of days per month, and 3) summed the mass of biodeposits calculated for each month.

Table V.3. 2016 biodeposition rates, biodeposit characteristics, and surface water column conditions associated with particle trap deployment. Deposition Rates: mean (±SE) total oyster deployment biodeposition rates and particulate organic nitrogen (PON) deposition. Biodeposit Characteristics: mean (±SE) particulate organic carbon (POC), particulate organic nitrogen (PON), and carbon/nitrogen molar ratio (C:N) of collected biodeposits. Surface Water Column Conditions: mean (±SE) surface water total suspended solids (TSS), particulate organic carbon (POC), particulate organic nitrogen (PON), carbon/nitrogen mass ratio (C:N), total chlorophyll-*a*, temperature, and salinity at particle trap locations.

	Summer 2016*	**Fall 2016**
Deposition Rates		
Biodeposition (kg dry wt. day^{-1})	35.1 (5.7)	31.7 (6.0)
Biodeposit N deposition (kg N day^{-1})	0.6 (0.1)	0.3 (0.1)
Biodeposit characteristics		
C content (%C)	12.0 (0.3)	7.4 (0.7)
N content (%N)	1.6 (0.0)	0.9 (0.2)
C:N	7.3 (0.1)	9.8 (1.3)
Surface Water Column Conditions		
TSS (mg dry wt./L seawater)	8.9 (0.8)	7.2 (0.7)
POC (uM C)	144.6 (17.7)	52.7 (4.8)
PON (uM N)	22.9 (3.3)	6.7 (0.6)
C:N (molar ratio)	6.33 (0.12)	7.92 (0.07)
Total Chlorophyll-*a* (ug/L seawater)	23.2 (2.8)	8.0 (1.3)
Temperature (Celsius)	30.5 (0.3)	17.3 (0.7)
Salinity	24.2 (1.7)	28.7 (0.0)

* Summer 2016 data is from a 8/13/16 biodeposit trap deployment conducted in Little Pond, Falmouth, MA. Ambient water column conditions were comparable between Lonnies Pond and Little Pond in August 2016.

Discussion:

Overall, the filtration of particulates from Lonnies Pond waters and its packaging into feces and pseudofeces appears to support a large amount of biodeposition to bottom sediments. This

provides the mechanism for the observed increase in water clarity within the oyster grow-out area, the reduction in particulate concentrations in water flowing through the oyster bags, and the increases in sediment respiration associated with the oyster deployment area. While all of these features are supportive of potential enhanced nitrogen removal, none result in significant negative impacts to the associated pond water column and sediments. As seen in the water quality results the chlorophyll concentrations were elevated within the oyster deployment area, but the effects disappeared by the border of the oyster rafts. This suggests that increases in local production stimulated by the increseased biodeposition of organic material to the sediments and excretion of inorganic nitrogen were more than offset by oyster removal of plankton with the net effect of increasing the overall water quality which extended a significant distance outside of the deployment area. In addition it is notable that biodeposition rates were similar in summer and fall, even with nearly 3 fold higher chlorophyll levels in summer. This is consistent with there being more than sufficient phytoplankton in Lonnies Pond for oysters (as indicated above, ca. 300 μg C/L). However, the increased food quality in summer is seen in the much higher nitrogen levels in the biodeposits in summer compared to fall.

Section VI. Biodeposit Impact Area

Although fecal pellets fall rapidly through the water column, variables such as pellet density and current velocity can affect the dispersion of pellets before they settle to the sediment surface. During the 2016 and 2017 sediment flux measurements an Acoustic Doppler Current Profiler (ADCP, Nortek Aquapro HR) was deployed near the sediment surface facing upward at the northern edge of the oyster propagation area. Later measurements included deployments near the eastern and western edges of the deployment area. Velocity measurements were made at 10 minute intervals and conducted at the highest possible sensitivity. Velocities measured acoustically are determined by sound reflected off particles within the water column with the assumption that the particles movement is also indicative of water movement. The particles in the vicinity of the oyster rafts are comprised of a mixture of fecal pellets and phytoplankton, with the latter being numerically dominant. Therefore, measured velocities are probably biased towards under estimation since the larger sized fecal pellets would tend to settle faster and move less laterally. The underestimation would be seen in vertical velocities as well since the velocity of falling fecal pellets would be confounded by phytoplankton with a lower settling velocity. Taking these caveats into consideration, the measured velocities should be regarded as conservative.

Velocity measurements completed in 2017 were consistent and generally confirmed measurements made in 2016 with the exception that the Nortek device is more sensitive than the ADCP used in 2016 so that more accurate directionality was available in 2017 (Figure VI.1). As seen in the time series velocity plot, the high velocities were recorded during flooding tides. During other parts of the tidal cycle velocities were minimal. Over the tidal period average water column current direction roughly correlated with prevailing wind direction, North-Northwest. However, longer deployments at the start of the 2018 season at the margins of the

eastern and western borders of the array indicated that average water column current direction, which were in shallower water, were predominately oriented east to west through the oyster deployment array.

Using the previously determined mean sinking velocity of fecal pellets (8.14±5.01mm/s) and the median depth around the border of the oyster deployment area, fecal pellet settling was modeled step-wise assuming fecal pellet production was similar among all bags. (Figure VI.2). The model results largely confirm the results from 2016 concerning the extent of the impact area of surficial sediments. At 5 meters from the edge of the deployment area deposition remains at 30 % of that directly under the deployment area and declines to 10%-15% at 10 meters. With the additional data captured in 2018 the impact area would extend around the entire deployment area with the same distances and gradients.

From the above discussion of biodeposition, a deposition value of 710 mg $N/m^2/d$ was derived. Applying this calculated distribution of nitrogen derived from oyster fecal pellets to the actual footprint of the oyster deployment area, the area affected (impact area) increases from 760 m^2, actually occupied by the oyster bags, out 11.75 m from the edge to where there was no longer direct contribution of fecal pellets to the sediment surface. Including the 11.75 m extension beyond the edges of the deployment area, the total impact area was calculated to be 2735 m^2, an increase of 448 m^2over the estimated 2016 area of 2287 m^2, which was determined using less sensitive instruments (Figure VI.3). These spatial estimates for biodeposition represent direct settling to sediments, but do not include bordering areas that may be effected by particle transport along the sediment surface post-deposition. These direct deposition areas and extended areas of deposition were used to determine the enhanced particulate nitrogen loading to Lonnies Pond sediments from the deployed oyster arrays and to target areas to assess potential enhancements of sediment denitrification.

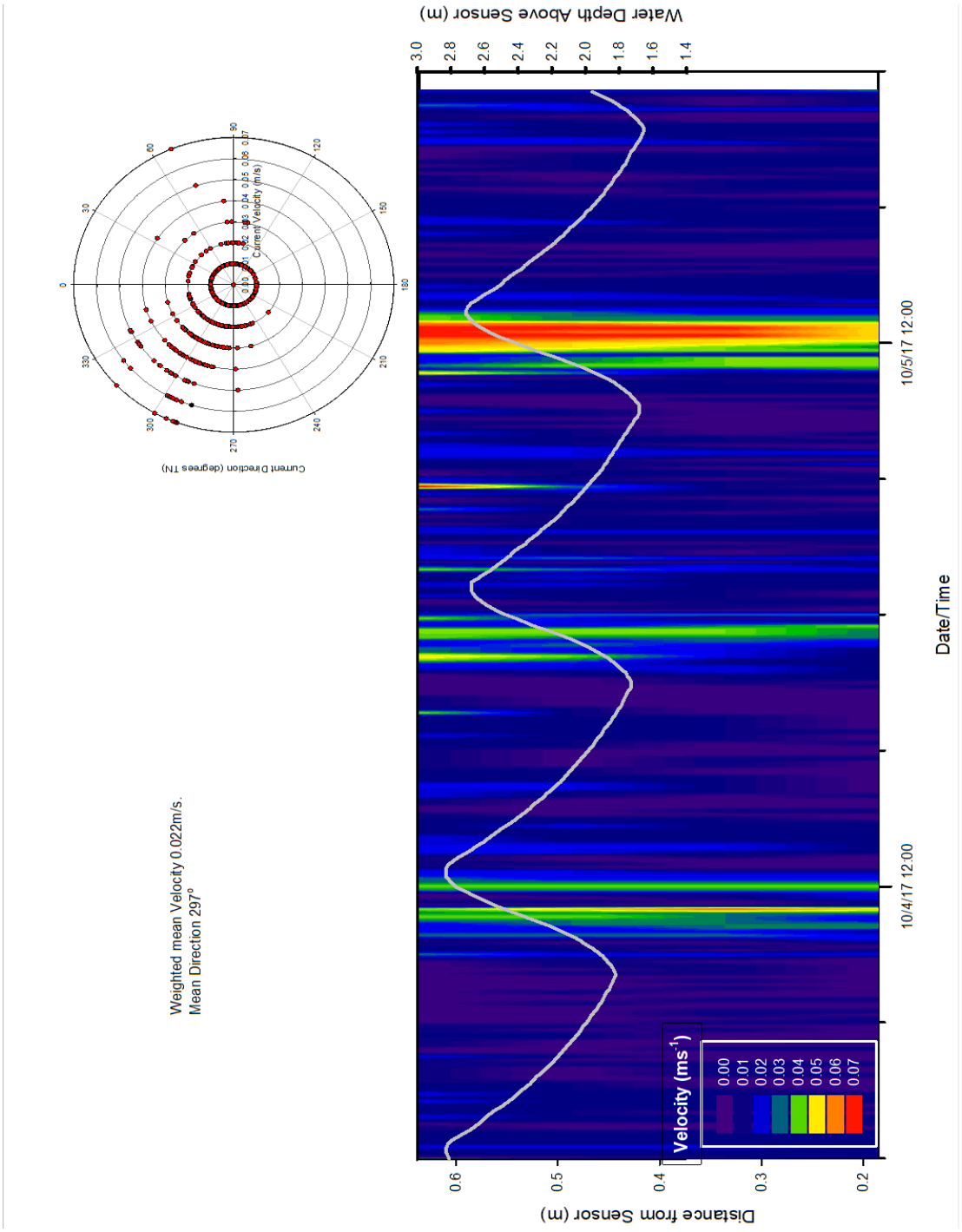


Figure VI.1. Top left: Compass rose plot of particle direction and velocity data for 23-24 August. Current direction was predominantly to the north north-west ~300 from True North . Velocities increase with distance from the center of the compass rose. Highest velocity was 0.07m/s (7cm/s). Right: Time series velocity data from the ADCP are shown at 10cm intervals above the ADCP which was moored to the bottom. Velocities at specific times and heights above the ADCP are displayed as different colors with purple indicating no water movement and red indicating the maximum observed velocity of 0.07 m/s. For reference the tidal height change in water depth is shown as a continuous white line indicating the depth of water above the ADCP.

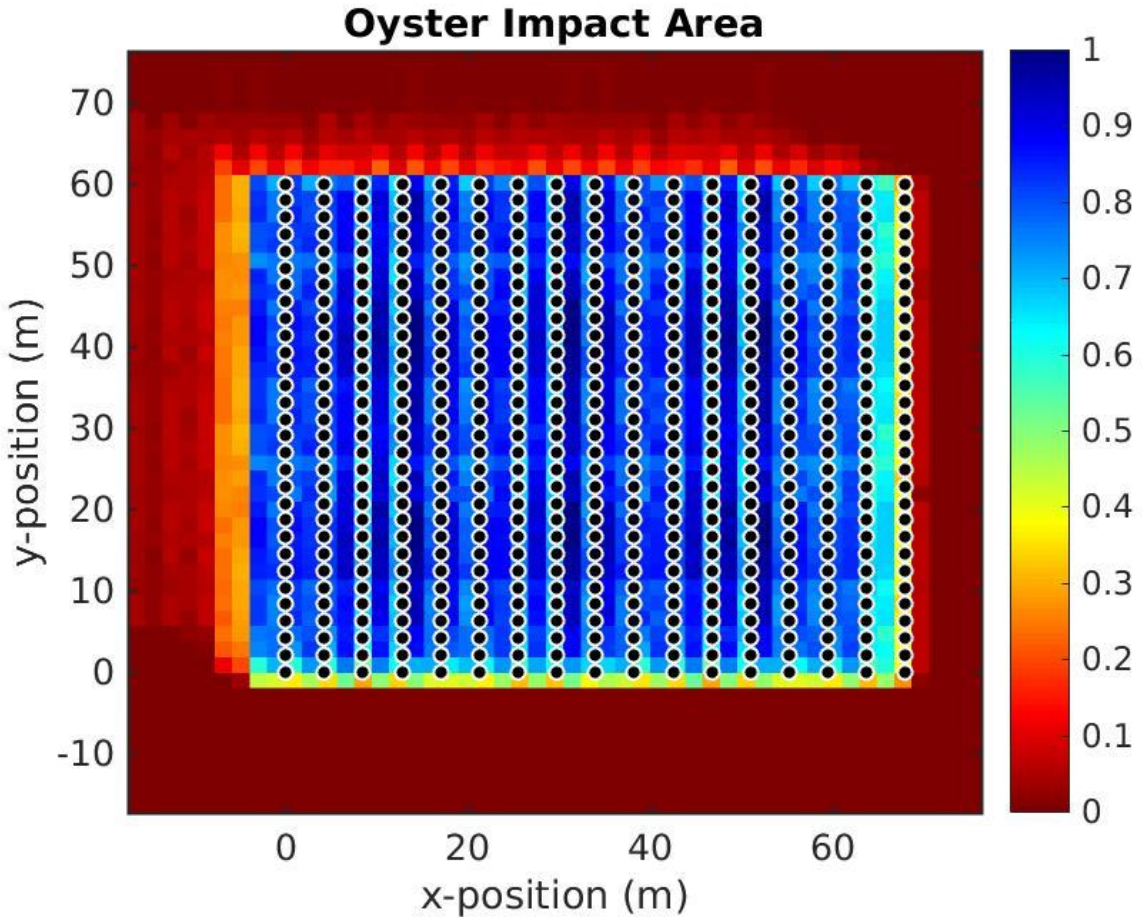


Figure VI.2. Expected deposition of fecal pellets to surficial sediments for pellets originating at the edge of the oyster array. Fecal pellet production was given as 1 and results are shown in the contours as a fraction of the pellet production. Thus, deposition areas colored dark blue received 100% of the average areal fecal pellet production and deposition; areas colored dark red received 0% of the average areal fecal pellet production and were not directly impacted by the oyster deployment. Note that the dimensions of the model grid are equal in both directions, but this has no impact on the deposition gradients at the edges of the model deployment area.

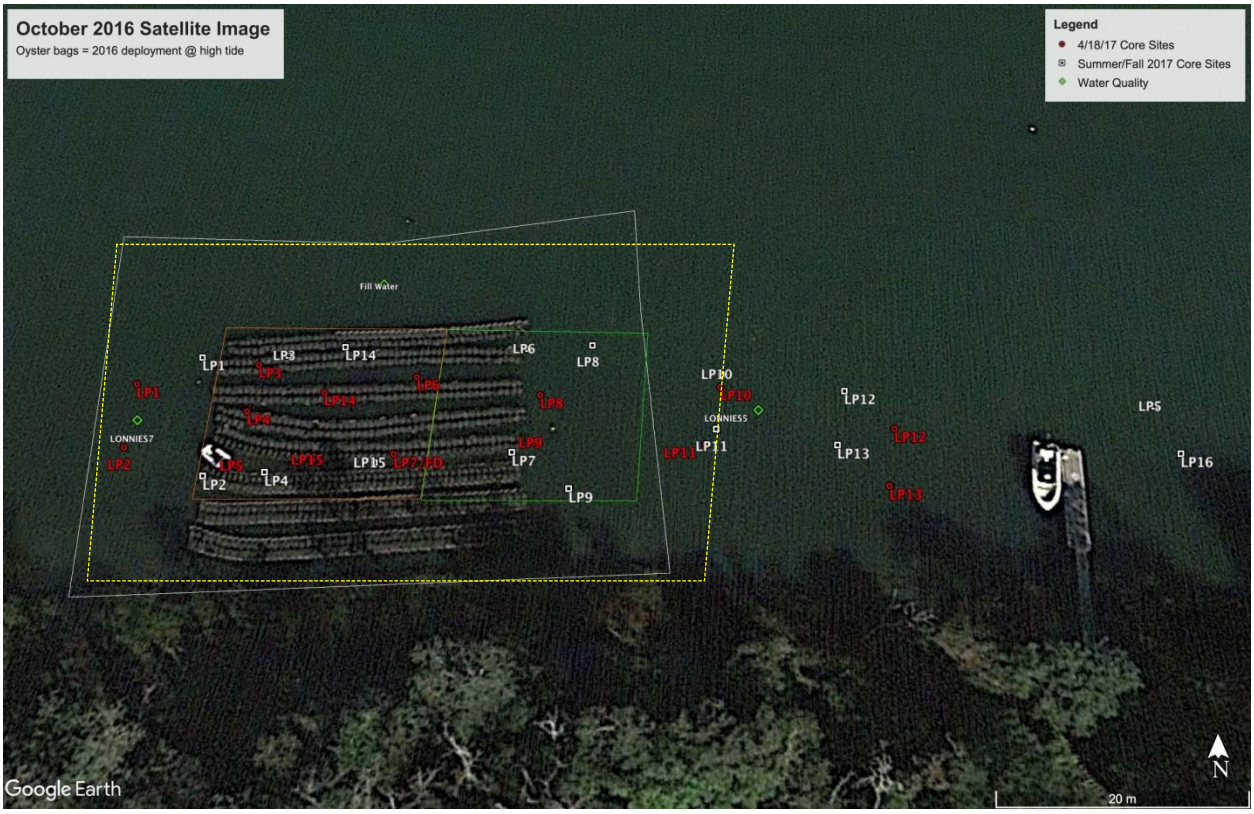


Figure VI.3. 2016 Aerial photograph showing the location of the oyster deployment area overlain with 2017 oyster deployment area (red and green polygons). Mooring and water column sampling locations (green diamonds), April (pre-oyster deployment red diamonds) and Summer/Fall (white square) flux core locations. Total area impacted by the oyster deployment as determined by fecal pellet distribution in 2016 is shown as the white bounded area while the 2017 total impact area is bounded by the yellow dashed area.).

Section VII. 2016 Nitrogen Cycling and Oyster Culture: Regeneration and Denitrification

In estuarine systems such as Lonnies Pond, nitrogen is transformed and recycled within the sediments and water column. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems under MEP investigation, recycled nitrogen can account for about half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. Failure to account for this recycled nitrogen generally results in significant errors in determination of the effects of nitrogen loadings, the overall nitrogen balance of the system and how oyster propagation may affect nitrogen dynamics at the sediment water column interface.

The organic rich nature and relatively shallow waters of coastal systems like the Lonnies Pond

sub-basin of the Pleasant Bay Estuary and others on Cape Cod result in sediments playing a significant role in system biogeochemical cycles. Organic matter deposition to sediments, hence benthic respiration, tends to decrease with increasing depth of overlying waters due to interception by water column heterotrophic processes resulting in lower deposition of labile (decomposable) organic matter. The result is that embayment respiration rates are typically many-fold higher than in the adjacent deeper offshore waters. With potential stratification of embayment waters, sediment metabolism plays a major role in bottom water oxygen declines (an ecosystem structuring parameter). This applies particularly to Lonnies Pond which periodically goes hypoxic (i.e. low D.O) during the summer months. It should be noted that while water depth is important in altering the deposition of labile organic matter to sediments, filter feeders and especially large filter feeders like oysters can overwhelm the "depth effect" due to the large amount and size of packaged feces that they emit. In these situations, oysters are projected to increase deposition which subsequently increases sediment respiration rates.

Measurements of Benthic Nutrient Regeneration, Denitrification and Sediment Oxygen Uptake:

In order to determine the contribution of sediment regeneration to nutrient levels within the oyster aquaculture portion of the Lonnies Pond system and the effect the oysters may have on nitrogen recycling rates and oxygen levels, sediment samples were collected and incubated under *in situ* conditions on 5 dates, 4/18, 6/27, 8/11, 9/19 and 10/3. The April 18, 2017 sampling occurred prior to the oyster deployment which began on April 5 and concluded on June 22. Thus the June 27 sampling represents the first sediment sampling of 2017 with a full complement of oysters and their associated biodeposition. The August 11 and September 19, 2017 sampling dates were during the period of maximum oyster activity in the summer interval (July- September) and the October 3, 2017 sampling was during the period of maximum oyster biomass (October-December). The April 18, 2017 sampling did not include deposition from 2017, but did include the residual effect from the 2016 deployment. The 2016 oysters were held over winter and replaced in 2017, but since their late 2016 season depositions were not fully degraded in the sediments, due to the cold temperatures (December – March), they were available to stimulate nitrogen cycling in the early spring 2017. Therefore the early spring denitrification enhancement needed to be measured to determine: 1) its magnitude and 2) if there were sufficient carry over to require addition to the 2016 deployment impacts and rates.

Time series measurements of total dissolved nitrogen, nitrate+nitrite, ammonium and ortho-phosphate were made on each incubated core sample. The rate of oxygen uptake was also determined in order to: (1) evaluate sensitivity to oxygen depletion of the oyster aquaculture area of Lonnies Pond, (2) rank sediments as to organic matter deposition rates (not possible using organic content) and (3) develop a nitrogen model for how the oysters may be affecting the nitrogen cycle in the sediments associated with oysters. Assays were performed on 16 cores from sites distributed throughout the oyster aquaculture area on each date. Cores were collected directly under the oyster aquaculture rafts and at distances east and west of the aquaculture area.

The results allowed determination of the spatial pattern and rate of nutrient exchanges from the sediments to the water column and how these rates may be affected by the cultivation of oysters in Lonnies Pond. From our experience, sediment regeneration during the summer is a large and important source of nutrients supporting both phytoplankton and macroalgal blooms in embayments throughout S.E. Massachusetts and the degree to which intensive oyster aquaculture can change those rates through enhancement of denitrification needs to be determined to support innovative management of these systems.

N_2 excess was measured using membrane-inlet mass spectrometry (MIMS). N_2 produced by denitrification is precisely detected by analysis of its ratio with the inert gas Argon. Water samples were collected and stored to prevent gas exchange or bubble formation. In the laboratory, sample water was pumped at ml/min rates through a gas permeable membrane in order to extract gas into the mass spectrometer inlet. The inlet was fitted with cryogenic traps to remove water vapor and CO_2 gas. Sample gas was analyzed by the mass spectrometer for masses 28 and 40 for determining the N_2 to Ar ratio. Calibration was made by comparison with a reference gas of known composition. A quadrupole mass spectrometer (e.g. Pfeiffer 422) was used for its sensitivity and speed of analysis and the analysis of the samples conforms to the same methods as was utilized during a comprehensive survey undertaken by the CSP in 2008. Water column respiration measurements were collected east and west of the oyster area at the Lonnies 5 and Lonnies 7 water quality monitoring sites.

Results:

Benthic results are summarized in Table VII.1 below. April cores were collected approximately six weeks prior to the deployment of the oyster rafts. The second set of cores was collected in late June just after the oyster rafts were fully deployed. Both the August and September cores were collected to coincide with peak growing season and the time during which the most stressed water quality conditions were expected. Finally, October cores were collected near the end of the growing season when the full effects of oyster culture could be determined. For comparison, the 2016 values are shown appended to the 2017 data in Table VII.1. To more easily view the data through the season the averages of the cores impacted by the oysters are shown in Table VII.2. The table also includes corresponding values for oyster impact area in 2016, during August 2016, when water temperatures were greatest. For comparison the 2016 data is also presented with values adjusted conservatively by a factor of 1.9 to correct for temperature differences to allow cross comparison throughout the season and for comparison to peak 2016 values. Higher temperatures increase bacterial respiration while lower temperatures decrease respiration. The actual factor for Lonnies Pond, found empirically varies from ~2.3-1.6.

Small scale sediment heterogeneity was common in the oyster deployment area in 2016. Sediment heterogeneity was observed by divers collecting the cores in 2017, however in 2017 significantly smaller differences were observed in the sediment biogeochemistry evaluated in

duplicate cores (LP7/7Dup). Nonetheless specific patterns were immediately obvious. Average sediment oxygen uptake rates were correlated positively with changing temperatures as was NH_4 flux. Nitrate uptake, however, was predominant only during April and October, which were the coolest months and had the lowest sediment oxygen uptake. During all other sampling dates the average nitrate flux was out of the sediment. This suggests that increased ammonium production did result in increased nitrate production but that the nitrate was not fully denitrified, possibly due to a very thin surface oxidized layer, which allowed a larger proportion of the nitrate to escape to the overlying waters, thus the efficiency of nitrate uptake into denitrification may be affected by redox status of the sediment during the most stressful parts of the summer (Figure VII.1)

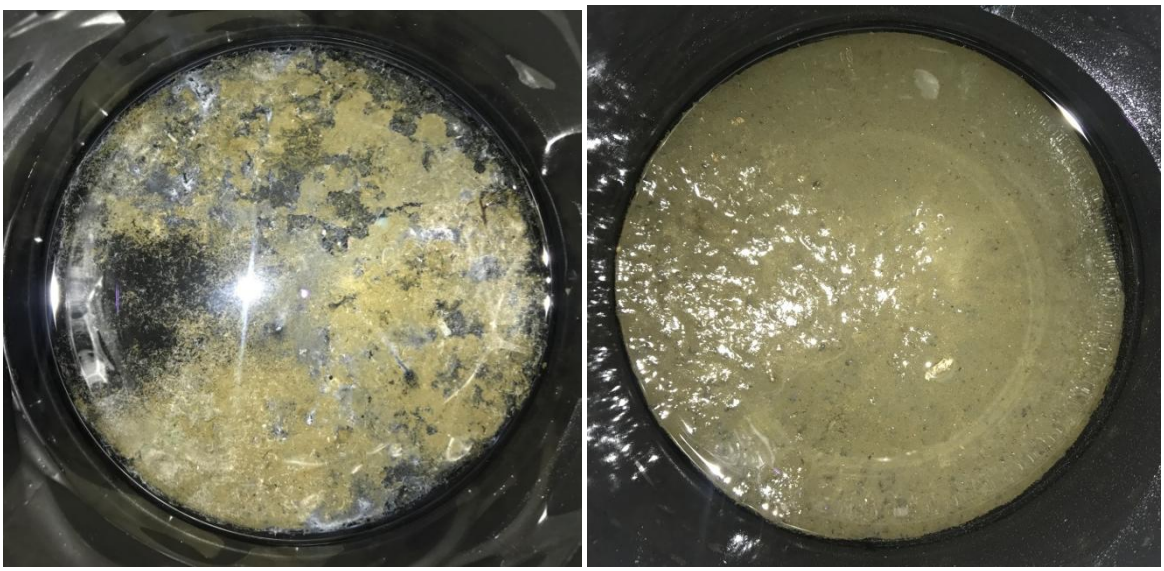


Figure VII.1 Images of sediment core surfaces from September 2017. Left: Core 3 within treatment area showed dark areas where reduced sediment was exposed to the water surface, thus preventing efficiently coupled nitrification and denitrification. Right: Core 13 outside of the treatment area showed a uniform oxidized surface.

Most importantly, the fraction of regenerated nitrogen used in denitrification was greatest in the shoulder months of summer, 74% and 29%, for April and October, respectively. While oysters had not yet been deployed in April, the residual organic matter from the previous Fall continued to be regenerated as water temperatures began warming accounting for the high rates observed. Low rates in June may represent a temporary deficit in sediment carbon between exhaustion of the previous year deposition, prior to a buildup of the current year's deposition.

Twice as many stations were sampled for benthic processes in 2017 than in 2016 to better quantify both background rates as well as treatment rates of sediment flux including denitrification. A conservative estimate of the total nitrogen removed by oyster enhanced denitrification can be made using our measurements of background denitrification with the

rates in the oyster deployment area. The background rates may be slightly high as spreading of the biodeposits by water currents was the only process examined. The 2017 background rates and rates measured under the oyster treatment are shown in Table VII.3 as well as the 2016 rates for comparison. By summing the product of the measured rates of denitrification by the intervals between the denitrification measurements and extending measurements forwards to Nov 15 when temperatures began to become too cold for significant oyster activity in both years it is possible to obtain an annual mass of nitrogen that was denitrified and compare that value to the total mass of nitrogen removed from the system by incorporation into oyster tissue. The annual enhanced denitrification resulted in a net loss of 9.7 kg N in 2017 compared to 9.54 kg N in 2016 (Table VII.4). Although the 2017 value was slightly larger than seen in 2016 both the impact area and the deployment duration were greater in 2017 than in 2016. The differences in the number of oysters, the size of the oysters, and the quantity of food (phytoplankton) available are all potential factors that can affect these results. The effect of all these factors is integrated environmentally and reflected in two primary variables: the incorporation of nitrogen into oyster tissue and the enhanced biodeposition of organic matter within the impact area. Examining these two variables (Table VII.4) we found that while enhanced denitrification was similar, the amount of nitrogen removal through assimilation in oyster tissue declined slightly from 2016 to 2017. However, denitrification, as a percent of nitrogen removal increased from 24.7% to nearly 36%. This result suggests that after a year of oyster culture the sediments were more enriched in organic matter and thus the ability to denitrify was enhanced. This result in 2017 can be partly attributed to carry over of deposition from the previous season oyster culture as seen in the high rates of denitrification in April 2017.

Table VII.1. Summary of benthic flux rates from core incubations conducted in August and October. The bottom panel shows October rates adjusted using a Q10 factor of 1.9 for direct comparison to August cores which were incubated at a temperature 10C warmer.

	4/18/2017, Temperature 12.7 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	33.05	0.03	-0.06	-0.03	2.44	2.53	97%
LP2	44.43	0.52	0.08	0.60	1.03	1.63	63%
LP3	66.73	1.23	-0.08	1.15	1.41	2.73	52%
LP4	113.37	1.38	-0.18	1.20	6.10	7.67	80%
LP5	62.83	1.75	-0.03	1.72	2.09	3.87	54%
LP6	71.46	0.20	-0.16	0.04	0.75	1.11	68%
LP7	ND	0.06	-0.03	0.03	ND	ND	ND
LP7 FD	71.13	-0.05	-0.22	-0.27	0.72	0.99	73%
LP8	37.68	0.00	-0.12	-0.12	0.89	1.01	88%
LP9	61.09	0.61	0.20	0.81	1.72	2.53	68%
LP10	22.01	-0.31	-0.09	-0.40	1.20	1.59	75%
LP11	29.66	-0.09	-0.07	-0.16	1.10	1.26	87%
LP12	36.84	-0.14	-0.11	-0.24	1.15	1.39	83%
LP13	44.92	-0.18	-0.10	-0.27	0.65	0.92	70%
LP14	55.52	-0.16	-0.09	-0.26	2.40	2.66	90%
LP15	42.90	-0.31	-0.08	-0.39	0.23	0.62	37%

	6/27/2017, Temperature 22.1 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	118.47	4.58	0.03	4.61	0.85	5.46	16%
LP2	105.29	5.02	0.14	5.16	1.93	7.09	27%
LP3	130.52	14.17	0.01	14.18	0.23	14.41	2%
LP4	134.04	12.33	0.04	12.37	1.08	13.45	8%
LP5	51.73	6.59	0.15	6.74	-2.53	9.27	-27%
LP6	239.20	5.43	0.44	5.87	1.12	6.99	16%
LP7	64.53	3.45	0.07	3.53	ND	ND	ND
LP8	60.98	3.90	0.25	4.15	-4.67	8.82	-53%
LP9	81.37	1.08	0.04	1.12	-4.05	5.17	-78%
LP10	68.06	0.26	0.05	0.30	-3.77	4.08	-93%
LP11	69.29	2.73	0.06	2.79	-2.74	5.53	-50%
LP12	169.23	7.84	0.11	7.95	-2.62	10.57	-25%
LP13	69.87	5.66	0.21	5.87	-2.71	8.59	-32%
LP14	138.06	11.18	0.40	11.58	1.08	12.66	9%
LP15	152.34	10.98	0.03	11.01	1.00	12.01	8%
LP16	101.77	6.17	0.40	6.56	0.69	7.26	10%

	8/1/2017, Temperature 23.6 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	58.14	8.69	-0.04	8.65	2.16	10.89	20%
LP2	72.81	6.41	-0.03	6.37	0.83	7.27	11%
LP3	176.21	26.93	-0.10	26.83	2.91	29.94	10%
LP4	124.63	11.47	0.15	11.63	2.58	14.20	18%
LP5	63.99	4.88	0.71	5.59	2.78	8.37	33%
LP6	101.91	7.76	2.70	10.47	4.75	15.21	31%
LP7	60.31	2.67	-0.04	2.63	ND	ND	ND
LP8	64.18	3.96	0.17	4.13	0.44	4.58	10%
LP9	112.24	7.38	0.44	7.83	1.06	8.89	12%
LP10	39.20	4.52	0.07	4.59	1.06	5.64	19%
LP11	222.07	9.72	0.26	9.98	3.40	13.38	25%
LP12	48.26	5.96	0.14	6.10	2.37	8.47	28%
LP13	92.45	0.98	0.06	1.04	3.04	4.09	74%
LP14	120.25	11.99	-0.08	11.90	0.58	12.65	5%
LP15	121.55	11.70	-0.10	11.60	2.33	14.13	17%
LP16	84.49	0.92	-0.05	0.88	2.55	3.52	72%

	9/19/2017 Dark, Temperature 23.5 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	83.42	6.89	0.07	6.97	-0.32	7.28	-4%
LP2	232.99	17.03	0.03	17.05	2.32	19.37	12%
LP3	116.82	4.91	0.05	4.96	0.37	5.33	7%
LP4	123.30	11.67	0.09	11.76	0.20	11.96	2%
LP5	53.60	5.78	0.16	5.94	0.30	6.24	5%
LP6	74.33	4.86	0.05	4.91	0.27	5.18	5%
LP7	61.67	1.81	0.05	1.86	ND	ND	ND
LP8	60.67	9.53	0.65	10.18	0.84	11.03	8%
LP9	49.81	2.52	0.13	2.65	-0.30	2.95	-10%
LP10	67.00	6.00	0.12	6.13	0.08	6.21	1%
LP11	79.18	4.76	0.31	5.06	0.39	5.45	7%
LP12	69.65	4.39	0.48	4.87	0.16	5.03	3%
LP13	82.69	5.31	0.12	5.43	4.21	9.64	44%
LP14	92.17	5.28	0.04	5.31	0.32	5.63	6%
LP15	59.95	3.55	0.06	3.61	-0.88	4.50	-20%
LP16	57.99	3.84	0.40	4.24	0.11	4.35	3%

	9/19/2017 Light, Temperature 23.5 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	78.09	0.22	-0.14	0.08	1.76	2.12	83%
LP2	154.22	7.65	-0.06	7.58	8.18	15.90	51%
LP3	109.51	15.71	-0.06	15.65	18.89	34.66	55%
LP4	102.15	9.79	0.02	9.81	12.22	22.03	55%
LP5	42.16	4.50	-0.06	4.44	5.17	9.73	53%
LP6	68.07	5.71	-0.13	5.58	5.96	11.80	51%
LP7	62.32	2.45	-0.04	2.41	ND	ND	ND
LP8	69.14	13.04	0.44	13.48	15.68	29.16	54%
LP9	62.60	0.64	-0.12	0.52	2.84	3.61	79%
LP10	78.93	4.99	0.02	5.01	5.49	10.50	52%
LP11	71.75	3.32	0.06	3.38	4.11	7.49	55%
LP12	49.93	5.33	0.09	5.42	5.97	11.38	52%
LP13	81.32	2.27	-0.11	2.16	3.25	5.63	58%
LP14	101.79	10.57	-0.21	10.36	13.86	24.65	56%
LP15	82.53	5.17	-0.07	5.11	7.06	12.30	57%
LP16	45.86	2.35	0.19	2.54	2.77	5.31	52%

	10/3/2017, Temperature 17 C						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMoles/m2/d)	(mMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	(uMoles/m2/d)	% Total Cycled N
LP1	73.18	3.92	-0.12	3.79	2.02	6.07	33%
LP2	52.99	1.80	-0.27	1.53	2.95	5.01	59%
LP3	117.51	6.13	-0.37	5.75	1.71	8.21	21%
LP4	21.49	0.99	0.12	1.11	0.56	1.67	33%
LP5	39.66	0.52	-0.15	0.38	1.06	1.73	61%
LP6	42.03	2.97	-0.12	2.85	0.57	3.66	16%
LP7	36.52	3.57	0.05	3.62	ND	ND	ND
LP8	27.04	3.20	0.00	3.20	0.38	3.58	11%
LP9	37.00	0.59	-0.04	0.54	0.83	1.45	57%
LP10	19.21	0.89	0.00	0.89	0.30	1.20	25%
LP11	53.73	0.90	-0.12	0.79	1.02	2.04	50%
LP12	23.81	0.38	-0.03	0.35	0.20	0.62	33%
LP13	63.86	0.51	-0.15	0.35	1.46	2.12	69%
LP14	101.31	6.63	-0.29	6.34	2.55	9.47	27%
LP15	17.86	4.38	-0.17	4.21	0.86	5.41	16%
LP16	21.82	0.45	-0.07	0.39	0.85	1.37	62%

August 16, 2016; 28 C							
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	% Total Cycled N
LP1	115.3	1.9	-0.03	1.9	5.5	7.4	74%
LP2	139.4	14.0	0.31	14.3	3.8	18.1	21%
LP2 DUP	379.3	36.4	0.18	36.5	1.8	38.3	5%
LP3	68.4	9.5	0.01	9.5	1.3	10.8	12%
LP4	97.9	14.1	0.05	14.2	1.4	15.6	9%
LP4 DUP	150.7	18.8	0.56	19.3	4.0	23.3	17%
LP5	108.7	7.2	0.03	7.2	1.4	8.6	16%
LP6	73.8	7.1	0.08	7.2	1.0	8.2	12%
LP8	55.4	4.6	0.21	4.8	1.2	6.0	20%

October 5, 2016; 18 C							
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled	Denitrified
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	% Total Cycled N
LP1	70.5	0.1	-0.38	-0.3	8.7	9.0	97%
LP2	17.1	5.9	-0.56	5.3	2.3	7.6	30%
LP2 DUP	72.3	0.3	-0.13	0.2	2.7	2.9	94%
LP3	101.8	7.1	0.22	7.3	3.9	11.1	35%
LP4	128.2	2.5	-0.16	2.4	0.7	3.0	23%
LP5	83.3	3.5	0.86	4.4	0.1	4.5	3%
LP6	59.0	-2.5	-0.31	-2.8	4.8	7.6	63%
LP7	31.9	1.3	0.05	1.4	1.5	2.8	52%
LP7 DUP	25.7	-1.1	-0.23	-1.3	2.0	3.3	60%
LP8	45.3	-2.1	-0.54	-2.7	5.1	7.8	66%

October 5, 2016; Adjusted to 28C using Q10=1.9						
	SOD	NH4	NO3	DIN	N2-N	Total N Cycled
Site ID	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)	(mMol/m2/d)
LP1	134.0	0.1	-0.7	-0.6	16.6	17.1
LP2	32.6	11.2	-1.1	10.2	4.3	14.4
LP2 DUP	137.3	0.6	-0.3	0.3	5.1	5.4
LP3	193.4	13.4	0.4	13.8	7.3	21.1
LP4	243.7	4.8	-0.3	4.5	1.3	5.8
LP5	158.3	6.7	1.6	8.3	0.2	8.6
LP6	112.2	-4.7	-0.6	-5.3	9.0	14.4
LP7	60.6	2.5	0.1	2.6	2.8	5.4
LP7 DUP	48.9	-2.0	-0.4	-2.5	3.7	6.2
LP8	86.0	-4.0	-1.0	-5.0	9.7	14.8

Table VII.2. Summary of benthic flux rates from core incubations conducted in 2017. The bottom panel shows 2017 rates adjusted using a Q10 factor of 1.9 only to allow direct comparison to August 2016 cores which were incubated at a temperature 28C.

2017 Mean Treatment Area Sediment Flux Rates							
Date	4/18/17	6/27/17	8/1/17	9/19/17	9/19/17*	10/3/17	8/16/16
Temperature	12.7 C	22.1 C	23.6 C	23.5 C	23.5 C	17 C	28 C
Rate (mMol/m^2/d)							
SOD	62.42	93.4	82.3	92.4	82.7	46.7	100.6
NH4	0.57	6.4	6.7	7.1	6.5	2.5	9.0
NO3	-0.06	0.1	0.2	0.1	0.0	-0.1	0.1
DIN	0.51	6.5	9.2	7.2	6.5	2.4	9.0
N2-N	1.91	1.0	1.8	0.4	NA	1.2	2.4
Total N Cycled	2.67	7.5	12.0	8.4	NA	3.6	11.4
Denitrified % Total N	71%	14%	15%	5%	NA	32%	21%
*Light Treatment							

2017 Mean Treatment Area Sediment Flux Rates Q_{10}=1.9 Reference temperature 28 C							
Date	4/18/17	6/27/17	8/1/17	9/19/17	9/19/17*	10/3/17	8/16/16
Temperature	12.7 C	22.1 C	23.6 C	23.5 C	23.5 C	17 C	28 C
Rate (mMol/m^2/d)							
SOD	166.7	136.3	109.1	123.3	114.0	94.5	100.6
NH4	1.5	9.3	8.8	9.5	8.9	5.0	9.0
NO3	-0.2	0.1	0.2	0.2	0.0	-0.2	0.1
DIN	1.4	9.5	12.2	9.7	8.9	4.8	9.0
N2-N	5.1	1.5	2.4	0.6	NA	2.3	2.4
Total N Cycled	7.1	10.9	15.9	11.2	NA	7.3	11.4
Denitrified % Total N	71%	14%	15%	5%	NA	32%	21%
*Light Treatment							

Table VII.3 Mean denitrification rates for cores collected in the biodeposit impact area associated with the oyster arrays (Treated) and outside the impact area (Background). The difference in these two values should represent the contribution made by the ongoing oyster culture (Oyster Effect).

	2017 Mean Denitrification Rates (mMoles/m^2/d)				
	Treated		Background		Oyster
Date	Mean	Std. Dev.	Mean	Std. Dev.	Effect
4/18/2017	2.9	1.8	0.9	0.4	1.9
6/27/2017	1	0.5	0.3	0.4	0.7
8/1/2017	2.4	1.3	0.8	0.4	1.6
9/19/2017	0.7	0.9	0.2	0.1	0.5
10/3/2017	1.5	0.9	0.8	0.5	0.8

	2016 Mean Denitrification Rates (mMoles/m2/d)				
	Treated		Background		Oyster
Date	Mean	Std. Dev.	Mean	Std. Dev.	Effect
8/16/2016	2.1	0.6	1	0.4	1.1
10/5/2016	4.1	2.5	1.2	1	2.9
4/18/2017	2.9	1.8	0.9	0.4	1.9

Table VII.4 Annual Nitrogen Removal Budget for the oyster impact area showing including contributions from enhanced denitrification and oyster harvest.

Year	2016	2017
Deployment Duration (days)	146	195
Enhanced Annual DeN2 ($mmol/m^2$ N)	298.0	253.3
Enhanced Annual DeN2 (gm/m^2 N)	4.17	3.55
Impact area (m^2)	2287	2735
Total Annual Enhanced DeN2 (gm N)	9541	9699
Total Annual Enhanced DeN2 (kg N)	9.54	9.70
Net Annual N removed by oysters (kg N)	39.1	27.2
Enhanced DeN2 as percent of N removed by oysters	24.4%	35.7%

Recommendations:

It is clear that denitrification adds significantly to the nitrogen removed by oyster harvest. But the previously reported 2016 data allowed only a very conservative estimate due to the lack of data from the following spring. At that time, it was recommended that better estimates can be supported if:

(1) additional time points were added to the denitrification time-series, particularly early and late in the season and in the following spring and early summer. The biodeposits take time to accumulate and will persist for months to 1+ years. Therefore, the period of enhanced denitrification is almost certainly longer than a single season that the oysters are in place. This was implemented in 2017 with a multi-year deployment with measured denitrification rates as accumulated biodeposits are remineralized and some denitrified. Also, more sampling of background denitrification rates were undertaken now that the footprint of biodeposition is more accurately mapped. In the 2016 surveys, area affected by biodeposits was only generally assessed (compared to 2017). Based upon these improvements the total nitrogen removed for 2016 and 2017 has been determined below (Section IX). All future denitrification surveys should include additional background sites, some farther away than in 2016.

Section VIII. Stream flow and Nutrient Load Measurement Method: Stream Discharge from Pilgrim Lake to Lonnies Pond (2016 - 2017)

Predicting changes in coastal embayment nitrogen related water quality from nutrient load reduction strategies, enhanced flushing with low nutrient water or oyster propagation is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land (watershed). Transport of nutrients (specifically nitrogen) to Lonnies Pond from the watershed is effected namely via direct groundwater discharge or surface water inflow (and to a lesser extent direct atmospheric depositions. Rates of nitrogen loading to Lonnies Pond via groundwater were based upon the delineated watersheds and land-use coverages developed by the Massachusetts Estuaries Project (MEP). Additionally, rates of surface water inflow and associated nitrogen load to Lonnies Pond were determined using standard hydrologic techniques employed both for this study as well as the MEP nutrient threshold assessment of Pleasant Bay, which also included Lonnies Pond.

Surface water flow and N load in each study was determined at the exact same gauging location situated at the base of the herring ladder connecting Pilgrim Lake to Lonnies Pond (Figure 1a, 1b). The only difference between the stream gauging effort in 2016-2017 vs. 2002-2003 when the MEP assessment was completed is that the MEP extended the surface water N loading analysis to quantify percent nitrogen attenuation. By example, if all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters (0% attenuation). This condition exists in watersheds where nitrogen transport from source to estuarine waters is uniquely through groundwater flow in sandy outwash aquifers. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its way to the adjoining embayment. Surface water systems, unlike sandy aquifers, do support the needed conditions for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) is diminished (attenuated) by natural biological processes that represent removal (not just temporary storage). For the current (2016-2017) investigation of the oyster filtering effect in Lonnies Pond, the measured surface water load is the attenuated load.

Given the importance of quantifying the balance of nitrogen into and out of Lonnies Pond to determine the effect of the oyster deployment, directly measured flow and load that integrates all contributors to upper watershed attenuation was undertaken by CSP scientists in a similar manner as was undertaken under the MEP (thereby allowing for direct comparison of data sets).

Surface water flow paired with weekly to bi-weekly sampling for nitrogen concentration of the discharge from Pilgrim Lake were combined to yield a nutrient load associated with the surface water flow into Lonnies Pond that integrated all of the processes presently attenuating nitrogen in the sub-watersheds up-gradient from the gauging sites, which are the watershed to Pilgrim

Lake and a small stream-only watershed between the Lake and Lonnie's Pond. Flow, concentration and nitrogen load were determined at the stream gauging site for twelve (12) months comprising a complete hydrologic year (low flow to low flow) from October 1, 2016 to September 30, 2017. During the study period, periodic velocity profiles were completed at the stream gauge location to compare to calculated flows determined by passing the measured stage data from the gauge through the updated stage - discharge relation (rating curve) that was originally developed by the MEP. The updated rating curve reflects additional flow measurements made in 2016 and 2017. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream flow (Q).

Determination of stream flow was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma (A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Under the MEP analysis for Pleasant Bay, periodic measurements of flows over a complete hydrologic year allowed for the development of a stage-discharge relationship (rating curve) that was used to obtain daily flow volumes from the detailed record of stage measured by the continuously recording stream gauge. In order to measure stage for the present Lonnies Pond oyster study, a stream gauge was redeployed in 2016 and was maintained through 2017 in order to determine the annual flow and nutrient load to Lonnies Pond during the study period. Water level data obtained every 10-minutes from the herring creek up-gradient of the culvert passing under Herring Brook Road was averaged to obtain hourly stages. These hourly stages values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain monthly flow. In the case of tidal influence on stream stage (as is the case with the herring creek), the diurnal low tide stage value was extracted on a day by day basis in order to obtain the stage value indicative of strictly freshwater flow. The lowest low tide stage

value for a given day was then entered into the updated MEP stage – discharge relation in order to compute daily flow for the Lonnies Pond oyster study undertaken in the 2016-2017 period.

The flow record generated by passing measured stage data through the rating curve for the surface water flow into Lonnies Pond via the herring ladder was merged with the nutrient concentration data obtained through the water quality sampling program to determine nitrogen loading rates to the head of Lonnies Pond. Nitrogen discharge from the stream was calculated using the paired daily discharge and daily nitrogen concentration data to determine the mass flux of nitrogen through a gauging site. For the gauging location in this study, weekly water samples were collected (at low tide to account for tidal influence) in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient load to Lonnies Pond as appropriate. The "measured load" was representative of attenuated nitrogen entering Lonnies Pond directly from surfacewater as opposed to groundwater (recharge over area delineated by watershed).

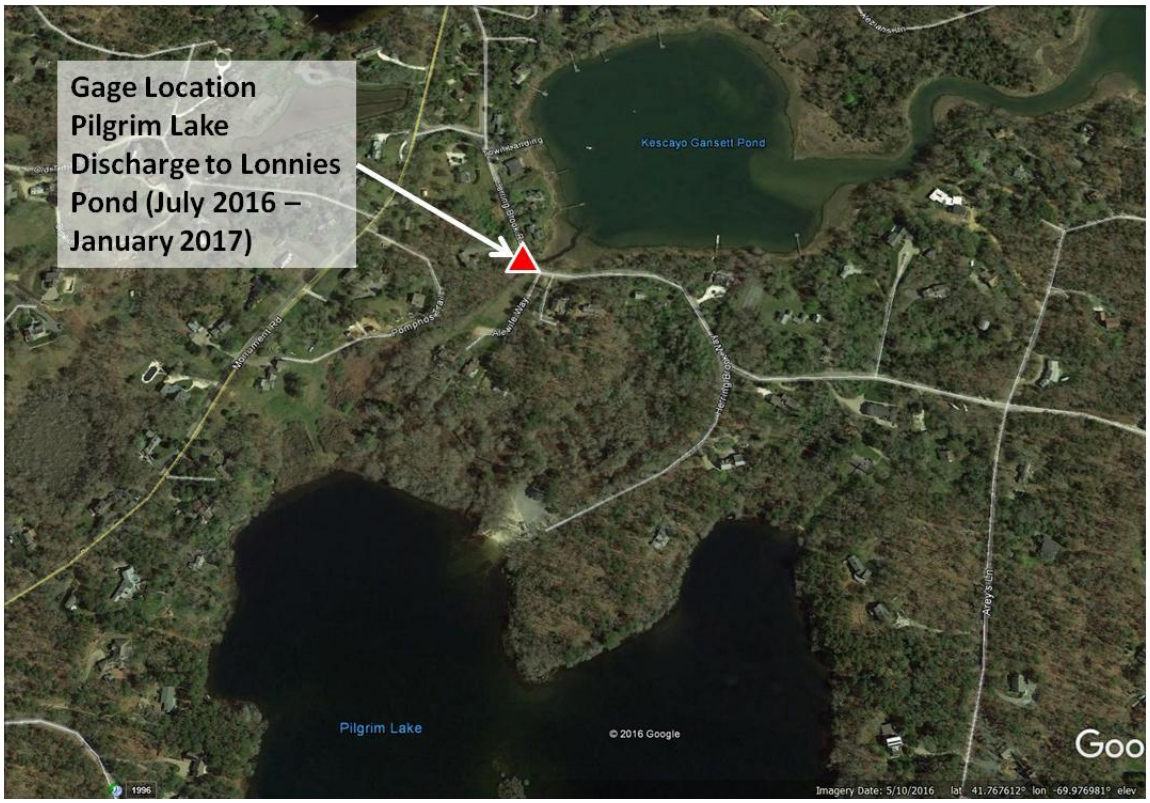


Figure VIII.1a. Location of stream gauge (red triangle) deployed at the base of the herring ladder between Pilgrim Lake and Lonnies Pond. An updated MEP rating curve initially developed in 2003 but refined with 2016-2017 flow measurements was utilized to determine daily flows and nutrient load to Lonnies Pond for the oyster study.

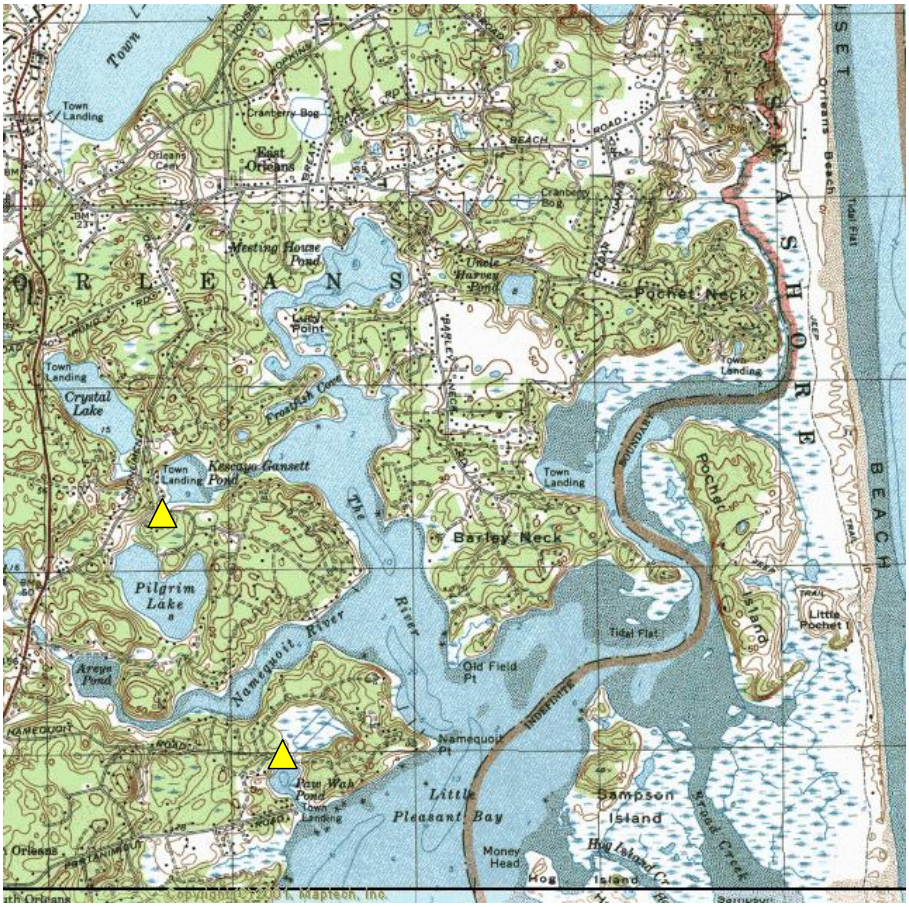


Figure VIII.1b. Location of MEP Stream gauge (yellow triangle) in the upper portions of the Pleasant Bay system embayment system. Rating curve, stage, flow, nutrient load and percent attenuation was determined for the 2002-2003 hydrologic year

Pilgrim Lake discharges freshwater and nitrogen load to the brackish waters of Lonnies Pond via a herring ladder that flows into a 1-meter diameter concrete culvert passing under Herring Brook Road. In order to quantify the flow of freshwater and the associated nitrogen load into Lonnies Pond, a stream gage was deployed immediately up-gradient of the culvert in the concrete box the herring ladder flows into on its way to Lonnies Pond.

The stream gage was deployed in late July 2016 and measured the stage of water in the box at a 10 minute frequency until October 31, 2017. As described above, the 10 minute stage data was averaged to obtain hourly stage which was then filtered to extract the lowest tide stage in a given day which would be representative of the freshwater portion of the flow (Figure 2a, b, c). The daily low tide stage was passed through the updated stage-discharge relationship originally developed by the MEP in 2002-2003 but modified to include flow measurements that were collected during the 2016-2017 Lonnies Pond study. Stage in 2016-2017 was measured at the same location as during the MEP stream analysis completed in 2002-2003. The 2016-2017

stage record was passed through the modified stage-discharge relation in order to calculate a volumetric flow in cubic meters per second (m^3/s) that was then converted to cubic meters per day (m^3/d) as depicted in Figure 3.

Total surface water inflow to Lonnies Pond (Table VIII.1) from Pilgrim Lake for the period October 1, 2016 to September 30, 2017 (a complete hydrologic year, low flow to low flow) and based on measured stage for that period and the modified MEP developed rating curve was 187,507 m^3 (average daily flow = 514 m^3). By comparison, total surface water inflow to Lonnies Pond from Pilgrim Lake during the MEP study period (October 2002-September 2003) was 355,279 m^3 (average daily flow = 973 m^3). The lower observed flows in 2016-2017 is primarily attributable to lower groundwater levels during the measurement period. During the 2002/2003 water year, January through May groundwater levels at the local long-term water level monitoring well were generally in the 75th and 90th percentile of all data and near average during the rest of the year, while groundwater levels were generally closer to the long-term averages during the 2016/2017 water year (Eichner, et al., 2018). As might be expected since precipitation and groundwater levels are related, lower precipitation rates were also noted during 2016/2017, but precipitation variations explained only 8% of the variation in streamflows, while groundwater variations explained 36% of flow variations.

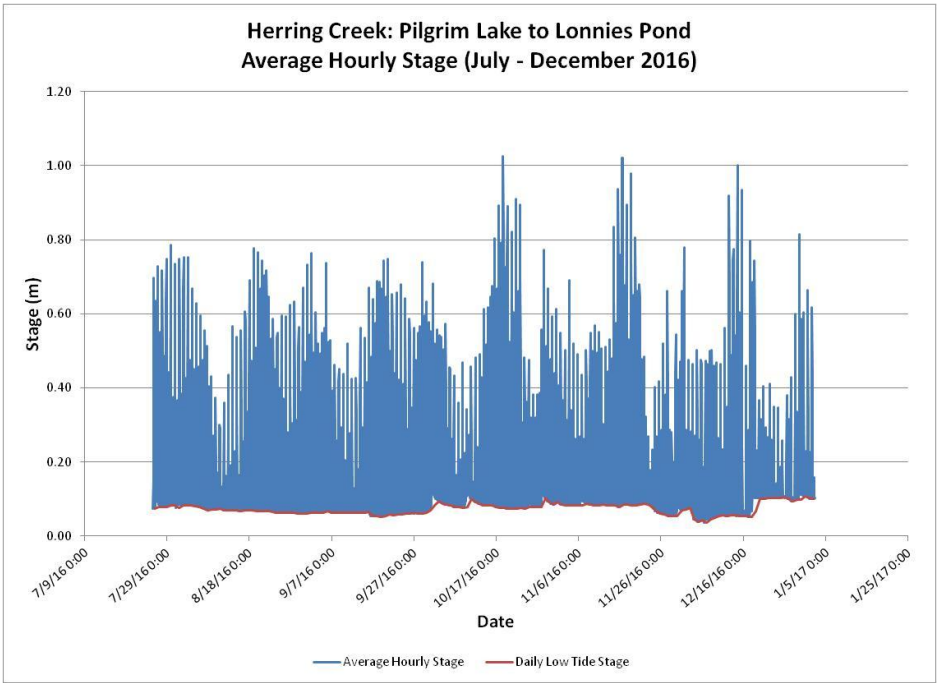


Figure VIII.2a. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, July 25, 2016 to December 31, 2016 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

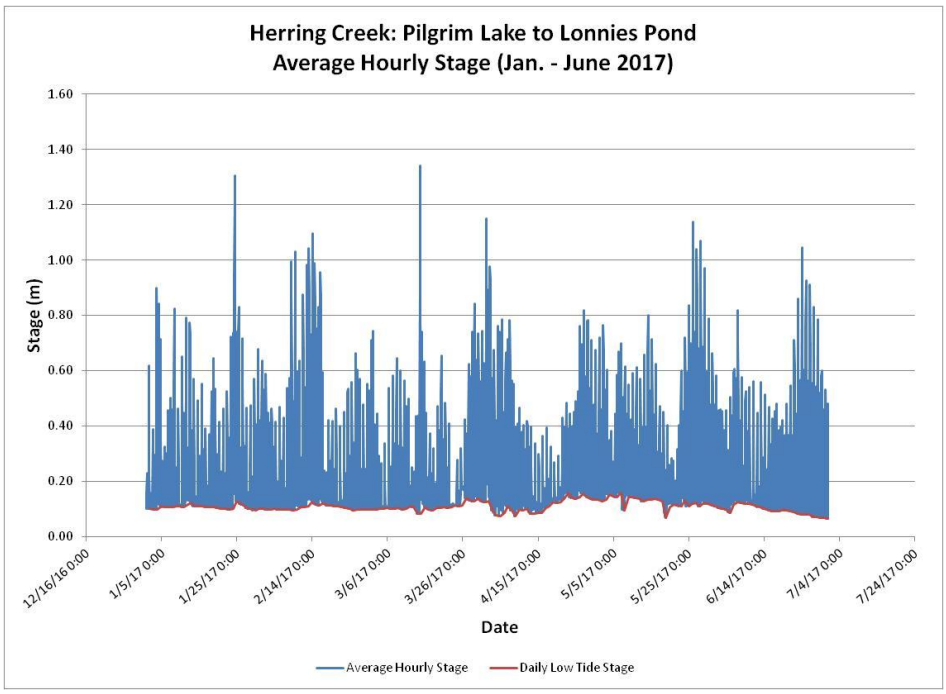


Figure VIII.2b. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, January 1, 2017 to June 30, 2017 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

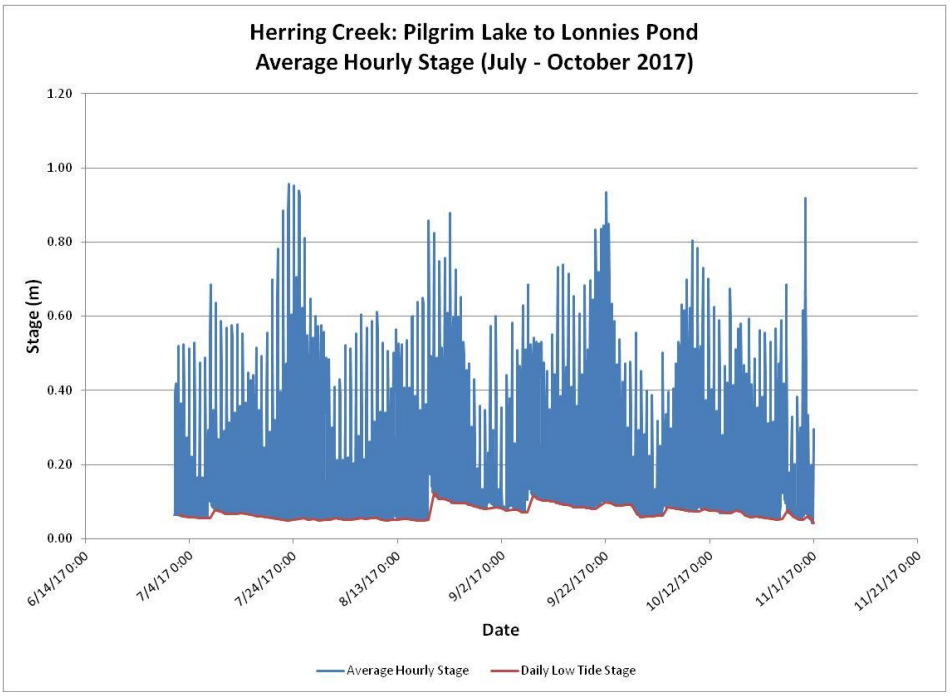


Figure VIII.2c. Average hourly stage record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, July 1, 2017 to October 31, 2017 and associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond.

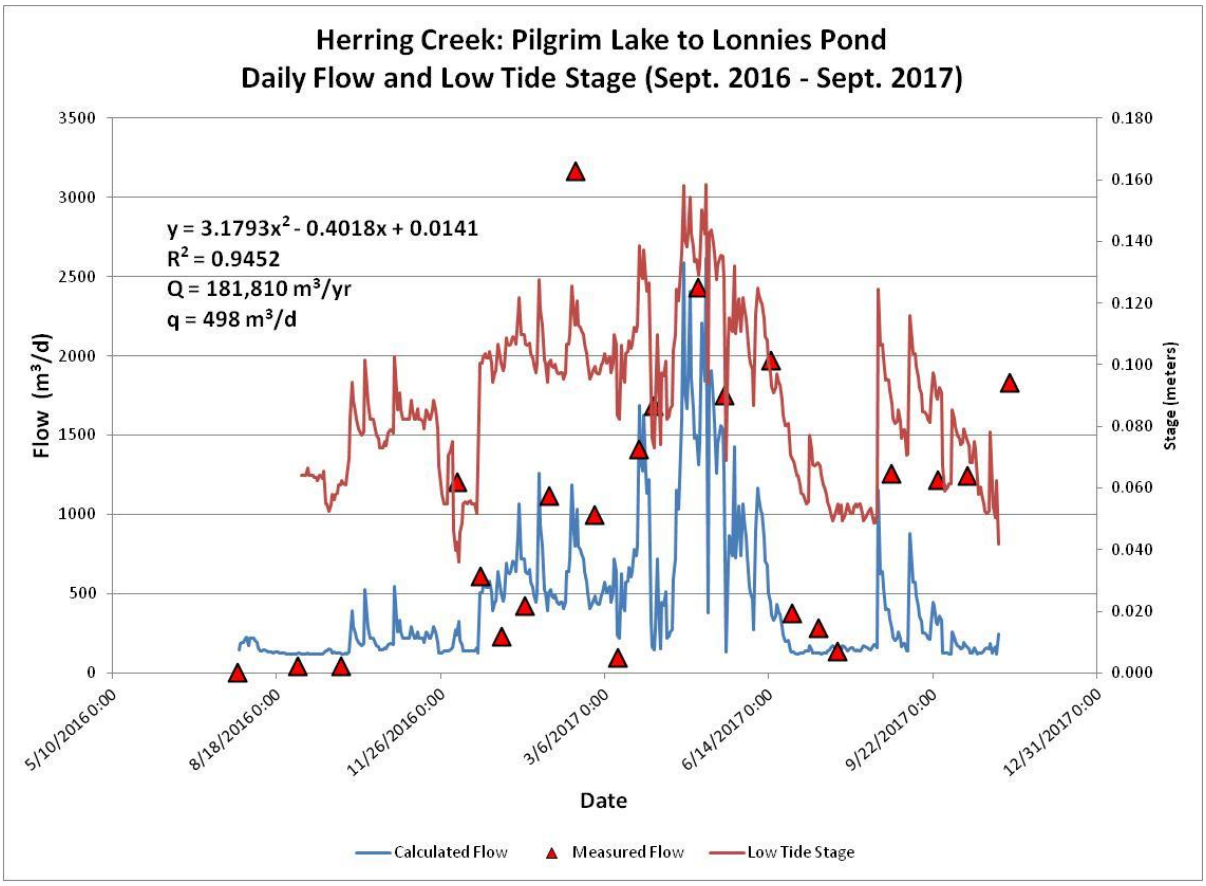


Figure VIII.3. Daily flow record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, September 1, 2016 to October 31, 2017, associated daily low tide stage used to calculate freshwater flow and nitrogen load to Lonnies Pond and comparison to measured point flow measurements.

Monthly Flow Pilgrim Lake to Lonnies Pond (August - December)		
MONTH	2016-2017 FLOW (m^3/month)	2002-2003 FLOW (m^3/month)
August	4457	--
September	3791	--
October	7450	8342
November	6360	33240
December	9893	36363
January	20111	30,062
February	16981	46,759
March	21964	59,961
April	28947	41,072
May	39226	51,896
June	14210	14,367
July	4394	11,522
August	8504	9,280
September	9467	12,415
October	4920	10,754
November	--	16,887
December	--	17,520
Total (Oct.-Sept.)	**187,507**	**355,279**
NOTE:		
Annual Precip 2002-2003 = 54.39 inches		
Annual Precip 2016-2017 = 40.79 inches		
Avg. Annual Precip 1993-2015 = 46.11 inches		

Table VIII.1. Summary of monthly flow volumes discharged to Lonnies Pond. 2016-2017 significantly lower total volume for the period October to September (hydrologic year) due primarily to lower groundwater levels compared to 2002-2003.

Based on the daily flows generated during the gauge deployment period and the approximately bi-weekly sampling of the flow into Lonnies Pond, sample concentrations were interpolated and then merged with the daily flows to obtain an estimate of the nitrogen load into Lonnies Pond during the critical period of the oyster deployment. On average for the period August through October 2016, total nitrogen concentration averaged 1.11 mg/L and ranged between 0.96 and 1.30 mg/L (Figure 4, Table 2). When combined with flow during the same period, TN load averaged 5.67 kg/month TN and ranged between a high monthly average load of 7.57 kg/month and a low of 4.67 kg/month (Figure 5, Table 3). By comparison, on average for the period August through October 2017, total nitrogen concentration averaged 0.59 mg/L and ranged between 0.55 and 0.66 mg/L (Table2). When combined with flow during the same period, TN load averaged 4.15 kg/month TN and ranged between a high monthly average load of 4.83 kg/month and a low of 2.90 kg/month.

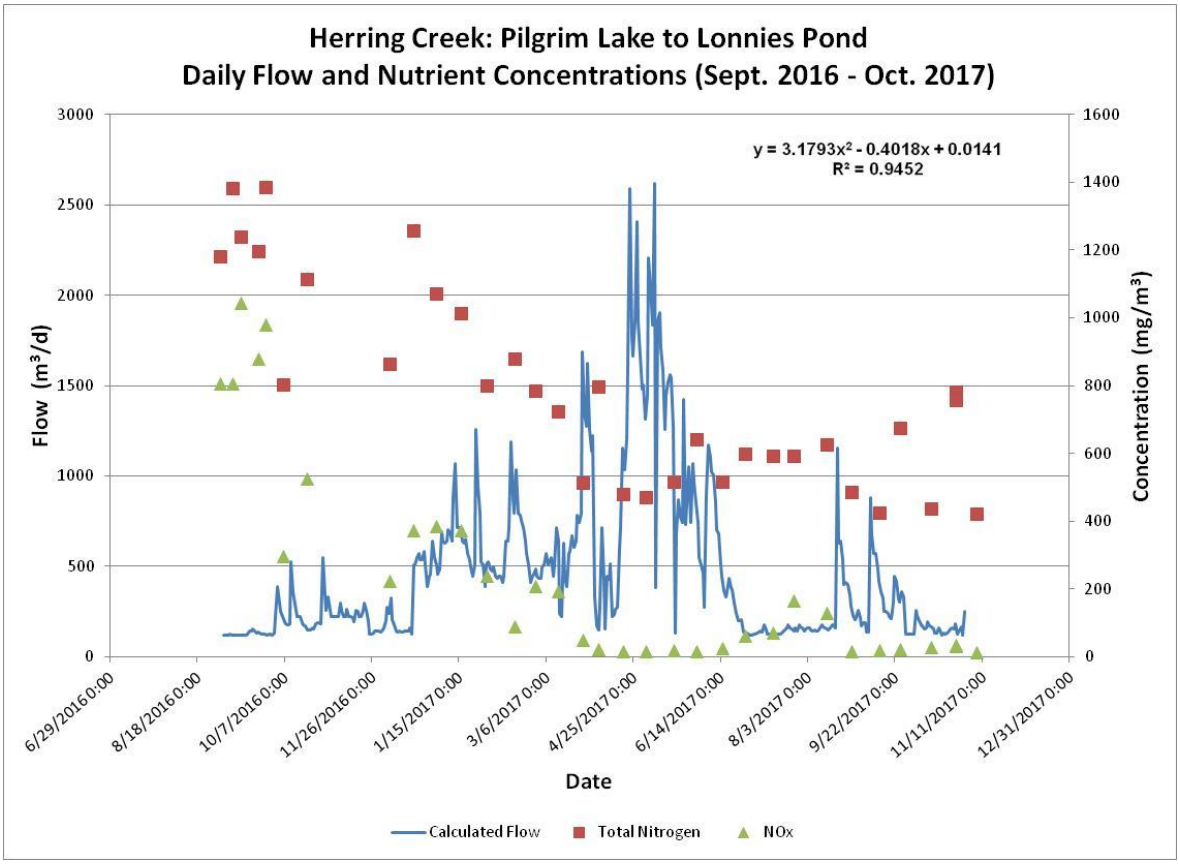


Figure VIII.4. Daily flow and stream nutrient concentration record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, September 1, 2016 to October 31, 2017 used to calculate freshwater flow and nitrogen load to Lonnies Pond.

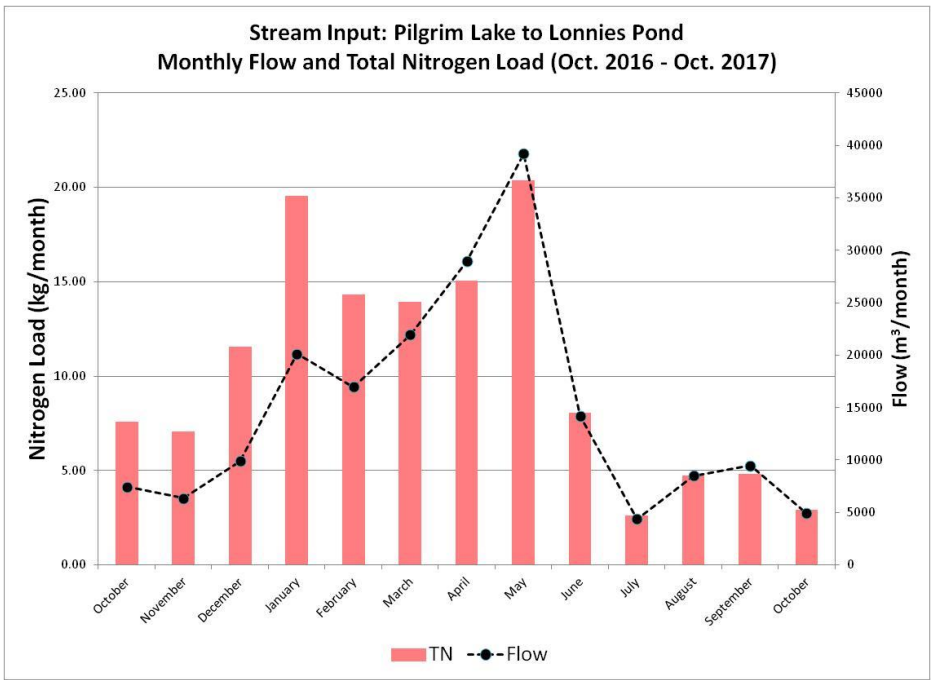


Figure VIII.5. Monthly flow and monthly stream total nitrogen load from Pilgrim Lake to Lonnies Pond.

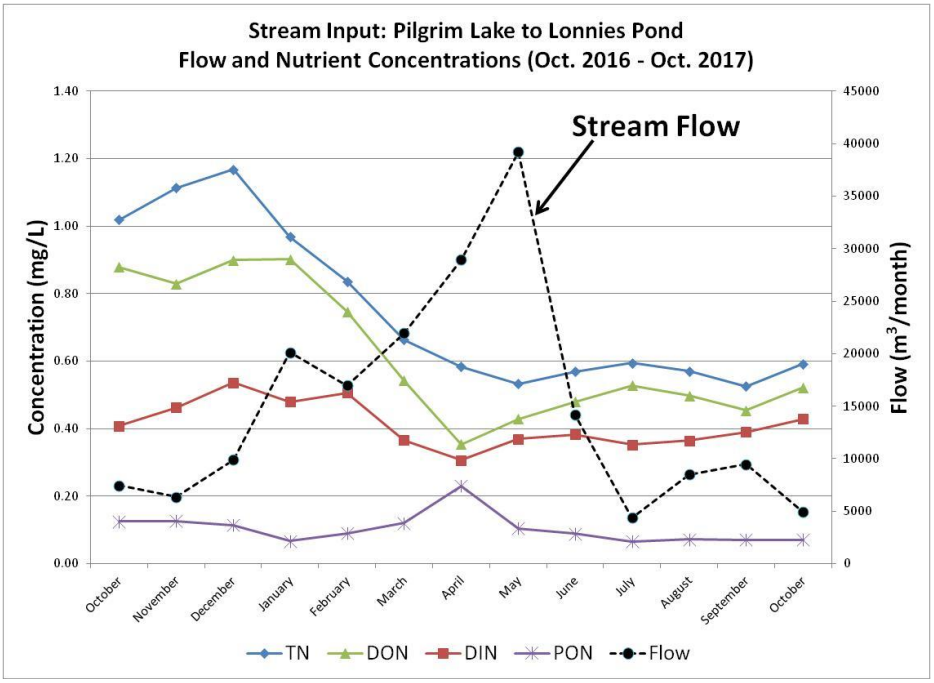


Figure VIII.6. Monthly flow and average monthly stream nitrogen constituent concentration record from Herring Creek discharge to Lonnies Pond from Pilgrim Lake, October 1, 2016 to October 31, 2017 used to calculate freshwater flow and nitrogen load to Lonnies Pond and determine seasonal differences in nutrient loading.

Considering the component nitrogen species, it appears that the total nitrogen concentration is

primarily comprised of dissolved inorganic nitrogen (DIN, 50%) and dissolved organic nitrogen (DON, 43%) with the remaining portion being comprised of particulate organic nitrogen (PON 7%). The 2003 stream nutrient concentrations determined during the MEP study were generally similar in that DIN and DON were the predominant fraction of the TN pool (30% and 58% respectively) with PON constituting the remainder of the total nitrogen (11%). DIN concentration in 2016 did appear higher than DIN levels in 2003 (50% vs. 30%), however, that may be the result of differences in annual hydrologic conditions and annually variable biogeochemical transformations in Pilgrim Lake. Lower volumetric discharge in the herring creek between Pilgrim Lake and Lonnies Pond could result in the slightly higher constituent concentrations for nitrogen (e.g. average TN 2016 {Aug.-Oct.} 1.11 mg/L, average TN 2003 {Aug.-Oct.} 0.791 mg/L). By comparison, total precipitation in the period August to October 2017 was 13.69 inches with an average TN concentration for that period of 0.59 mg/L.

NUTRIENT CONCENTRATIONS (based on samples w/o interpolation)						
Year	NH4 Avg. Monthly (mg/L)	NOX Avg. Monthly (mg/L)	DIN Avg. Monthly (mg/L)	DON Avg. Monthly (mg/L)	PON Avg. Monthly (mg/L)	TN Avg. Monthly (mg/L)
2016						
August	0.07	0.50	0.57	0.40	0.10	1.07
September	0.07	0.93	0.99	0.21	0.10	1.30
October	0.02	0.41	0.43	0.41	0.11	0.96
November *	0.01	0.35	0.46	0.83	0.13	1.11
December	0.04	0.30	0.34	0.54	0.11	1.06
* November concentrations are based on interpolation						
2017						
January	0.079	0.331	0.410	0.479	0.072	0.961
February	0.070	0.149	0.219	0.505	0.109	0.833
March	0.036	0.122	0.158	0.352	0.110	0.620
April	0.026	0.019	0.044	0.306	0.287	0.637
May	0.045	0.017	0.062	0.371	0.109	0.542
June	0.062	0.044	0.106	0.372	0.079	0.557
July	0.072	0.117	0.189	0.345	0.058	0.592
August	0.033	0.072	0.105	0.373	0.078	0.556
September	0.052	0.020	0.072	0.411	0.067	0.550
October	0.079	0.031	0.110	0.478	0.071	0.659
2003						
August	0.14	0.22	0.36	0.36	0.08	0.80
September	0.06	0.14	0.20	0.43	0.07	0.70
October	0.06	0.20	0.26	0.51	0.11	0.88
November	0.03	0.08	0.11	0.59	0.09	0.79
December	0.08	0.21	0.28	0.50	0.12	0.91
Avg. Conc. (Aug.-Oct. 2016)	**0.05**	**0.61**	**0.67**	**0.34**	**0.10**	**1.11**
Avg. Conc. (Aug.-Oct. 2017)	**0.05**	**0.04**	**0.10**	**0.42**	**0.07**	**0.59**
Avg. Conc. (Aug.-Oct. 2003)	**0.09**	**0.19**	**0.28**	**0.43**	**0.08**	**0.79**
NOTE: Oysters Removed from Lonnies Pond in December 2016.						

Table VIII.2. Nutrient concentrations by month (August - December) 2016 vs. 2003 entering Lonnies Pond from Herring Creek.

NUTRIENT LOADS						
Year	NH4 Monthly Load (kg/month)	NOX Monthly Load (kg/month)	DIN Monthly Load (kg/month)	DON Monthly Load (kg/month)	PON Monthly Load (kg/month)	TN Monthly Load (kg/month)
2016						
August	0.30	2.07	2.37	1.87	0.44	4.67
September	0.25	3.39	3.65	0.81	0.32	4.78
October	0.16	3.33	3.49	3.03	0.92	7.57
November	0.09	2.28	2.37	2.93	0.81	7.08
December	0.47	3.40	3.87	5.36	1.17	11.56
2017						
January	1.71	6.84	8.55	9.66	1.34	19.54
February	1.42	2.51	3.93	8.82	1.56	14.31
March	0.70	2.47	3.17	7.69	3.07	13.94
April	0.89	0.50	1.39	8.84	4.81	15.04
May	1.58	0.68	2.27	14.12	3.99	20.38
June	0.83	0.39	1.22	5.54	1.29	8.05
July	0.31	0.46	0.78	1.54	0.29	2.60
August	0.30	0.66	0.96	3.12	0.65	4.73
September	0.41	0.19	0.60	3.57	0.67	4.83
October	0.31	0.14	0.45	2.10	0.35	2.90
2003						
August	1.35	2.18	3.53	3.40	0.71	7.64
September	0.64	2.17	2.81	4.59	0.85	8.26
October	0.61	1.92	2.53	5.92	1.23	9.68
November	0.41	1.26	1.67	9.75	1.53	12.96
December	ND	ND	ND	ND	ND	ND
Total Load (Aug.-Oct. 2016)	0.71	8.80	9.51	5.71	1.69	17.02
Avg. Load (Aug.-Oct. 2016)	0.24	2.93	3.17	1.90	0.56	5.67
Total Load (Aug.-Oct. 2017)	1.02	0.98	2.01	8.79	1.66	12.46
Avg. Load (Aug.-Oct. 2017)	0.34	0.33	0.67	2.93	0.55	4.15
Total Load (Aug.-Oct. 2003)	2.60	6.27	8.87	13.91	2.79	25.57
Avg. Load (Aug.-Oct. 2003)	0.87	2.09	2.96	4.64	0.93	8.52
NOTE: Oysters Removed from Lonnies Pond in December.						

Table VIII.3. Nutrient loads by month (August - December) 2016 and 2017 vs. 2003 entering Lonnies Pond from Herring Creek.

Section IX. Lonnies Pond Oyster Study 2016 - 2017: Conclusions

The major results of the 2 year pilot deployment of oysters in Lonnies Pond are summarized below. While there are areas of the analysis that need refinement and additional quantification, a few things are clear from this extended deployment:

1) In both years there was a clear reduction in phytoplankton biomass by oyster filtration as water flowed through the oyster culture area. Significant reductions in total chlorophyll-*a* of >50% were commonly observed in samples adjacent versus within the deployment area.

2) Significant ($p<0.5$) reductions in total chlorophyll-*a* and particulate organic nitrogen (PON) were seen in tidal studies designed to capture water as it flowed through the culture area. Reduction in bioactive nitrogen was also seen, mainly due to the reduction in its main component, PON. Given the short time that any packet of water is in contact with the oysters, the large quantifiable reductions in all particulate groups is clear evidence of the ability of these types of oyster deployments to improve water quality even in nitrogen enriched waters

3) Biodeposition of feces and pseudofeces from the oysters was clearly evident in the region of the oyster deployment and the sediment region receiving biodeposits. The boundary of impact was refined in 2017 using a more sensitive acoustic device than in 2016. The oysters process more particulates than they incorporate by 2 fold. The deposition of organically labile particulate matter in biodeposits stimulated overall sediment respiration rates. This stimulation occurred in summer and fall with temperature moderating the absolute rate. Comparing October rates adjusted for temperature effects (Q_{10}) with August rates, overall respiration rates (carbon turnover) were similar, but with a shift towards greater uptake of NH_4 and NO_3 and greater denitrification. Rates of N biodeposition were directly measured yielding rates of 0.58 kg-N d^{-1} and 0.30 kg-N d^{-1} in August and October, respectively. The water quality surveys documented a peak in both particulate nitrogen and chlorophyll-*a* (phytoplankton biomass) in August compared to October due to a summer phytoplankton bloom (see Section II).

4) Denitrification (transformation of fixed nitrogen to nitrogen gas, N_2) was enhanced in sediments receiving oyster biodeposition. In September/October when oysters had reached their mid-season biomass, an amount equivalent to almost 1/3 of the biodeposition rate was denitrified each day. The study indicated that denitrification continues to be enhanced past the time of oyster harvest as the sediment incorporated biodeposits continue to contribute nitrogen to denitrification into the following spring when waters re-warm.

5) The second year of oyster deployment in the same area resulted in an increase in nitrogen removed through denitrification by 50% (2017[year 2] versus 2016 [year 1]) over the single season. It appears that the initial 1 year new deployment did not deliver sufficient biodeposits to the sediments to maximize the amount of nitrogen removal through denitrification. The second year also was initiated earlier than year 1 and with more oyster biomass early on, such that denitrification was higher for a longer period.

6) Should a rotational deployment be initiated, it will be important to gauge the potential reduction in denitrification if only 1 year deployments are made. At this point the optimal rotation time is unclear. In addition, it appears that the need to maximize biodeposits as early as April/May should be considered in planning where possible.

7) Re-examining the full denitrification and refined impact area and biodeposition over the 2 year deployment indicates that the initial deployment of seed only from June to December resulted in an increased nitrogen removal of 0.25 kg N per 1 kg N in harvest, but when continued into the second year the increased removal was significantly higher ~0.37 kg N per 1

kg N removed in harvest. These rates are lower than for Little Pond Falmouth, but are in the range of 0.5 kg N per 1 kg N removed in harvest found elsewhere.

8) As part of the overall effort, stream discharges to Lonnies Pond were determined in summer 2016 and summer 2017 during the oyster deployment. The flow data are consistent with 2016 being part of the drought (Aug.-Oct., 15,698 m^3) with 2017 flows being higher (Aug.-Oct., 22,891 m^3) due to higher precipitation. Precipitation in 2016 was reduced over long-term averages and more significantly flow through the main surface water discharge (Herring Run) was far below historic levels (e.g. 2003), with 2016 rates being 52% of 2003 surface water flow volumes (32,449 m^3) in the August through October period. Flow for the same period in 2017 compared to 2003 was 29% lower. At these flow levels, it did not appear that the oyster study was influenced by surface water flows in 2016 or 2017. It should be noted that at the low surface flows of 2016, average monthly nitrogen loading (Aug.-October.) to Lonnies Pond waters from Pilgrim Lake was significantly lower than 2003 loads (5.67 vs. 8.52 kg/month). It should be noted that while flows in 2016 where lower than for the same period in 2017, average monthly TN load to Lonnies Pond in 2016 (5.67) was slightly higher than for the same 2017 period (4.15) due to the very high measured TN concentrations in the stream water (1.11 mg/L and 0.59 mg/L respectively). The interannual variation in TN concentration is likely related to the turnover time of Pilgrim Lake, which is controlled by the freshwater inflow volume (lower in 2016 than 2017).

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APPENDIX E: Lonnie's Pond Water Quality Sampling Sheet/chain of custody form

COASTAL SYSTEMS GROUP
Chain of Custody Record

Personnel Contacts

RECEIVED		RECEIVED	
name		name	
date	time	date	time
COLLECTED		CONTACT	
name		name	
date	local	phone	

Sample Notes

Special notes/ Sample Handling	Total number of samples

Sample Status

Sample ID	Sample Date	NH4	PO4	NO3/NO2	TDN	POCN	TSS	CHLA	TP	TDP	Salinity	pH	Alkalinity	TN	WINKLER

APPENDIX F: Boston University Stable Isotope Laboratory Shellfish N Content Assay SOP

Appendix A

Boston University Stable Isotope Laboratory QAQC

and

Science Wares SOPs

BOSTON UNIVERSITY
STABLE ISOTOPE LABORATORY

Robert Michener, Laboratory Manager
Department of Biology, 5 Cummington Street
Boston, MA 02215
Tel. 617-353-6980, Fax: 617-353-6340 email: michener@bu.edu

Quality Assurance and Quality Control

Instrumentation for stable isotope analysis has expanded to include both the original Finnigan Delta-S and now two GV Instruments IsoPrime isotope ratio mass spectrometer. With the addition of the GVI instruments and associated peripherals, we have automated stable isotope analysis of most organic (and some inorganic) samples for carbon-13 and nitrogen-15. The workhorse of continuous flow measurements of solid samples for carbon and nitrogen isotopes is done by the GVI IsoPrime and a Eurovector elemental analyzer, combined with a diluter and reference gas box.



Samples for automated isotope analysis are first weighed out into tin boats to the nearest 0.01 mg on a Mettler AE240 or a Sartorious micro electronic balance. During a sequence run by the mass spectrometer, each sample is flash combusted at 1800ºC in the Eurovector CN analyzer; the combustion products (CO_2, N_2 and H_2O) are separated chromatographically and introduced into the mass spectrometer, with water removed in a chemical trap. The gases of interest are then introduced into the mass spectrometer for isotope analysis and the rest pumped away. The sample isotope ratio is compared to a secondary gas standard, whose isotope ratio has been calibrated to international standards. For $^{13}C_{V\text{-}PDB}$ the gas was calibrated against NBS 20 (Solenhofen Limestone), NBS 21 (Spectrographic Graphite), and NBS 22 (Hydrocarbon Oil); for $^{15}N_{air}$ the gas was calibrated against atmospheric N_2 and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). All international standards were obtained from the National Bureau of Standards in Gaithersburg, MD.

International standards used for water samples include V-SMOW, GISP and SLAP, which were utilized to calibrate the secondary gas standard. In the past, water samples were prepared using the guanidine hydrochloride technique for oxygen-18 and the zinc reduction technique for deuterium (zinc obtained from John Hayes, Indiana University). With the addition of the GVI MultiFlow and ChromeHD systems, we are now able to automate both procedures. Oxygen-18 analysis is done via CO_2 equilibration and deuterium analysis is done via pyrolysis in the ChromeHD system.

When running gas samples on the Finnigan Delta-S, as a daily check on instrument performance we run a second gas (lecture N_2 or CO_2) that is isotopically distinct from our standard gas. If the isotope values are within 0.05 per mil of its long-term record, analysis proceeds; otherwise, further analysis stops until any problems are resolved. Internal precision for the instrument is $\pm$0.014 per mil. For solid continuous flow samples, a suite of in-house standards are first analyzed. If they fall within laboratory specifications, client sample analysis then proceeds.

Required external precision of a sample (i.e. replicate analysis) for either ^{15}N or ^{13}C is 0.2 per mil. Typically, our precision is better than 0.1 per mil for well-ground organic tissue samples using the trapping box.

Samples run in continuous flow mode are currently within 0.2 per mil for both nitrogen and carbon. In addition to carbon and nitrogen isotopes from the same sample, continuous flow will also report %C and %N data.

The lab runs one replicate per 10 samples, and any anomalous results are rerun. As a check on the combustion and cryogenic distillation steps, a laboratory standard is run every 15 samples. This standard is either peptone, a hydrolyzed animal protein from Sigma Chemical Company, glycine, or citrus leaves, SRM 1572. Both have been well documented by several stable isotope laboratories and their isotopic values are well known. Its value must be within 0.15 per mil of its documented value. If it does not, the samples preceding the standard are considered suspect and rerun.

The addition of the GVI Instrumentation precision of water samples (oxygen-18 and deuterium) has improved significantly and is extremely good. The lab generally runs duplicates of all samples for oxygen-18 if there is enough water. The precision is usually 0.1 permil or better. An internal lab standard is run after every 4 client samples as a check on the instrumentation. Deuterium samples are run with the ChromeHD pyrolysis system. Three injections are done with each sample, with the first injection discarded, due to memory effects in the system. The standard is Boston University deionized water, collected in batch fashion and stored. The water standard is within 0.2 per mil of its long-term value for deuterium and 0.2 per mil for oxygen-18. In addition, the metabolic samples are inputted to a spreadsheet that calculates FMR (Field Metabolic Rates). If calculated values are not within acceptable ranges, the suspect samples are rerun. The calculations are based on the equations of Lifson and McClintock (1966), as modified by Kenneth Nagy, UCLA.

For carbonate samples, NBS-20 and Carera-Z are used as two point calibration standards. Precision is currently 0.05 permil for carbon-18 and 0.06 permil for oxygen-18. CO_2 air and breath samples are calibrated using atmospheric air and a 1% CO_2/helium mix gas. The mix gas was checked against calibration gases obtained from Oztech Corporation, Texas.

Data is presented in a tabular form and can be sent by fax, mail or email. The sheet includes sample ID, mass/volume used, isotopic value and % organics (if applicable). All isotopic data are rounded to 2 decimal places.

We request that a sample list be included with all samples and that all samples be clearly identified. This allows the Laboratory Manager to look over the data and compare the isotope values against generally accepted values for that type of sample. Any samples that appear anomalous are rerun if possible to check their values; if preloaded, they are flagged as anomalous for the client.

Percent organics and nitrogen protocol

Samples are weighed out to 0.001 mg into tin capsules on a Sartorius XM1000P microbalance. They are combusted in a Fisons NA1500 elemental analyzer and measured using Eager200 software. Check standards are inserted into the run to ensure precision and quality control. Any anomalous samples are reweighed and rerun. Precision for replicate samples is 0.2 percent for carbon, and 0.5 percent for nitrogen, but will vary depending on the heterogeneity of the material.

The elemental analyzer is recalibrated each day using a size series of 5 acetanilide standards ranging from 2 to 0.2 mg. A sixth acetanilide is then measured to check for accuracy.

Samples can be either dried and ground by the client, or shipped to the laboratory in dried or wet form and ground by the lab. A mortar and pestle and liquid nitrogen are used to ensure a well-ground, homogenous mix. Samples can be stored in any container, but preferably in scintillation vials or Eppendorf tubes.

If samples are to be prepared by the client, they should be placed in 96 well trays, leaving slots 6 and 12 open for BUSIL internal standards. The amount of material will vary, but should be around 1, 2, and 5 mg for animal tissue, plant tissue, and soils, respectively. The spreadsheet found on the BUSIL website (http://www.bu.edu/sil/PDF%20files/BUSIL%20EA%20Sample%20Submission.xls) should be filled out and sent electronically to the laboratory manager prior to shipping.

The results are put into an Excel spreadsheet and sent to the client, reporting sample ID's, masses, and percent carbon and nitrogen.

Maintenance on the elemental analyzer is performed after a run of 120 samples. Excess tin and ash are removed from the combustion column. The reduction column is changed after 300 to 500 sample analyses. The combustion column is replaced after 1,500 samples.