Attachment 3A - 3F
Email Attachments – 3-11-2015

City Of Taunton

Review of Proposed NPDES Permit Issues and Suggested Resolution of Scientific Uncertainties

February 10, 2015

Taunton Estuary Coalition Objectives

Protect Estuary Resources

- Understand the science
- Invest in solutions that address causes of resource degradation
- Avoid expenditures that won’t produce benefits

Concerns Raised by City

- Reliability of Sentinel Method in Complex Estuary (Peer Review Request)
- Use of MHB16 to Predict Taunton Estuary DO Conditions
- Nutrient Reductions Since 2005
- Brayton Point Changes Since 2005
- Outdated Marine DO Criteria

Conceptual Model for EPA Permit

- Excess TN causes excessive Plant Growth
- Excessive Plant Growth causes low DO in Taunton Estuary
- Taunton Estuary responds like Mount Hope Bay
- Conditions have not improved since 2005

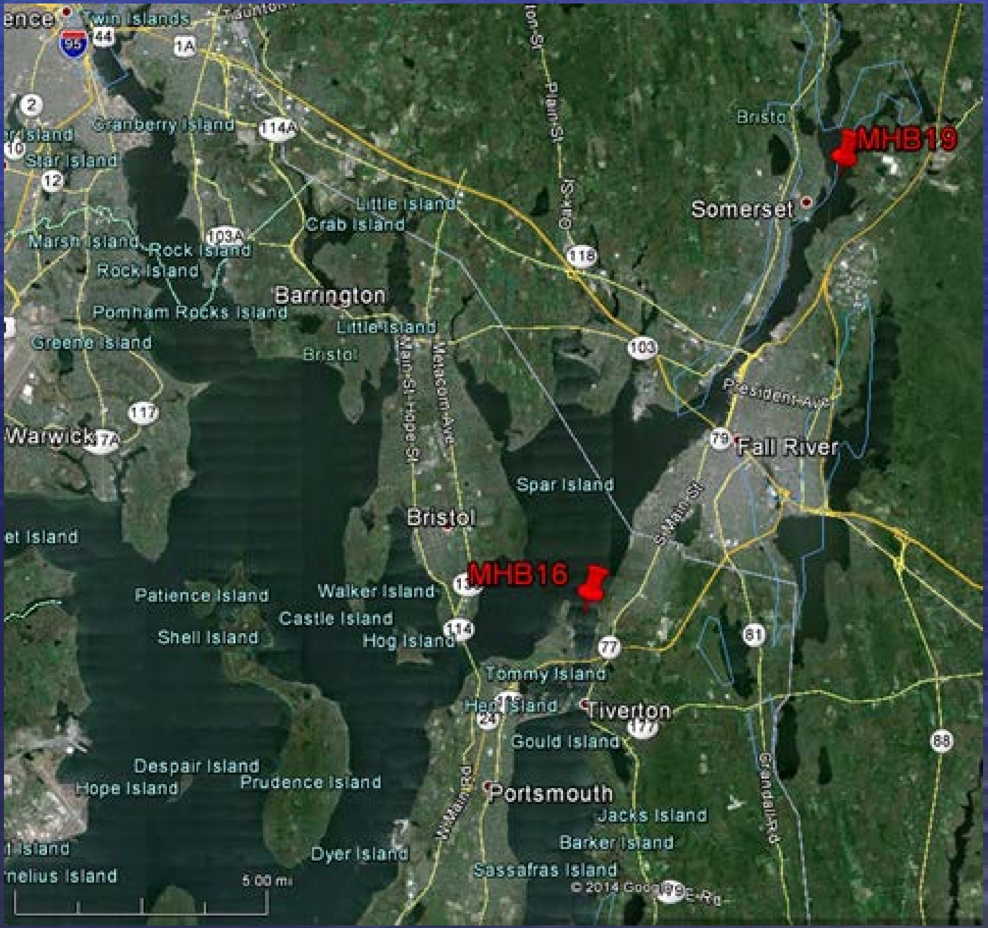
“The Sentinel Method”

Taunton River Estuary, MA

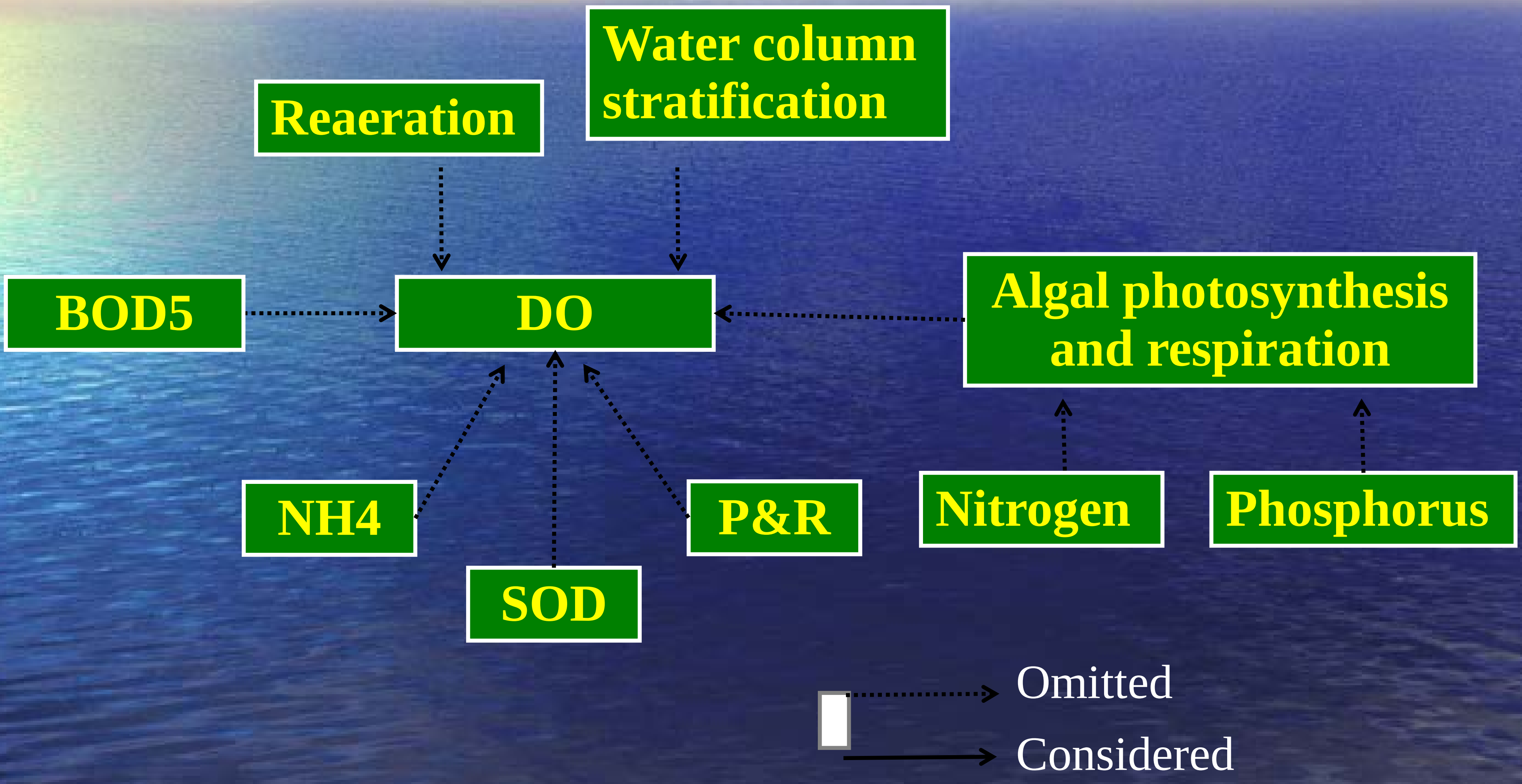
EPA determined DO standard met at MHB16 but not MHB19

EPA assumed TN at MHB16 required to meet DO WQS at MHB19 (10 mi upstream)

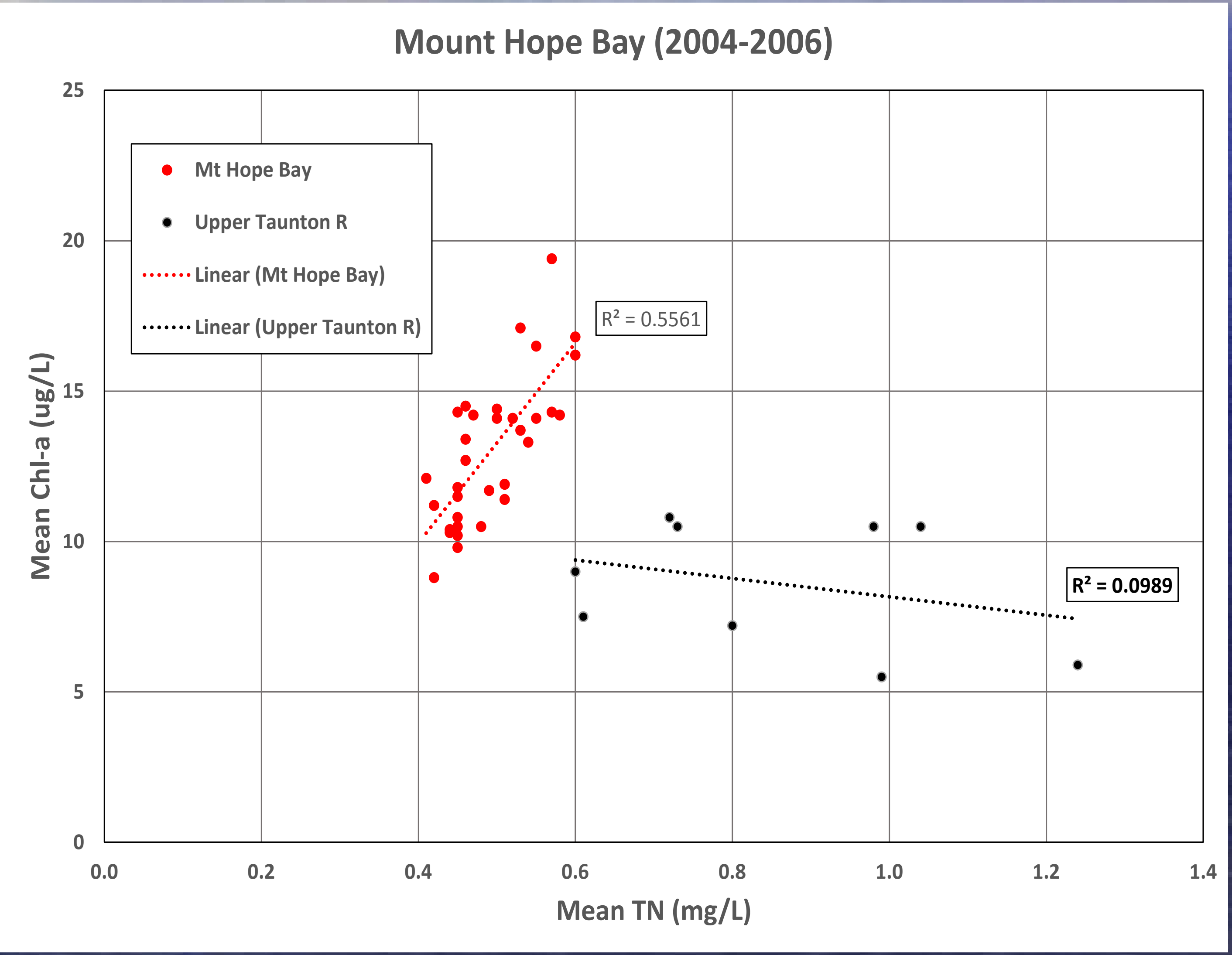
No modeling or consideration of hydrodynamic differences



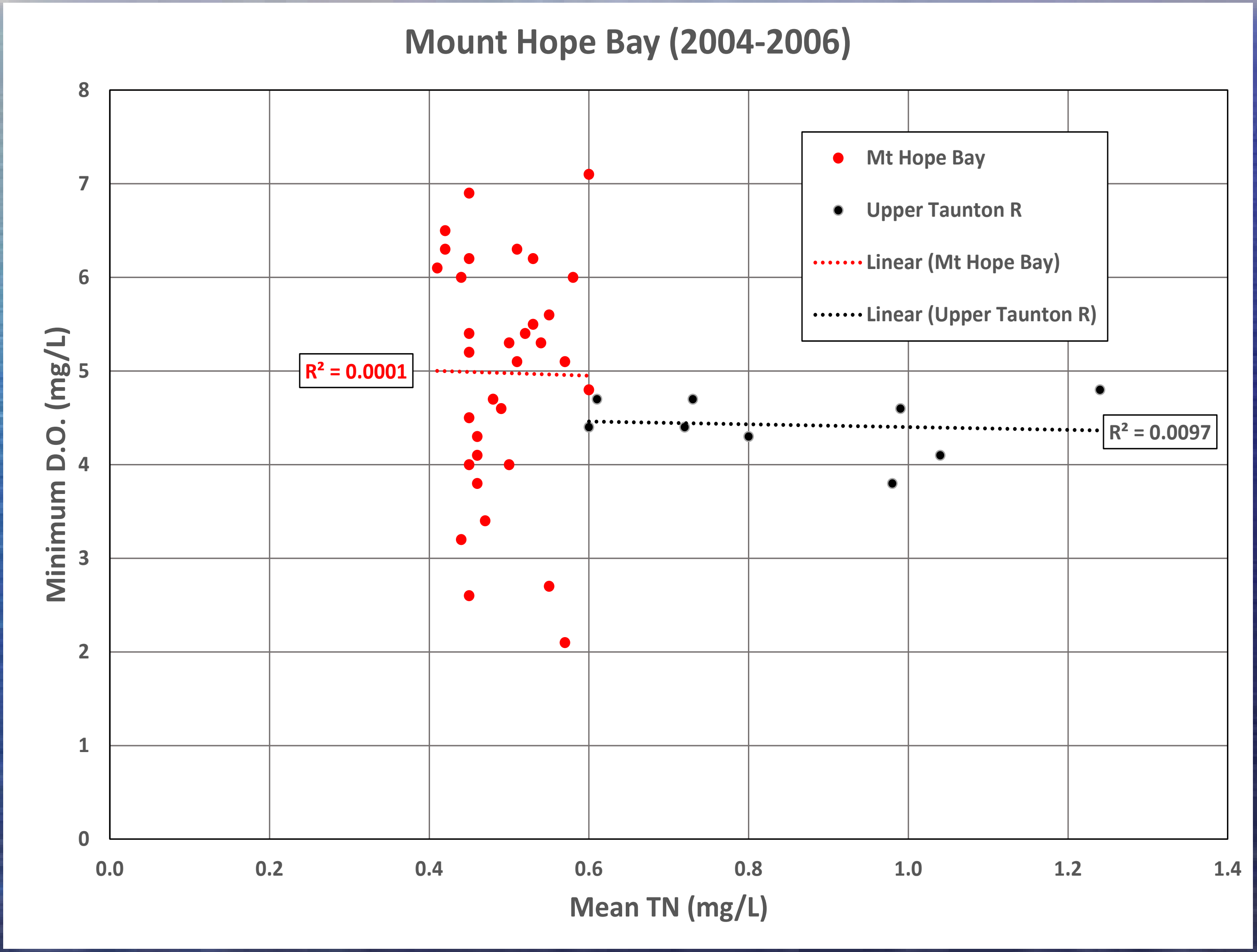
Factors Influencing Water Column Dissolved Oxygen



Taunton Estuary Algal Response Differs from MHB



Taunton Estuary DO Response Differs from MHB



Expert Opinions

- Dr. Steven Chapra – Tufts Univ.
- Dr. Craig Swanson – RPS Group
- Great Bay Peer Review

All concur the present analyses are deficient and TN impact predictions are not defensible

EPA FOIA Response

Dec. 24, 2014

Sentinel Method has never undergone any prior review to ensure it is scientifically defensible

No records in EPA possession confirming approach is “scientifically defensible and an acceptable approach for generating numeric nutrient criteria and/or establishing numeric nutrient limits under 40 CFR 122.44(d)”

EPA 2010 Stressor-Response Document did not include DO impact assessment in guidance

Other Missing Information

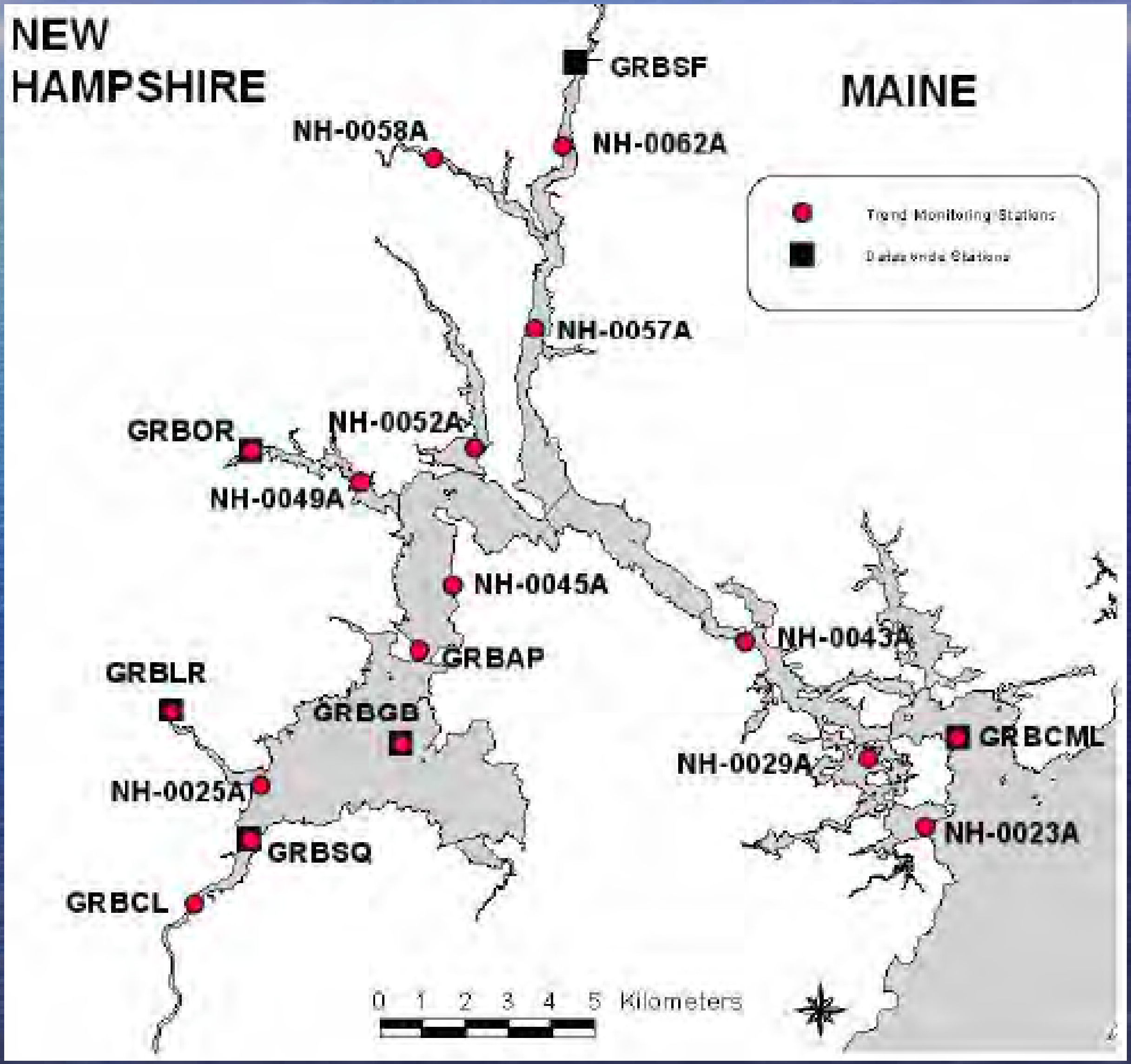
- WWTP upgrades affecting organic loadings to Taunton Estuary (e.g., CSO projects)
- Impact of Brayton Pt. facility closure
- Impact of reduced TN on both systems

"NBC monitoring does not include eutrophication indicators…so their data cannot be used for assessment of the response of the system to the load reduction" USEPA Mansfield Permit Response

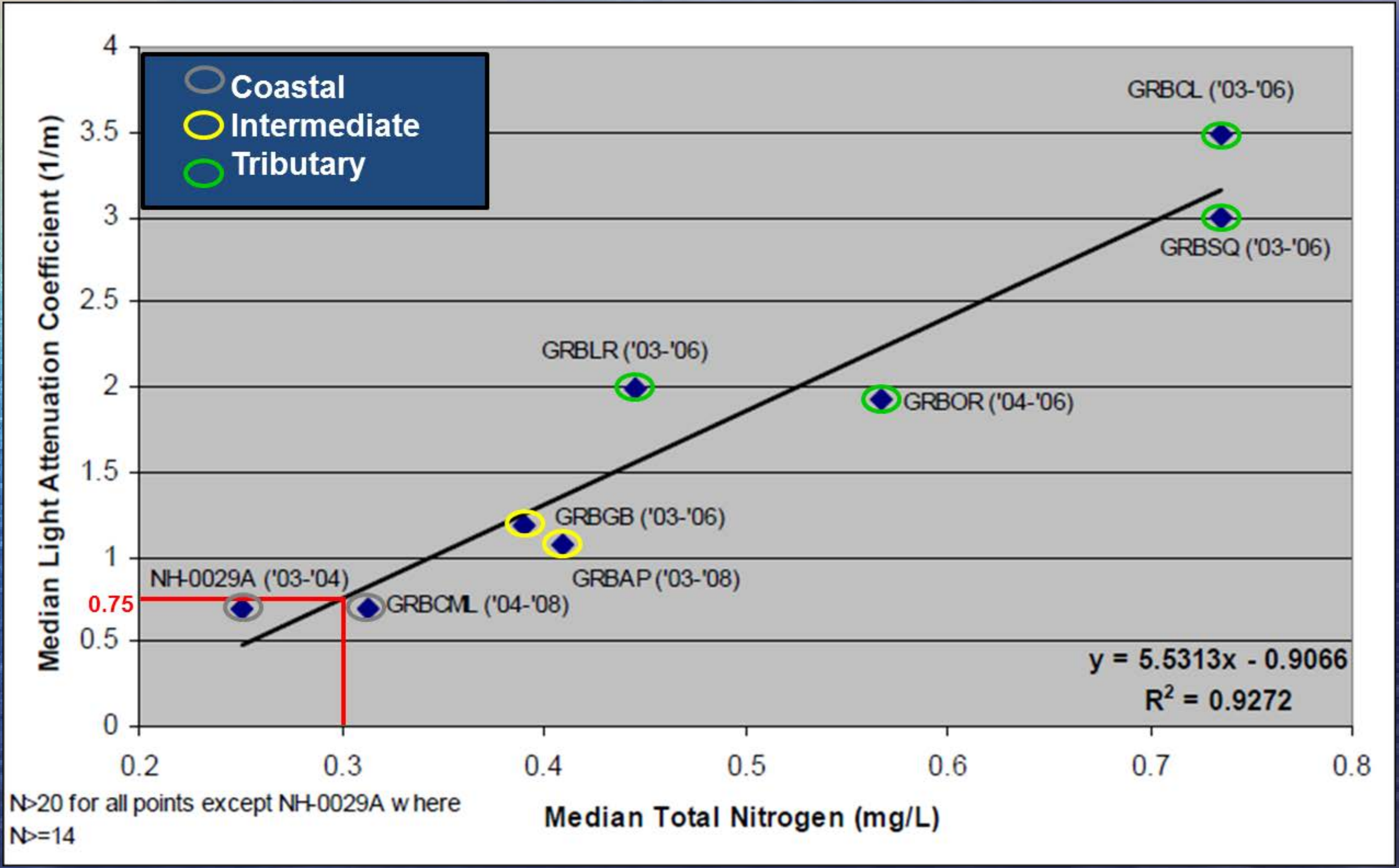
Recent Actions in Other Estuaries Relevant to Taunton Estuary

Great Bay Peer Review

Trend Monitoring Stations for Water Quality in the Great Bay Estuary (New Hampshire DES, 2009)



Estuary Evaluation Method Essentially Identical to Taunton Case



Peer Review Panel

Review of 2009 Numeric Nutrient Criteria

- Dr. Vic Bierman - system modeler
- Dr. Robert Diaz - DO
- Dr. Ken Reckhow - statistics
- Dr. Jud Kenworthy - eelgrass

Two of these experts previously used by MassDEP

GBE Peer Review Conclusions

The DES 2009 Report did not adequately demonstrate that nitrogen is the primary factor in the Great Bay Estuary because it did not explicitly consider any of the other important, confounding factors in developing relationships between nitrogen and the presence/health of eelgrass (Bierman, 18).

Scientific knowledge indicates a causal linkage between TN and DO, due to the growth and decomposition of algae. However, the data analysis does not support this TN-DO linkage in the NH DES data (Reckhow, 48)

The results in the 2009 report are not acceptable or reliable for setting nutrient criteria (Reckhow, 38).

These conclusions are consistent with prior MassDEP peer review assessments

Going Forward Cooperatively (as in New Hampshire)

- Defer issuance of permits pending the development of additional information; avoids regulatory confrontation
- Taunton will proceed with voluntary efforts to reduce nitrogen levels at their facility (major upgrade)
- MassDEP and the Coalition work together to plan and finance additional monitoring and research as recommended by the peer reviewers

EPA has decided to defer NH permitting for at least 18 months

Limitations at the Taunton WWTF

- Biological treatment process is at two elevations
- Upper treatment train handles 1/3 of plant flow
- Lower treatment train handles 2/3 of plant flow.
- Current treatment process provides nitrification only
- Limited land area for additional tanks and equipment
  - Primary clarifier
  - Anoxic reactors
  - Aerobic reactors
  - Denitrification filters
  - CSO mitigation

Possible Treatment Alternative TN Reduction

- PHASE I - 4-stage Bardenpho process
  - Can meet a TN of 5 mg/l (Seasonal Average)
  - New anoxic reactors in each treatment train
  - Additional aerobic volume
  - Fixed film media
  - Complete plant upgrade including electrical systems

- PHASE II (If Necessary) - Denitrification filters and an intermediate pump station required to meet TN of 3 mg/l

Nitrification Denitrification Costs

- WWTP Upgrade to meet 5 mg/l (Seasonal average)
- $40-$45 million Capital Costs
- Over 30% of the single family households will be paying over 2% of the median household income
- Estimated completion of construction Fall 2020

Discussion of Issues

- Response to Mayor's Questions
- Independent Peer Review of Sentinel Method
- Ability to Use Adaptive Management
- Update of Applicable DO Criteria
- Cooperative Data Collection and Analysis

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

Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators

Interim Report

Brian L. Howes
Roland Samimy
Brian Dudley

(MEP Technical Team)

For:

Massachusetts Department of Environmental Protection (DEP)

July21, 2003

Revised: September 16, 2003
Revised: December 22, 2003

DEP/SMAST Massachusetts Estuaries Project

Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators

Interim Report

B.L. Howes, R. Samimy & B. Dudley
MEP Technical Team

Approach to Site-Specific Thresholds

The "Massachusetts Surface Water Quality Standards" (314 CMR 4.00) establish quantitative and qualitative standards for the protection of surface waters in both inland waters and coastal marine systems. Although there are several quantitative criteria provided in the standards, no specific thresholds or criteria are provided for nitrogen as it relates to eutrophication and its associated ecological impact on the health of Massachusetts coastal embayments. The Water Quality Standards do provide qualitative standards for the control of eutrophication in all surface waters that firstly, require controls on both point and non-point discharges to control eutrophication or excessive growth of weeds or algae and secondly, allow for the development of site-specific limits necessary to control eutrophication and its impact on embayment health. The ultimate goal of the DEP/SMAST Massachusetts Estuaries Project is to not only to assess the current condition of 89 embayments in southeastern Massachusetts but, more importantly, to develop critical site-specific nitrogen thresholds that can be used as a management tool by the communities to identify corrective and protective measures needed both now and in the future. As a nutrient specific watershed management tool, the nitrogen thresholds and the process by which they are developed help communities focus implementation strategies on manageable (anthropogenic and subject to TMDL allocation process) sources of nutrients versus those that are naturally occurring.

In order to accomplish this goal the Estuaries Project must also provide a means to bridge the gap in the existing water quality standards by providing a translator between the current narrative standard and nitrogen thresholds (as they relate to the ecological health of each embayment) which can be further refined based on the specific physical, chemical and biological characteristics of each embayment. This report is intended to provide a detailed discussion of the issue and types of indicators that can be used, as well as propose an acceptable range of nitrogen thresholds that will be used to interpret the current narrative standard.

An essential component of the DEP/SMAST Massachusetts Estuaries Project (MEP) is the development of site-specific critical thresholds for the coastal embayments within the study region. While the qualitative nature of these thresholds will be common to almost all embayment systems, the quantitative thresholds will vary between and within embayments. Given that general thresholds (one size fits all) for embayments would have to be tailored to protect the most sensitive systems, this approach was rejected as it tends to "over manage" the less sensitive systems. The result of "over management" is the addition of significant additional and unnecessary costs to municipalities and the Commonwealth relative to the implementation of management alternatives. In contrast, site-specific thresholds are developed on the basis of specific basin configuration, source water quality and watershed spatial features for each embayment. By being tailored to each estuary's specific characteristics, the results are more accurate and require a smaller "safety factor" in the critical nitrogen targets used for developing nitrogen management alternatives. The site-specific approach has been recommended by the USEPA in developing Nutrient Criteria for estuaries (USEPA 2001). The MEP has already determined that total nitrogen thresholds based upon the same habitat quality can vary more than 50%, due to their specific oceanographic setting. This wide range greatly increases the need for site specific quantitative thresholds, and reinforces the cost savings projections of this approach.

Quantitative site-specific thresholds provide for the "best management" approach for each embayment, supporting both good stewardship and cost effectiveness. The development of these thresholds is a multi-part process that demands reliance on scientifically credible principles and approaches. In addition, the process needs to relate clearly to the established regulatory framework governing surface water quality management in the State of Massachusetts. The Estuaries Project Technical Team is developing these thresholds using a 3-step process, each step building upon the previous step and all aimed at producing a defensible and validated series of nutrient related embayment thresholds.

1. Definition and selection of key water quality indicators for Site-specific Threshold determination.
2. Draft (straw man) qualitative and quantitative Threshold levels
3. Calibration and refinement of Thresholds based upon embayment 1-20 analysis.

The purpose of this Interim report, as part of the threshold determination process, is to address steps 1 and 2 listed above which is to present the key water quality indicators, that will be used to develop nutrient thresholds and provide initial qualitative and quantitative thresholds that will be further refined with the collection of additional data and modeling. Additionally, this interim document has been developed to discuss how the indicators relate to state established surface and coastal water classifications as presented in the Massachusetts Surface Water Quality Standards. This document is the first step towards reconciling critical thresholds that take into consideration ecological sensitivities with the requirements of the State Water Quality Standards and the development of appropriate Total Maximum Daily Loads (TMDLs).

Though the execution of the Estuaries Project does culminate in the development of nitrogen TMDLs for the embayments under investigation, the determination of whether or not the State Water Quality Standards can be attained for a specific embayment is not achieved at this point. Rather, attainability of the water quality standard evolves from the process of implementing the critical nutrient threshold and associated TMDL. The TMDL is to state what the loading of nitrogen needs to be to meet the water quality standards while the phases of the implementation process will determine what may be naturally or economically/technically achievable as identified through comprehensive water resources planning. If it is apparent that natural conditions prevent attainment of water quality standards, or that the designated uses identified in the standards may not be an appropriate goal, then consideration might be given to revising the state classification of the embayment consistent with the Use Attainability Analysis (UAA) provisions of the Clean Water Act.

The water quality indicators presented herein are not meant to be a comprehensive list of all possible parameters. Rather the indicators selected are those that are either (a) an essential component of all estuarine habitat health criteria, (b) of proven utility in southeastern Massachusetts embayments, or (c) supported by the Linked Management Model Approach being used by the MEP. The goal of the Interim Thresholds document is to attempt to rank the indicators in importance as well as reach consensus as to the water quality indicators for which quantitative ranges will be reviewed in a subsequent version of the Thresholds document. Additionally, any ranges provided for critical parameters presented in Table 1 of this Interim Nutrient Thresholds document are for illustrative purposes only and will be made quantitative as possible based upon data collected under the Massachusetts Estuaries Project.

After initial water quality indicators are qualitatively and quantitatively defined the third step will be to compare those indicators to newly collected data and revise the thresholds where appropriate. This will be done after data has been collected for the initial 20 priority embayments. The evaluation and refinement of thresholds will continue throughout the conduct of the Estuaries Project. It is clear that the application of quantitative thresholds for each indicator may not be possible and some hybrid of qualitative and quantitative indicators is likely. However, the scope of the MEP will provide the needed field data collection to support thresholds development and the final refined thresholds will be fully scientifically defensible and a major product of the Estuaries Project.

Commonwealth Surface Water Quality Regulation and Classifications

The current Commonwealth Surface Water Quality Standards are presented in 314 CMR 4.05(4). The standards, presented in detail below, relate to both human health and ecological health. However, it is clear that nutrient related habitat quality is not a major focus of the present standards and that overall, the standards applicable to habitat criteria are qualitative assessments (except for D.O.) of a few general nutrient and habitat indicators and overarching statements of anti-degradation.

The anti-degradation provisions, simply stated, require that for all existing uses associated with a specific surface water body, water quality shall be maintained such that existing uses can be sustained. The regulations further require that certain high quality and significant resource waters be protected beyond the minimum national criteria. This requirement is especially true in cases where the character and value of the resource water cannot be adequately described or protected by traditional criteria. Eutrophication is specifically addressed in these anti-degradation provisions, although qualitatively.

The Commonwealth's water quality regulations also call for prohibition of new point source discharge of nutrients to lakes and ponds and the implementation of the highest and best practical treatment to control nutrients in existing point source discharges. Non-point source nutrient control is required at the level of best management practice. While the eutrophication provisions specifically address lakes and ponds, statutory requirements at both the federal and state level require the protection of all navigable waters, including coastal embayments and estuaries. Accordingly, appropriate management practices also must be employed to protect and preserve coastal resources.

The current "Massachusetts Surface Water Quality Standards" set forth classifications for coastal and marine waters. These classifications apply standards that are both quantitative and descriptive and, at a minimum, require "good aesthetic value". The three classes are SA, SB and SC. A description of each follows:

Class SA

As quoted from 314 CMR 4.05(4)(a) "These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas, they shall be suitable for shellfish harvesting without depuration (Open Shellfish Areas). These waters shall have excellent aesthetic value." The specific criteria for these waters are tabularized below:

Parameter	Standard
Dissolved Oxygen	Not less than 6.0 mg/L unless background conditions are lower; natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge
Temperature	Shall not exceed 85°F nor a maximum daily mean of 80°F.
PH	Shall be in the range of 6.5 through 8.5 standard units and not more than 0.2 units outside the normally occurring range.
Fecal Coliform	a. Waters approved for shellfishing shall not exceed a geometric mean MPN of 14 colonies/100 mL, nor shall more than 10% of the samples exceed an MPN of 43 colonies/100 mL. b. Waters not designated for shellfishing shall not exceed a geometric mean MPN of 200 colonies/100 mL, nor shall more than 10% of the samples exceed an MPN of 400 colonies/100 mL.
Solids	Shall be free from floating, suspended and settleable solids in concentrations of combinations that would impair any use assigned to this class, that would cause any objectionable conditions or that impair the benthic biota or degrade the chemical composition of the bottom.
Color and Turbidity	Shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.
Oil and Grease	Shall be free from oil and grease and petrochemicals.
Taste and Odor	None other than of natural origin.

Class SB

As quoted from 314 CMR 4.05(4)(b), "These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfish Areas). These waters shall have consistently good aesthetic value." The specific criteria for these waters are tabularized below:

Parameter	Standard
Dissolved Oxygen	Not less than 5.0 mg/L unless background conditions are lower; natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge
Temperature	Shall not exceed 85°F nor a maximum daily mean of 80°F.
PH	Shall be in the range of 6.5 through 8.5 standard units and not more than 0.2 units outside the normally occurring range.
Fecal Coliform	a. Waters approved for restricted shellfishing shall not exceed a geometric mean MPN of 88 colonies/100 mL, nor shall more than 10% of the samples exceed an MPN of 260 colonies/100 mL. b. Waters not designated for shellfishing shall not exceed a geometric mean MPN of 200 colonies/100 mL, nor shall more than 10% of the samples exceed an MPN of 400 colonies/100 mL.
Solids	Shall be free from floating, suspended and settleable solids in concentrations of combinations that would impair any use assigned to this class, that would cause any objectionable conditions or that impair the benthic biota or degrade the chemical composition of the bottom.
Color and Turbidity	Shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.
Oil and Grease	Shall be free from oil and grease and petrochemicals that produce a visible film on the surface of the water, impart an oily taste to the water or an oily or other undesirable taste to the edible portions of aquatic life, coat the banks or bottoms of the water course, or are deleterious or become toxic to aquatic life.
Taste and Odor	None in such concentrations or combinations that are aesthetically objectionable, that would impair any use assigned to this class, or that would cause tainting or undesirable flavors in the edible portions of aquatic life.

Class SC

As quoted from 314 CMR 4.05(4)(c), "These waters are designated as a habitat for fish, other aquatic life and wildlife and for secondary contact recreation. They shall also be suitable for certain industrial cooling and process uses. These waters shall have good aesthetic value." The specific criteria for these waters are tabularized below:

Parameter	Standard
Dissolved Oxygen	Not less than 5.0 mg/L at least 16 hours of any 24-hour period and not less than 4.0 mg/L at any time unless background conditions are lower; natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 50% of saturation due to a discharge
Temperature	Shall not exceed 85°F.
PH	Shall be in the range of 6.5 through 9.0 standard units and not more than 0.5 units outside the normally occurring range.
Fecal Coliform	Shall not exceed a geometric mean of 1000 colonies/100 mL nor shall 10% of the samples exceed 2000 colonies/100 mL.
Solids	Shall be free from floating, suspended and settleable solids in concentrations of combinations that would impair any use assigned to this class, that would cause any objectionable conditions or that impair the benthic biota or degrade the chemical composition of the bottom.
Color and Turbidity	Shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.
Oil and Grease	Shall be free from oil and grease and petrochemicals that produce a visible film on the surface of the water, impart an oily taste to the water or an oily or other undesirable taste to the edible portions of aquatic life, coat the banks or bottoms of the water course, or are deleterious or become toxic to aquatic life.
Taste and Odor	None in such concentrations or combinations that are aesthetically objectionable, that would impair any use assigned to this class, or that would cause tainting or undesirable flavors in the edible portions of aquatic life.

Additionally, the regulations apply additional minimum criteria to all surface waters. These are tabularized below:

Parameter	Standard
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.
Bottom Pollutants or Alterations	All surface waters shall be free from pollutants in concentrations or combinations or from alterations that adversely affect the physical or chemical nature of the bottom, interfere with the propagation of fish or shellfish, or adversely affect populations of non-mobile or sessile benthic organisms.
Nutrients	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication.
Radioactivity	All surface waters shall be free form radioactive substances in concentrations or combinations that would be harmful to human, animal or aquatic life or the most sensitive designated use.
Toxic Pollutants	All surface waters shall be free form toxic substances in concentrations or combinations that would be harmful to human, animal or aquatic life or wildlife. This includes consideration of site-specific limits, human health risk levels and accumulation of pollutants.

Of these general criteria, the nutrient and dissolved oxygen requirements relate most directly to the Estuaries Project; however, the aesthetic and bottom pollutant/alteration requirements must also be considered. Under this classification system almost all of the habitat health requirements are set forth under the “nutrient” parameter, which refers to both site-specific limits and control of eutrophication. This provides a mechanism for linking the current system with more detailed habitat health criteria thus providing a translator between the water quality standards and direct habitat health indicators.

Overall, the regulations present public health criteria that are generally quantitative while ecological health, as currently described in the surface water classifications, is essentially qualitative. One major reason for this difference is that public health is significantly controlled by disease prevention, and based on bacterial indicators (Fecal Coliform, and more recently Enterococcus). These indicators are relatively straight-forward to establish and support quantitative thresholds. Protection of ecological or habitat health is more difficult to develop given the complexity of biological systems and the diversity of potential indicators. In addition, it is difficult to couple habitat health to a single indicator.

In addition to the difference in approach of the regulatory standards for protection of the public versus ecological health of coastal embayments, there is a significant discontinuity between the spectrum of habitat qualities and the range of water quality classifications. In effect, the classes of water quality all represent systems with nutrient related health ranging from excellent to good. In contrast, the Commonwealth's embayments fall into 6 categories of nutrient related health, ranging from excellent to severely degraded with the upper 4 categories supporting some fish and shellfish species and likely acceptable under some circumstances (refer above). Reconciliation of the current classifications with a broader range of ecological health classes is a major challenge for the development of embayment nutrient related thresholds in the Commonwealth.

In the interest of providing more descriptive and understandable classifications, it is proposed to describe six classes of water quality ranging from Excellent to Severely Degraded. These classes ideally would be determined both by numerical standards or ranges for specific constituents and also by more qualitative indicators of ecological health. Specific parameters would include dissolved oxygen, organic and inorganic nitrogen, transparency, phytoplankton (as chlorophyll-a pigments), and temperature. Indicators of ecological health would include eelgrass distribution, macroalgal distribution and benthic animal populations. These criteria are developed in the sections below.

Habitat Indicators for Embayment Specific Threshold Determination

Assessment of embayment health and subsequent determination of critical nutrient thresholds capable of maintaining or restoring the ecological health for a specific embayment must be conducted relative to scientifically justifiable and agreed upon habitat measures. There are a wide variety of measures that give indication of the ecological health of an embayment. Some of the indicators are biological (eelgrass, macroalgae, benthic animals) while others are chemical (Dissolved Oxygen, organic and inorganic nitrogen, phytoplankton pigments, etc.), physical (water clarity, temperature) or geochemical (sediment characteristics). For the purposes of the Massachusetts Estuaries Project and the use of the Linked Nutrient Management Model Approach, habitat indicators that are of primary concern in gaging embayment health and nitrogen assimilative capacity are:

- plant presence and diversity (eelgrass, macroalgae, etc.)
- animal species presence and diversity (finfish, shellfish, infauna)
- nutrient concentrations (nitrogen species)
- chlorophyll concentration
- dissolved oxygen levels in the embayment water column

These indicators form the basis of an assessment of a system' s present health. When coupled with a full water quality synthesis and projections of future conditions based upon water quality modeling, site-specific thresholds can be developed for these systems. Additional information on temporal changes within each sub-embayment and its watershed further strengthens the analysis. Descriptions of these parameters as they relate to thresholds development are given below:

Biological Indicators:
Based on accepted estuarine principles, the best biological indicators of embayment health are those species that are non-mobile and that persist over relatively long periods if environmental conditions remain constant. The rationale in using such non-mobile and persistent species as indicators of overall system health is that these types of organisms integrate environmental conditions over seasonal and annual intervals. This approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate capture of environmental conditions difficult.

As a basis for preliminary nutrient (nitrogen) threshold determination, focus is placed on two major biological habitat quality indicators:

- Eelgrass vs. macroalgal distribution
- Benthic animal communities (presence and diversity)

Eelgrass is a sentinel species for indicating nitrogen over-loading to a coastal embayment as supported in the established literature (Short *et. al.*, 1995, Orth *et. al.,* 1983, Twilley *et. al.,* 1985). It is also a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. In nitrogen rich (over-loaded) systems, eelgrass distribution tends to be much less wide spread across an embayment and macroalgal presence typically increases. Eelgrass beds are routinely mapped state-wide for comparison to historic records (DEP, C. Costello) for determination of the stability of this resource and temporal trends in habitat quality. Temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing - new inlet) in nutrient enrichment. In addition to coverage information (presence or absence), the density of the eelgrass beds can be used to determine the role of this resource in system function. This latter density value allows for future tracking of changes in eelgrass bed health, which is frequently not possible from bed delineation alone.

Losses of bed area and/or thinning of beds (decreases in density) are generally both linked to nutrient enrichment. This linkage between eelgrass loss and nutrient enrichment needs to be corroborated on an embayment specific basis, as there are factors other than nutrients which have been linked to eelgrass declines (disturbance, disease, animal interactions, etc). The extent of areal or density loss, which represents a distinguishable ecological impairment, has not been fully quantified. In the case of loss of bed area the issue is clearer. Since eelgrass beds represent high quality estuarine habitat, in and of themselves, the loss of bed area represents impairment of estuarine function. In this case the issue is primarily the level of detection of bed loss using the best available technology, in general on the order of 10%. Loss of ecological function by decreasing density within a bed is harder to quantify and presents additional difficulties in acquisition of supporting data. It is likely that declines of 25% would be needed for detection within large embayment systems, but this is an area of present research.

In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of nutrient related habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. This approach has been accepted in the regulatory community particularly in relation to pollution (oil, metals, etc) effects on marine habitats. The MEP is following the approach used in the pollution related efforts where pollution tolerance of individual species allows their use as indicators. In the case of MEP, nutrient related tolerance (e.g. organic matter loading) is used instead of pollution as the primary factor.

Benthic animal communities associated with increasing nitrogen loading shift in response to the resultant increase in organic matter deposition to the sediments. The effect of organic matter loading is to increase organic matter content of sediments, and resulting increased sulfide concentrations. In addition, the level of sediment oxidation decreases, with reducing (sulfidic) conditions reaching the surface at the highest levels of organic input. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano, 1986, Pearson and Rosenberg, 1978) of a wide variety of species and a number of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the WHOI Nantucket Harbor Study (Howes et al. 1997). Assemblages are classified as representative of excellent or healthy conditions, intermediate in stress, or highly stressed conditions. Both the distribution of species and the overall population density are taken into account. Additional benthic community indices are also used where appropriate as detailed by the USEPA October 1996 Long Term Monitoring Assessment Research Report.

Chemical Indicators:
Dissolved oxygen (DO) is a critical indicator of nutrient over-enrichment and eutrophication. The frequency and duration of depletion of dissolved oxygen in bottom waters of embayments is critical to the structuring of habitat. The larger and longer the oxygen depletion, the more stressed the plant and animal communities. Short-term oxygen depletion during summer months can result in the loss of whole benthic communities and poor benthic productivity throughout the entire year. The challenge inherent to 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. Since D.O. modeling is generally imprecise as to the extent and duration of D.O. depletion in estuarine waters, the Estuary Project will not conduct modeling but rather, will deploy electronic sensor systems at critical locations within each estuary during July and August of the field data collection year. The sensors also measure temperature, salinity and chlorophyll-a.

Nitrogen is the critical determinant of habitat quality within shallow coastal embayments. Nitrogen in and of itself does not generally play a significant direct role in habitat health. Its action is primarily through the trophic sequence. Increased nitrogen results in higher phytoplankton production, hence organic matter load in waters and sediments. The higher organic matter load results in increased oxygen consumption and therefore an increased likelihood for bottom water oxygen depletion. Phytoplankton biomass and low oxygen negatively affect eelgrass health. Organic matter loading increases in embayments typically negatively impacts benthic animal communities. Therefore, nitrogen is the driving parameter in the sequence of:

N Load → Plant Production → Organic Matter Load → O_2 Uptake → Community Decline

Fixed nitrogen in embayments is primarily in the forms: nitrate, nitrite, ammonium, dissolved organic nitrogen and particulate organic nitrogen. The inorganic forms (nitrate, nitrite, ammonium) are directly available to support phototrophs, while the organic forms (dissolved organic nitrogen and particulate organic nitrogen) are the result of plant uptake and are composed of living and dead organic matter. In the shallow embayments of southeastern Massachusetts the particulate organic nitrogen is generally held within living and decaying phytoplankton. Since nitrogen is continually cycling between all of the major nitrogen forms, an assessment of total nitrogen is needed in order to gauge the level of nitrogen within an embayment and therefore its potential nutrient related health. Reliance on a nitrogen fraction, e.g. inorganic nitrogen, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants.

Physical Indicators:
Embayment water clarity serves as one of several critical physical indicators of embayment water quality and general system health. Clarity is a measure of dissolved and suspended organic and inorganic matter in the embayment water column. The organic matter of most interest relative to clarity relates to phytoplankton measured as chlorophyll-a pigments. The concentration of chlorophyll in the water column provides a quantitative assessment of phytoplankton blooms typically driven by nutrient loading to the embayment. As such, higher nutrient loading to a system typically leads to increased aquatic plant productivity that in turn is indicated by high concentrations of chlorophyll in the water column and reduced water clarity. The accepted method for measuring water clarity is by secchi disk. Along with measurement of secchi depth in the field, water samples are retrieved and analyzed for chlorophyll concentration in the water column. Low water clarity in combination with high chlorophyll concentrations becomes a powerful indicator of nutrient enrichment in an embayment and in therefore considered as primary measure to which critical thresholds are related for a specific embayment.

Temperature is an important indicator relating to system sensitivity to eutrophication through two processes. First, the solubility of oxygen is directly related to water temperature, with lower solubility at higher temperatures. Second, biological processes are positively related to temperature. Respiration rates (oxygen consumption) typically increase two- to three-fold for every $10^{o}C$ increase in water temperature. The result is higher rates of oxygen consumption from a smaller oxygen pool in summer. Due to these interrelationships with oxygen, warm waters will generally be more sensitive to the organic matter production resulting from nitrogen loading than will cold waters.

Sediment characteristics prove to be yet another indicator of embayment habitat health and a component in the development of critical nutrient thresholds. Sediment characteristics relate both to habitat for benthic animals and to recycling of nitrogen. Benthic animal communities vary with and also modify sediment characteristics. Key characteristics for benthic communities are organic matter content, grain-size and oxidation status/sulfide. The general paradigm is for organic-rich fine-grained sediments with a depauperate benthic community to be highly reducing/sulfidic. These conditions are typical of heavily organic matter loaded systems with periodic oxygen depletion of bottom waters.

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 water column heterotrophic processes. The result is that embayment respiration rates are typically many times higher than in the adjacent offshore waters. With periodic stratification of harbor waters, sediment metabolism plays a major role in bottom water oxygen declines (an ecosystem structuring parameter). In addition to “new” nutrients (nitrogen) entering the estuary from the surrounding watershed, nitrogen is 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, recycled nitrogen can account for about half of the nitrogen supply to phytoplankton blooms during the warmer summer months.

Nutrient Related Water Quality Indices:
Indices have been developed as an approach to simplifying complex and diverse data sets in order to focus on key classification issues. One such index, presented only as an illustration, was developed as part of the Buzzards Bay Monitoring Program, Baywatchers. The Bay Health Index was developed for the shallow embayments of Buzzards Bay (Costa *et al.*, 1992 and in press) and has been modified slightly using recent data (Howes *et al.*, 1999). The Index is based upon transparency (measured by secchi), nitrogen concentration, chlorophyll-a pigments, and oxygen levels (lowest 20% of samples). Best and worst average conditions for each parameter yield scores of 100 and 0, respectively. The ranges were selected based upon embayment data collected from Buzzards Bay. The ranges reflect a preliminary assessment of the relation of each factor to overall habitat quality. Therefore, the ranges do not relate to existing water quality classification numerics. The range (highest to lowest quality) for each parameter utilized to develop the Bay Health is as follows:

- Bottom water dissolved oxygen between 90% and 40% of air equilibration
- Transparency between 3 m and 0.6 m
- Total nitrogen between 0.28 mg N/L and 0.61 mg N/L, and
- Chlorophyll-a pigments between 3 μg/L and 10 μg/L

A refinement of this index with cross-comparisons to the biological community and sediment characteristic data may yield a useful simplifying mechanism for the integration of the nutrient related water quality data into the thresholds analysis.

Ideally, the Estuaries Project will be able to develop a habitat quality threshold index that incorporates all of the various key indicators.

Nitrogen Thresholds and Habitat Quality Classification

Nitrogen is a natural and necessary part of coastal ecosystems. If nitrogen levels are too low, the productivity of coastal embayments can be impaired. However, too much nitrogen loading to a coastal water body can have detrimental effects. At low to moderate levels of nitrogen loading shallow semi-enclosed embayments will have moderate to low phytoplankton levels, a high degree of light penetration, and oxygen levels close to equilibration with the atmosphere. These conditions support eelgrass beds and diverse benthic (bottom dwelling) animal communities and fish populations.

Addition of nitrogen to "healthy" low nitrogen systems will initially increase their productivity resulting in higher fish and shellfish yields. However, additional loading will begin to alter the ecological functioning, hence health of the ecosystem. While this process of nitrogen loading and ecological response is a continuum, there are key ecosystem changes that indicate a need for setting a nitrogen loading limit for the recipient system. The manifest change in the system makes it possible to set "threshold" nitrogen levels. Several decades ago, coastal ecologists put forward the concept of "assimilative capacity". Assimilative capacity for nitrogen is the level within the receiving waters that can be achieved without discernible ecosystem impairment or degradation. As nitrogen loading to coastal waters has increased, there has been a growing need to determine these thresholds for management purposes.

The major difficulty with determining a system's assimilative capacity is four-fold as follows:

(a) each embayment has its own capacity based upon its depth, flushing rate, surface vs. groundwater inflows, and sub-ecosystems (eelgrass, salt marshes etc.)
(b) coastal embayments within the temperate zone have a high degree of temporal and spatial variation, so that a large amount of data collection is required
(c) relatively small increases in water column nitrogen can result in significant ecological changes
(d) evaluations are presently through inter-ecosystem comparisons

Nitrogen Related Habitat Quality Classifications:
Despite the difficulties, the protection and restoration of coastal embayments from nitrogen overloading has required the development of approaches for determining nitrogen thresholds. While this effort is ongoing (e.g. USEPA TMDL studies, USEPA 2001), southeastern Massachusetts has been the site of intensive efforts in this area (Eichner *et al*.,1998, Costa *et al.*,1992 and in press, Ramsey *et al*., 1995, Howes and Taylor 1990, and the Falmouth Coastal Overlay Bylaw) . While each approach may be different, they all focus on matching changes in nitrogen loading from watersheds to embayments with the goal of projecting the level of increase in nitrogen concentration within the embayment waters. Each approach depends upon estimates of circulation with the embayment; however, few directly link the watershed and hydrodynamic models and virtually none include internal recycling of nitrogen (as was done in the present effort). Therefore, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" remains somewhat subjective. In the present effort we have used the site-specific data (specifically, the gradient in N concentration) and ecological health within the

embayments monitored by Falmouth Pondwatch to "tune" general thresholds used by the Cape Cod Commission, Buzzards Bay Project and Massachusetts State Regulatory Agencies.

Since the nitrogen levels in receiving water bodies increase gradually with the incremental development of coastal watersheds, their health undergoes a gradual decline considered cultural eutrophication. The gradual ecological changes within estuarine systems take the form of increasing phytoplankton production and epiphyte production and reducing light penetration. These processes reduce the habitat quality for both benthic animals and eelgrass, but during initial stages of these processes or in "borderline" cases, eelgrass beds persist and benthic animal communities may actually increase due to increased food supply. At higher nitrogen levels, eelgrass beds will become less dense and will begin to disappear from the deeper areas and benthic animal communities will begin to shift from dominance by stable diverse deep burrowing and suspension feeding invertebrates to less diverse deposit feeding animals. At even higher nitrogen levels, the beds will disappear completely and benthic communities will shift to shallow burrowers with short-lived opportunistic life histories. At higher levels of eutrophication, benthic communities may be completely absent during the warmer months, particularly August) due to associated nutrient related effects on bottom water oxygen depletion.

Since the presence of eelgrass beds in coastal environments is a generally accepted criterion of high quality conditions, the level of nitrogen at which eelgrass beds become impacted can be considered one type of first level "threshold". For example, nitrogen levels resulting in a clear reduction in eelgrass density or coverage, or where eelgrasses are heavily covered with epiphytes, yields a threshold that can be determined for separating "good" from "moderately impaired" conditions. Benthic infaunal communities in high quality conditions will be diverse and stable and dominated by deep burrowing deposit feeders and suspension feeders. This environment is also capable of supporting economically important benthic animals such as scallops and various clams and blue crabs. Crossing this initial threshold, shifts the benthic community to more deposit feeders and less dominance by deep burrowers.

A second level threshold, "moderate impairment", is the point at which all or almost all of the eelgrass has disappeared, but where there are still diverse and productive benthic communities. These systems are characterized by higher nitrogen concentration, periodic moderate blooms of phytoplankton, and oxygen concentrations that show some moderate depletion. The benthic communities in these situations are typically moderate burrowing deposit feeders with some filter feeders. However, these conditions are still capable of supporting productive economically important bivalves (e.g. *Mercenaria, Mya, Crassosterea*), but not generally scallops. Below the second level threshold there has been a shift in dominance towards opportunistic species (small, high reproductive rate, rapid development, etc) from stable or equilibrium species (large, low reproductive rate, slow development, etc).

A third level threshold along the nitrogen impact continuum is the point at which the habitat quality is "significantly impaired". Significant impairment means the loss of diverse animal communities and replacement by smaller, shorter-lived animals of intermediate burrowing capabilities. The benthic communities in these areas typically are dominated by small "worms" (polychaetes and oligochaetes). However, shellfish beds may still be productive, but generally only those species which can withstand periodic hypoxia. Phytoplankton blooms are typical, but oxygen levels do not generally fall below 4-5 mg/L. Macro-algae may be present.

The final level of nutrient related water quality degradation is “Severe Degradation”. Under these conditions, algal blooms are typical with chlorophyll-a levels generally >20 μg/L, oxygen depletions to hypoxic levels are common, there are periodic fish kills, and macro-algal accumulations occur with both ecological and aesthetic impacts. In these regions, the benthic communities contain only a few species and may be virtually absent periodically during summer months. Under these conditions the benthos has lost most of its ecological resource value.

In addition, we also considered an “Excellent Quality” condition, which clearly can support dense eelgrass and possibly scallops. This classification typically has high dissolved oxygen (greater than 90% of air equilibration), low phytoplankton (chlorophyll a <3 μg/L), and high water transparency (secchi >3 meters). These types of conditions are typical of the source waters of Vineyard Sound, Buzzards Bay, and within the scallop areas of Nantucket (Howes *et al.*, 1997).

Relationship of Surface Water Quality Standards to Nitrogen Classification

The concept of Water Quality Standards can be difficult to grasp given that waterbodies are classified based upon the level of quality the system "should be maintained at" and not the systems current level of quality. As such, a system that can achieve the highest quality waters, for example with full eelgrass coverage, clear water, diverse animal populations and the absence of phytoplankton and macroalgal blooms would be classified SA. This classification would be given even if the water body is presently showing periodic hypoxia and large algal accumulations. In essence the classifications are functionally a management "target" and represent resource conditions that restoration and conservation projects should attain.

Water quality classifications need to account for both the level of water quality (both high and low) and the frequency of departures from high water quality. A system which is generally showing high quality conditions, but has brief periodic declines in key parameters may still be classified SA or SB based upon the eelgrass or animal criteria. In contrast, systems that show long periods of poor water quality will be impaired and the duration and level of the poor water quality can be used to determine the degree of impairment. It is important to stress that not all systems can support conditions consistent with SA or SB targets. Some systems are structured in a manner that they are very sensitive to nitrogen inputs and as a result will appear degraded even without anthropogenic contributions. These systems are naturally nutrient enriched and some may even sustain eutrophic conditions to the level of seasonal anoxia of bottom waters. Frequently, these systems can be identified by their basin configuration and tidal exchange, but not always.

A mainstay of Water Quality Classification should be the use of multiple criteria and the pre-eminence of ecological indicators over individual parameters. For example, dissolved oxygen levels generally are highly variable in estuarine systems. In addition, the development of new instrumentation for continuous recording of D.O. increases the likelihood of detecting low frequency, short-term oxygen depletions, which may occur periodically in high quality systems. Integrated evaluation of parameters, like D.O., with ecological indicators like eelgrass distribution, provides the most accurate approach to classification.

It is not possible at this time to put quantitative nitrogen levels on each Water Quality Class. In fact, initial results of the Massachusetts Estuaries Project (Chatham Embayment Report 2003) indicate that the total nitrogen level associated with a particular ecological response can vary by over 1.4 fold (e.g. Stage Harbor versus Bassing Harbor in Chatham MA). Although between embayments nitrogen criteria may be different, it does appear that within a single embayment a consistent quantitative nitrogen criterion can be developed. However, there is sufficient information to provide qualitative description and to provide quantitative examples from a detailed case study described below. This approach has been followed in the proposed SA, SB and "Impaired" Classifications detailed below:

Nitrogen Threshold Case Study:
The difficulty in developing a nitrogen threshold is linking nitrogen concentrations to the more diagnostic biological and chemical indicators of habitat quality. The results of three attempts at nitrogen thresholds determination for three Cape Cod embayments are shown in **Table 1**. The

specific values are from an SMAST Case Study of Great, Green and Bournes Ponds on Cape Cod and application of Cape Cod Commission (Eichner *et al.*, 1998) and Buzzards Bay Project/MCZM (Costa *et al.*, 1992 and in press) approaches. In addition, information on eelgrass distribution and fish kills was developed from a long-term data set developed by Falmouth Pondwatch. While the specific values will change based upon site-specific data, the general approach and rationale for each of the classifications of nitrogen based water quality thresholds should have region-wide application.

Table 1. Nitrogen thresholds and coastal water classifications for refinement by the Massachusetts Estuaries Project. Threshold values need to be site-specific, the values presented are for Great, Green and Bournes Ponds in the Town of Falmouth. Abbreviations: CCC – Cape Cod Commission, BBP/MCZM – Buzzards Bay Project/ Massachusetts Coastal Zone Management, ND – not determined. Values are long-term (>3 yr) average mid-ebb tide concentrations of total nitrogen (mg/L) in the water column.

Classification of N based water quality	Trophic classification	SMAST[1]	CCC	BBP/MCZM	314 CMR 4.05(4) Classification
Excellent	Oligotrophic	< 0.30	ND	ND	SA
Excellent/Good	Oligo to Mesotrophic	0.30 – 0.39	< 0.34	< 0.39	SA
Good/Fair	Mesotrophic	0.39 – 0.50	0.34 – 0.39	0.39 – 0.44	SB
Moderate Impairment	Mesotrophic to Eutrophic	0.50 – 0.70	ND	ND	Impaired
Significant Impairment	Eutrophic	0.70 – 0.80	ND	ND	Impaired
Severe Degradation	Hyper-Eutrophic	>0.80	ND	ND	Impaired

SA waters: (a) suitable for shellfish harvesting without depuration, (b) excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation, (c) excellent aesthetic value.

SB waters: (a) suitable for shellfish harvesting with depuration, (b) habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation, (c) consistently good aesthetic value

1 The nitrogen values presented were developed as part of the Ashumet Valley Plume Nitrogen Management Project for the Town of Falmouth and AFCEE by MEP Tech Team members B.L. Howes and J.R. Ramsey. These values are preliminary and need refinement by the MEP. Note that classification is by sampling location not full estuary, since each system shows a nitrogen gradient from headwaters to inlet.

SA Classification :

SA Waters are those of Excellent and Excellent/Good Health in shallow depths. These have been separated since Excellent Health SA waters are generally NOT found within enclosed or semi-enclosed waterbodies, but are more generally found in nearshore and offshore open coastal waters (i.e. bays or ocean). Excellent/Good Health SA waters are those of high quality within enclosed or semi-enclosed coastal basins (i.e. embayments). A preliminary attempt at integrating quantitative and qualitative information on the key indicators (based upon the case study) is given in the descriptions that follow:

Excellent Health:
Nitrogen levels below 0.30 mgN/L are typical of near shore Buzzards Bay (Howes *et al.*, 1999, Costa *et al.*, 1992 and in press), Vineyard Sound (Howes and Goehringer, 1996) and the scallop producing areas of Nantucket (Howes *et al.*, 1997). Waters with these nitrogen levels typically have oxygen levels greater than 6.0 mg/l and only small oxygen depletions, generally not less than 90% of air equilibration. Chlorophyll-a pigment levels are typically less than 3 μg/L and transparency (secchi depth) greater than 3 meters **(Table 1).** These coastal waters all support dense eelgrass beds and may have scallops. Macroalgae is generally not present. Fish kills are not observed. Benthic animal communities are diverse and stable and consist of moderate to deep burrowing forms with some suspension feeders. Communities dominated by larger long-lived forms are the norm, with opportunistic species only rarely present. Average nitrogen concentrations in near shore Vineyard Sound are 0.29 mg N/L. These conditions represent the "best" quality waters that the tributary embayments can attain.

Excellent to Good Health:
Excellent to good nitrogen related water quality conditions show some enrichment over offshore source waters of Vineyard Sound, with some possible (but hard to quantify) decline in quality. Eelgrass beds are present, macroalgae is generally non-existent but in some cases may be present, benthic animal diversity and shellfish productivity are high, oxygen levels are generally not less than 6.0 mg/l with occasional depletions being rare (if at all), chlorophyll-a levels are in the 3 to 5 μg/L range. The Cape Cod Commission concluded that the threshold of nitrogen enrichment, which is protective of embayment habitat quality, is "background" plus 0.05 mg N/L, the Buzzards Bay Project using a similar approach determined "background" plus 0.10 mg N/L. Existing data indicates that there are embayments where each criterion (+0.05 or +0.10 mg N/L) is most appropriate. It is equally clear that +0.05 mg N/L is more protective of the embayment health. The CCC and BBP thresholds are <0.34 mg N/L and <0.39 mgN/L, respectively.

In the Case Study embayments, additional data was evaluated to refine the threshold. First, near the inlet in Bournes Pond, nitrogen levels average 0.39 mg N/L and by the above criteria the location supports good habitat quality. Second, monitoring of West Falmouth Harbor indicates that 0.35 mg N/L supports eelgrass beds and good habitat quality. As concentrations rose at the Inner Harbor Stations to levels above 0.40 mg N/L, with the entry of the Wastewater Treatment Facility nitrogen plume, eelgrass beds began declining and localized macro-algal accumulations have been reported (G.R. Hampson, personal communication). In addition, areas within Clarks Cove (sub-embayment of New Bedford Harbor), which support productive shellfish beds, but have had some loss of eelgrass beds, exhibit total nitrogen levels of approximately 0.4 mg N/L. Similarly, analysis of the Nantucket Harbor System indicated that while in the deep basins moderately stressed animal communities (e.g *Mediomastus, Streblospio, Ampelisca*, etc) and moderate oxygen depletions were occurring above 0.35 mg N/L, in the shallower regions (<2.5 meters) good conditions persisted to 0.38 mg N/L (Howes *et al*., 1997). These higher quality regions were dominated by larger filter feeding and deep burrowing forms (e.g. *Spistula*, *Parapionosyllis*, *Sphaerosyllis*, etc). Based on existing regional data, there is a range of threshold values for the critical differentiation between water quality classifications. For the case study, total nitrogen levels of 0.30-0.39 mg N/L were used to designate "excellent to good" quality areas.

Both categories of "excellent" and "excellent to good" are considered equivalent to the state water quality classification of SA.

SB Classification :

Good to Fair Health:
Similar to the threshold for Excellent to Good Quality areas, the upper limit where "good" becomes "fair" is somewhat broad and hard to define. This is clearly a subjective point, as there is no clear ecological principal that can be used for reference. Generally, however, the conditions identified above in the excellent to good category are present in that benthic animal diversity and shellfish productivity are high, oxygen levels are generally not less than 5.0 mg/l with depletions to <4 mg/L being infrequent, chlorophyll-a levels are in the 3 to 5 μg/L range and nitrogen levels are in the 0.39 - 0.50 range. The only difference for this category is changes in eelgrass and macroalgae, although there is generally a shift away from suspension feeding to moderate depth deposit feeders. There may also be some indicators of enrichment (*Ampleisca, Mediomastus*). In the "good to fair" category eelgrass is not present (it would still be considered SA water body if historical records document that eelgrass was present in the past or, in the case of insufficient documentation, if potential conditions are such that eelgrass should be present) and macroalgae is not present or present in limited amounts even though a good healthy aquatic community still exists. Potential for satisfactory water column conditions such that eelgrass community could be supported is determined using best professional judgment taking into consideration factors such as depth, wave action, and sediment type as discussed in the *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat Based Requirements and Restoration Targets,* EPA 903-R-00-014, December 2000.

This category is considered equivalent to the state water quality classification of SB.

Impaired Categories

Moderately Impaired Health:
Similar to the threshold for "Good to Fair" Quality areas, the upper limit where "moderate impairment" becomes "significant impairment" is somewhat broad. Once again this is clearly a subjective point, as there is no clear ecological principal that can be used for reference. We can then define the threshold to "Significant Impairment" used for this evaluation as the nitrogen level where there is loss of diverse animal communities and replacement by smaller, shorter-

lived animals of intermediate burrowing capabilities. Shellfisheries may shift to more resistant species. Oxygen levels generally do not fall below 4 mg/L, although phytoplankton blooms raise chlorophyll a levels to around 10 μg/L. Eelgrass is not sustainable and macro-algae accumulations occur in some regions of the embayment.

In the Case Study, embayment regions supporting total nitrogen levels >0.5 mg N/L were clearly impaired. The lower Green Pond basin has total nitrogen concentrations at 0.50 mg N/L, and has lost its eelgrass beds over the past decade. Within West Falmouth Harbor eelgrass loss was lost at nitrogen levels about 0.4 mg N/L. Eelgrass within the Great, Green, and Bournes Pond systems is generally lost also at the ca. 0.40 mg N/L level, which is at the SA/SB boundary. The generally high resource quality of SB waters for shellfish, finfish, recreation and aesthetics is generally maintained to the 0.50 mg N/L level. However, in areas of these systems where nitrogen levels exceed 0.5 mg N/L, animal communities decline and macroalgal accumulations begin to effect aesthetic quality. These systems tend to be relatively consistent and still maintain many resource values between 0.50 – 0.70 mg N/L.

Significantly Impaired Health:
The higher levels of ecological impairment from nitrogen enrichment relate to systems or regions of systems that are “Eutrophic”, 0.60/0.70 mg N/L. The upper end of this category relates to “Severe Degradation” or “Hyper-Eutrophic” conditions. This upper end can be seen in the Buzzards Bay Monitoring Program results as 0.80 mg N/L. The level of nitrogen related to Significant Impairment supports large phytoplankton blooms (chlorophyll a of approximately 20 μg/L) such as seen in impacted environments as Eel Pond in Mattapoisett, Slocums River, and Little River. Within Great, Green, and Bournes Ponds, concentrations of approximately 0.7 – 0.80 mg N/L show conditions of clear degradation of ecological function. The transition from “significant impairment” to “severe degradation” appears to be in the 0.80-0.90 mgN/L range. However, the transition is not crisp, but somewhat broad. This is clearly a subjective point, as there is no clear ecological principal that can be used for reference associated with stressful oxygen conditions, major phytoplankton blooms, and absence of eelgrass. Significantly impaired waters will have periodic hypoxia, loss of diverse benthic animal populations, and periodic phytoplankton blooms. These systems do not contain eelgrass and have macroalgal accumulations and water quality declines showing loss of aesthetic value. At higher levels, periodic fish kills, significant macro-algal accumulations, and aesthetic (odor) problems are observed, indicative of “severely degraded” conditions. Under these conditions benthic communities are dominated by shallow dwelling opportunistic species (e.g. *Capitella, Streblospio, Solemya,* etc). Diversity (H’) and Eveness (E) are low. The range of 0.60/0.70 to 0.80 mg N/L is indicative of conditions where stress tolerant species persist in the Case Study Systems.

Severely Degraded:
This classification is consistent with Hyper-Eutrophic conditions, where periodic complete or near complete loss of oxygen occurs periodically in bottom waters. Large and pervasive macro-algal accumulations observed, generally each summer. Periodic fish kills occur and benthic communities are often nearly absent during the warmer months or are composed of only a few species of the most stress tolerant (opportunistic) species. Severely degraded or Hyper-eutrophic systems are identified both by their level of degradation and the consistency of their poor water

quality (i.e. the systems are not just periodically poor, but are regularly poor throughout most of the warmer months). The levels consistent with this definition are total nitrogen values >0.80 mg N/L.

Habitat Quality Classification Issues to be Resolved

In addition to refining the key indicators to be used in embayment specific habitat quality classifications and thresholds (as discussed above), other classification issues also need to be resolved. Major issues associated with the development or application of habitat thresholds that have been identified to date are as follows:

- Integration of multiple indicators which may show different results.
- Thresholds for Embayments versus salt marshes
- Upper versus lower embayment thresholds
- Awareness of Stable versus Transitional Habitat Quality

Variation in multiple indicators:
The proposed threshold approach by the Estuaries Project will use multiple indicators ranging from chemical and physical indicators to community (biological) features. It is certain that on occasion, various indicators will recommend different habitat classifications. When this situation occurs, the present approach is to weight the biological community indicators or key structuring indicators over some of the more variable indicators. For example, the documented rapid loss of eelgrass, rise of macroalgae and periodic oxygen depletion would be stressed over water column chlorophyll levels suggestive of Excellent Quality Habitat. The general procedure at present is to weight those factors that are more integrative of the environment over those which are more variable and therefore may not be adequately captured by monitoring.

Embayments versus Salt Marshes:
Several of the estuaries within the Estuaries Project region are predominantly salt marsh. While the general indicators used for classifying health and developing thresholds are similar between embayments and tidal marshes, the nitrogen tolerance of these 2 types of marine systems is very different. Embayments are generally nitrogen sensitive and show habitat quality declines at relatively low levels of ambient nitrogen. In contrast, salt marshes are very tolerant of nitrogen loading to both the emergent vegetation and to the creek bottoms. These differences must be accounted for as the Estuaries Project determines loading tolerances for system management.

Upper versus Lower Embayment Thresholds:
Given that nutrients typically enter estuaries at the upper most regions that are the most poorly flushed regions, there is generally a gradient in habitat quality from the headwaters to the tidal inlet. The result is that both the classification of different regions of the same estuary will differ as will their tolerance to nitrogen inputs. In many systems the lower regions of an embayment can assimilate higher nitrogen loads without a decline in habitat quality compared to upper regions. Therefore, a single estuary may have several nitrogen threshold levels throughout its tidal reaches. This pattern also occurs in embayments with multiple “branches” where each “branch” may have its own nutrient gradient.

When developing critical nitrogen loading thresholds, the nitrogen inputs from both the surrounding watershed and that transported in tidal flows from other segments of the same estuary need to be addressed.

Stable versus Transitional Habitat Quality:
In all classification and threshold analysis there needs to be an awareness that the conditions during the data gathering may not be in steady state. For example, there may be water quality conditions non-supportive of eelgrass beds, yet beds are present with high coverage. This has occurred in situations where nitrogen loads have increased at a rate faster than the rate of response of eelgrass distribution. In the case of eelgrass, several years may be required to fully manifest a shift in distribution in response to a rapid increase in nitrogen loading. As a result, the Estuaries Project is constantly seeking additional historical data from which to determine whether systems are relatively stable (on a 10 year interval) or in transition.

Further reconciliation of the existing Massachusetts Surface Water Quality Standards with the more ecologically oriented proposed habitat quality classifications will be needed. This is particularly evident with regard to specific indicators as well as the more qualitative nature of the state standards when addressing ecological state.

Summary

This interim report documents the progress made on steps one and two of a three- step process for developing site-specific nutrient criteria. The first step was the definition and selection of components for site-specific threshold determination. The components include State Water Quality Standards and embayment habitat indicators (biological, chemical, and physical). The second step was the development of draft qualitative and quantitative threshold levels. Threshold levels are proposed for six general water quality categories: excellent, excellent/good, good/fair, moderate impairment, significant impairment, and severe degradation. These initial levels (thresholds) will be used to interpret, or translate, habitat quality to narrative nutrient criteria in the State Water Quality Standards. The last step of the process will include calibration and refinement of thresholds, based on the detailed analysis of embayments, and the development of individual site-specific criteria.

Before the final criteria are established, several habitat quality classification issues need to be resolved, including, but not limited to: variation in multiple indicators, embayments versus salt marsh habitat, upper versus lower embayment thresholds, and stable versus transitional habitat quality.

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DEP #2004-04/604
DEP #2005-05/604
DEP #2006-04/604

Summary of Water Quality Monitoring Program for the Mount Hope Bay Embayment System (2004 – 2006)

(Final August 16, 2007)

Mt. Hope Bay – Estuarine Water Quality Monitoring 604(b) Grant

Submitted to:

MA Department of Environmental Protection

By:

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Roland Samimy

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

For:

Southeastern Regional Planning and Economic Development District (SRPEDD)

and the

MA DEP 604(b) Program

Summary of Water Quality Monitoring Program for the Mount Hope Bay Embayment System (2004 – 2006)

Mt. Hope Bay – Estuarine Water Quality Monitoring
(DEP #2004-04/604, #2005-04/604, #2006-04/604)

Submitted to: MA Department of Environmental Protection

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In fulfillment of Grant Requirements per funding from the U. S. Environmental Protection Agency to the Massachusetts Department of Environmental Protection under Section 604(b) Water Quality Management Planning Grant. Start Date: 15 April 2004. These data were collected strictly for the purpose of water quality research under a contract between the University of Massachusetts-Dartmouth and the Massachusetts Department of Environmental Protection (MassDEP) and as such are jointly owned. The University of Massachusetts – Dartmouth does not warranty the data for any other purpose than its original intent. Any other use of these data is prohibited without the written permission of both the University of Massachusetts-Dartmouth and the Massachusetts Department of Environmental Protection.

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1.0 BACKGROUND AND OVERVIEW:

The project goal was to collect and analyze water samples and associated field parameters relevant to the nutrient related water quality of the Mount Hope Bay – Taunton River System. This water quality monitoring effort is a collaborative effort between the Coastal Systems Program (CSP) within the University of Massachusetts – Dartmouth, School of Marine Science and Technology and the Southeastern Regional Planning and Economic Development District (SRPEDD) whereby the CSP and SRPEDD assembled a couple water sampling team trained and coordinated by University of Massachusetts – Dartmouth, School of Marine Science and Technology (SMAST), Coastal Systems Laboratory Staff under the direction of Sara Sampieri and Jen Antosca (field oversight) or Dale Goehringer (logistics coordination). Each water sampling team was responsible for collection of water samples at assigned sampling stations with logistical support by SMAST. Personnel from the Coastal Systems Laboratory within SMAST were also involved in the field sampling in order to assist in the collection of samples and insure proper transport and delivery of samples to the Coastal Systems Analytical Facility where chemical assays were performed.

The water quality data collected by the combined efforts of each sampling team is required for application of the Linked Watershed-Embayment Approach of the Massachusetts Estuaries Project (MEP). All embayments undergoing MEP analysis require a minimum of three years of high-quality water chemistry and field data related to nitrogen dynamics. Although there is some existing water quality data that may be incorporated into the Estuaries Project approach, a complete water quality monitoring effort must be implemented in order to satisfy the full water quality monitoring data requirements of the MEP. In order to initiate the needed data collection for the Mt. Hope Bay – Taunton River Estuarine System to support entry into the Estuaries Project and thereby allow full evaluation of protective measures, the SRPEDD received DEP 604(b) funding support for collection, processing and analyses of water samples from the overall embayment system. In total, three grants were obtained allowing water quality data collection at the estuarine stations during the summer of 2004, 2005 and 2006, as well as stream flow and water quality data collection initiated in the spring of 2004 and continuing to present. Stream gaging and water sample collection was begun on the Taunton River and 4 tributary streams discharging into the Taunton River under the first 604(b) grant (2004-04/604). Data collection efforts on those 5 surface water inflows to Mt. Hope Bay were completed under the second 604(b) grant (2005-04/604). Data collection on the three remaining surface water inflows to Mt. Hope Bay were initiated in the spring of 2006 under the third 604(b) grant (2006-04/604) and are on-going for approximately 6 more months into the future. A locus map is provided as Figure 1.

Samples and field data were collected from 22 marine and 5 stream sample stations in the Mt. Hope Bay – Taunton River Estuarine System, during 6 sample rounds from June through mid-September, 2004 (DEP#2004-04/604), 2005 (DEP#2005-04/604) and 2006 (DEP#2006-04/604). Marine stations were sampled at approximately two-week intervals during the falling tide (targeting the 2 hours before and after mid-ebb) during the early morning hours (6-9 A.M.). Streams with tidal influence were sampled at ebb slack tide, independent of time of day. Stream samples were collected on a weekly basis for the entire stream gage deployment period on each surface water system. Sampling was conducted on the marine stations June through mid-

September in order to focus on what is typically the period of poorest nutrient related water quality. Sample stations were located by Global Positioning System (GPS, see detail below) and on-shore landmarks as appropriate during an initial survey with SMAST staff.

At each marine sampling location (MHB 1-21, MHB-DO, water samples were collected for dissolved oxygen by Winkler titration (Hach or YSI 85 meter, see detail below) and temperature. Salinity/specific conductance were measured in the Coastal Systems Laboratory. Sampling teams with SMAST Staff aboard used the YSI for profiling of D.O., temperature and specific conductance, as well as collecting water with a Niskin sampler for D.O. by Winkler Titration and temperature by dial thermometer (Surface and Bottom). A Secchi Disk was used to determine light penetration at each site. Water samples for nutrients and chlorophyll a were collected using a 2.2 liter Niskin Sampler at surface, middle and bottom water depths at most stations due to the large total depths at most stations. At shallower stations, water samples were obtained from either surface and bottom depths or, in the case of very shallow stations, only a middle depth.

At each stream sampling location (MHB-A,B,C,D,E) weekly water quality samples were collected for approximately 16 months. Water samples were collected by SMAST Staff at slack low tide. Whole water samples and filtered samples (0.45 um) were collected at each stream. The stream gauges were downloaded at 1 to 1.5 month intervals.

SMAST received all water samples within 6 hrs of their collection and conducted chemical analyses: nitrate+ nitrite, ammonium, particulate and dissolved organic nitrogen, and ortho-phosphate, chlorophyll *a* and pheophytin, particulate carbon and TSS for all samples and total phosphorus for stream samples. The School for Marine Science & Technology Coastal Systems Analytical Facility (Dr. Brian Howes, Program Manager and Sara Sampieri, Analytical Facility Manager, 508-910-6352) performed all chemical assays under their laboratory SOP and Quality Assurance Plan procedures.

The estuarine watercolumn data for 2004, 2005 and 2006 and stream data for gage locations MHB-A,B,C,D,and E have been incorporated into this report. Results of the stream gaging effort for the gage locations MHB-F,G and H as supported by DEP #2006-04/604 will be submitted to the MassDEP at the end of the grant in the form of a Technical Memorandum. The discussion includes the sampling undertaken, discussion of nutrient related water quality spatial distribution (Section 3.1), as well as flow and nutrient levels in freshwater inputs (Section 3.2). The raw data is presented in electronic format. It is important to note that the major focus of this effort is to support future MEP analysis, which will include a complete water quality and habitat quality assessment. However, based upon the available data it was possible to provide a preliminary assessment of the current status of the Mt. Hope Bay – Taunton River Estuarine System relative to nutrients.

Mt. Hope Bay and Taunton River Estuarine Monitoring
DEP #2004-04/604, #2005-05/604 and #2006-04/604
Coastal Systems Program-SMAST/SRPEDD Collaboration

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

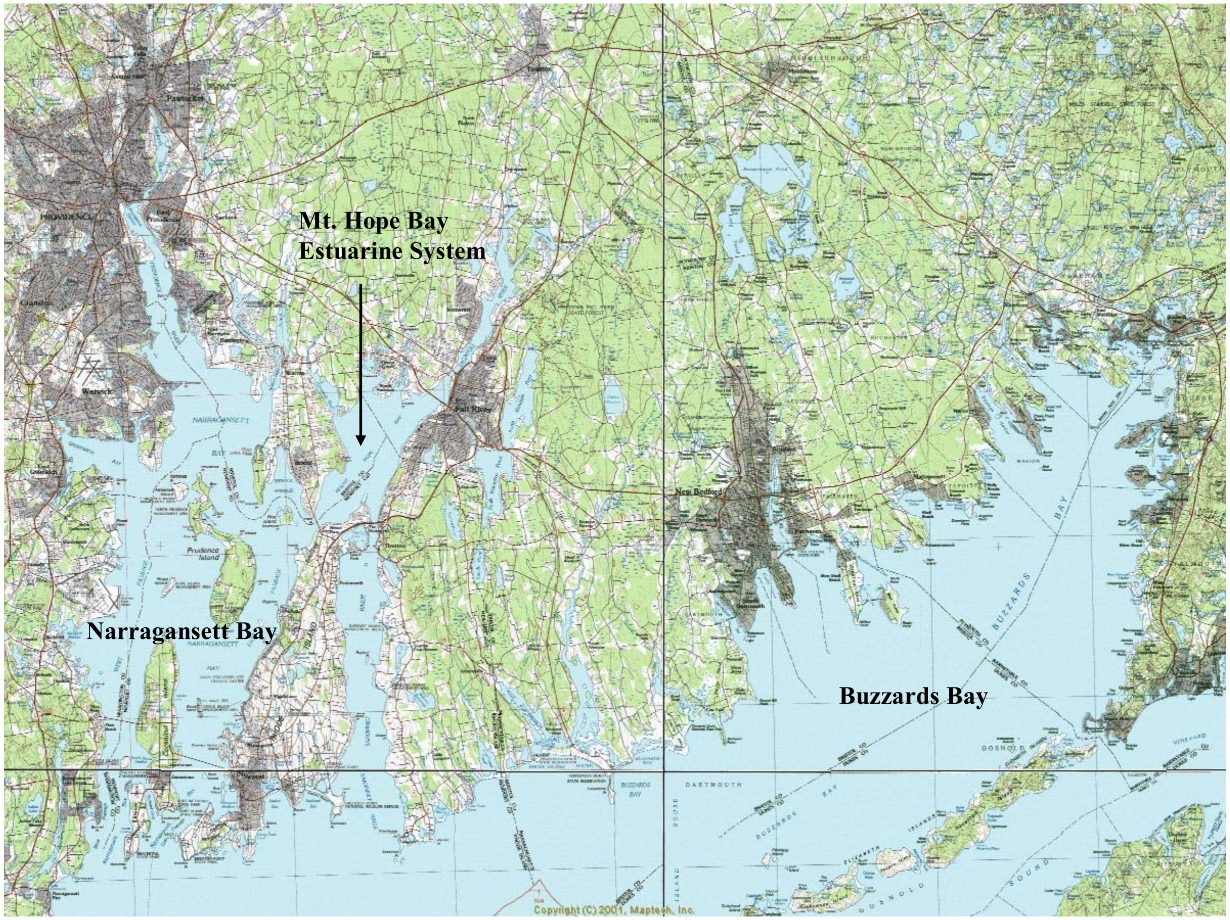

Figure 1 – Locus map depicting Mount Hope Bay and the inflowing Taunton River surface water system

2.0 METHODS:

Sampling and analysis of both estuarine and stream sites followed the Sampling and Analysis Plan (SAP) developed for this project and approved by DEP and EPA.

2.1 Lab analyses:

Marine (M) and stream (S) water samples collected under the 604(b) grant were analyzed at the Coastal Systems Analytical Facility for the following constituents:

- Nitrate + Nitrite (M,S)
- Ammonium (M,S)
- Ortho-phosphate (M,S)
- Total phosphorus (S)
- Particulate Carbon (M,S)
- Particulate Nitrogen (M,S)
- Dissolved Organic Nitrogen (M,S)
- Chlorophyll *a* & pheophytin *a* (M,S)
- Specific Conductance (M,S)
- Total Suspended Solids (M)

Carbon-clean glass fiber filters were used for particulate analysis and nitrocellulose filters for chlorophyll *a* analysis. Dissolved nutrient samples were filtered in the field (0.45um) using cellulose acetate filters. Laboratory analytical standards were met for each batch of samples assayed. Samples were received at the analytical facility within 6 hours of collection and were accompanied by a Chain of Custody Form.

2.2 Field Data Collection:

Dissolved oxygen was assayed in the field by 2 methods: (1) field teams with SMAST Staff used an YSI 85 meter and probes (for temperature also) following the calibration procedures specified by the manufacturer and specified in the SAP and (2) other field teams used the Winkler titration method (Hach, 0.5 mg/L) on samples collected by Niskin sampler, with temperature by dial thermometer. Depending on the total depth at a given station, measurements were collected from surface (0.15 m depth), middle depths generally 2m and bottom waters (0.5 m off bottom). In all cases, water samples were collected for laboratory analysis of salinity. Additionally, sampling teams made measurements of Secchi depth, Wind Speed (Beaufort Scale), tide stage, rainfall.

2.3 Personnel:

The field portion of the estuarine water quality monitoring effort relied upon teams of samplers assembled from a small pool of volunteers identified through a couple of the local NGO's in the region, specifically Save the Bay and Green Futures. In the absence of volunteers on some of the sampling dates, SMAST staff completed the sampling such that 100 percent sample recovery was achieved throughout the duration of the Mt. Hope Bay Sampling Program. The sampling teams were trained and supervised by SMAST personnel under the direction of Sara Sampieri and Jen Antosca (field oversight) or Dale Goehringer (logistics coordination). Each participating group has assigned a point of contact responsible for coordinating a team of samplers tasked to sample designated stations as follows:

- SRPEDD – Bill Napolitano
- Green Futures – Roland Garant (with field assistance from Jen Antosca - SMAST)
- Save the Bay – John Torrgin
- SMAST 1 – Mike Bartlett
- SMAST 2 – Sara Sampieri

Sampling personnel were trained by, SMAST Technical Staff to assure that the sample collection and handling procedures are followed. In addition, SMAST Staff generally partnered with the volunteer teams in the field. All personnel were provided with a copy of the relevant pages of the SAP and field SOP's. Chain of Custody Forms and procedures were followed for all sampling events. This project would not have been possible, but for the efforts of these volunteers, and they deserve credit for the successful completion of the full sampling schedule.

2.4 Materials:

Niskin Samplers for collection of estuarine watercolumn samples and Sampling Kits for each field team (data and COC forms, thermometers, field filters, Hach D.O. Kits, Secchi Disk and misc. supplies) were provided by SMAST. Sampling Teams for each event also received a cooler with the necessary number of high density polyethylene (HDPE) bottles (1 L) for whole water samples for particulate and chlorophyll *a* assays and 60 milliliter polyethylene bottles (HCl leached) for dissolved nutrients. The YSI 85 meters were supplied and maintained by SMAST.

2.5 Estuarine and Stream Sample Locations:

All portions of the overall Mt. Hope Bay – Taunton River estuarine system (MHB 1-21 and MHB-DO) designated as estuarine were tidal. Only the stream gauging/water quality sampling stations (MHB-A,B,C,D,E) were fresh water (<0.2 ppt). All estuarine samples were collected from boats, while stream samples were collected from the center of the channel by wading up gradient of the gage site or by Niskin sampler from a bridge as was the case for the Taunton River gaging station (MHB-A) as the river is too deep to be waded. The marine sample station locations are shown in Figure 2.

The estuarine sampling stations in Mt. Hope Bay are shown in Figure 2 and include:

- The estuarine reach of the Taunton River: MHB-21,19,18,1,2
- The estuarine reach of the Assonet River: MHB-20
- The main basin of Mt. Hope Bay: MHB-3,5,811,12,13,14,15,16, MHB-DO
- The estuarine reach of the Kickamuit River: MHB-9,10
- The estuarine reach of the Cole River: MHB-6,7

- The estuarine reach of the Lee River: MHB-4,17

Each of the major surface fresh water inflows to the Mt. Hope Bay Estuarine System were gauged and sampled just prior to discharge to estuarine waters. The fresh water stream sites shown in Figure 3, 4, 5 as follows:

- Taunton River at Weir Village bridge crossing: MHB-A
- Three Mile River at Route 138: MHB-B
- Segreganset River at Elm Street (up gradient Rt. 138): MHB-C
- Assonet River at the Route 79 bridge crossing: MHB-D
- Quequechan River at rail road bridge (Battleship Cove): MHB-E

All five gaging locations were marginally tidal in that stage records at all sites indicated a high and low tide stage reflective of ebb and flood conditions. Prior to initiating the extended deployments (16-20 months) salinity in the stream flow was checked to confirm that fresh water (salinity < 0.5 ppt) could be measured at low tide. All the gage locations had salinity values at low tide of less than 0.5 ppt and were therefore deemed acceptable locations for conducting stream gaging (e.g. measurement of stage and development of a stage-discharge relation from which to calculate daily flows). In the case of tidal influence on the measured stream stage for each of the five gaging locations, the diurnal low tide stage value was extracted on a day-by-day basis in order to resolve the stage value indicative of strictly freshwater flow. The lowest tidal stage value was selected for a given 24-hour period and that stage value was then entered into the stage – discharge relation in order to compute daily flow.

Table 1. Summary of Sub-Embayments to the Mt. Hope Bay Estuarine System and Parameters to be Analyzed:

Sub-System	**Station I.D.**	**Dissolved Nutrients**	**Particulate Nutrients**	**Chlorophyll /Pheophytin**	**Field Parameters**
Mt. Hope Bay	MHB 3 – 16 & MBH-DO[1]	X	X	X	X
Taunton River Estuary	MHB 1,2,17-21	X	X	X	X

[1] **MBH-DO** is a historic mooring location within the mid-bay.
Dissolved nutrients: nitrate, nitrite, ammonium, dissolved organic nitrogen.
Particulate nutrients: particulate carbon and nitrogen; also specific conductance and TSS
Phytoplankton pigments: chlorophyll *a* and pheophytin *a*
Field parameters: Dissolved oxygen (% sat. & milligrams per liter), temperature, Secchi depth

Table 2. Mt. Hope Bay System estuarine sampling station locations and depth of collection for nutrient (i.e. all chemical analyses) and dissolved oxygen samples. The presented coordinates for these stations were those being used for all years of sampling (summer 2004,05,06) under the multiple 604(b) Grants.

Station	(North) Lat	(West) Lon	Sta Depth (meters)	Nutrient Sampling Depths			D.O. Sampling Depths		
				Surf	2 meter	Btm	Surf	Mid	Btm
MHB-1	41' 43.801	71' 8.902	9.50	X	X	X	X	X	X
MHB-2	41' 42.95	71' 9.731	11.00	X	X	X	X	X	X
MHB-3	41' 41.894	71' 11.413	5.00	X	X	X	X	X	X
MHB-4	41' 42.882	71' 11.872	3.40	X		X	X	X	X
MHB-5	41' 42.24	71' 12.184	5.00	X	X	X	X	X	X
MHB-6	41' 43.714	71' 13.492	4.50	X	X	X	X	X	X
MHB-7	41' 43.064	71' 13.114	4.00	X	X	X	X	X	X
MHB-8	41' 42.233	71' 12.864	4.50	X	X	X	X	X	X
MHB-9	41' 43.456	71' 15.784	1.20		X		X	X	X
MHB-10	41' 42.67	71' 15.027	3.75	X	X	X	X	X	X
MHB-11	41' 41.594	71' 13.867	5.35	X	X	X	X	X	X
MHB-12	41' 41.682	71' 13.129	4.50	X	X	X	X	X	X
MHB-13	41' 40.868	71' 13.303	5.50	X	X	X	X	X	X
MHB-14	41' 40.335	71' 12.489	6.50	X	X	X	X	X	X
MHB-15	41' 39.457	71' 14.097	13.90	X	X	X	X	X	X
MHB-16	41' 39.124	71' 12.827	12.50	X	X	X	X	X	X
MHB-17	41' 43.902	71' 11.506	1.50	X		X	X	X	X
MHB-18	41' 45.443	71' 7.919	7.40	X	X	X	X	X	X
MHB-19	41' 46.599	71' 6.990	5.78	X	X	X	X	X	X
MHB-20	41' 48.136	71' 5.430	1.05		X		X	X	X
MHB-21	41' 48.335	71' 7.110	3.10	X		X	X	X	X
MHB-DO	41' 41.142	71' 12.198	5.75	X	X	X	X	X	X

GPS Datum = WGS84
Water Samples are collected: Mid-water only, if total depth <1.5m; Surface and Bottom, if total depth is 1.5m-3.5m; Surface+2m+Bottom, if total depth >3.5 meters. All estuarine sampling conducted on ebbing tide.

Table 3. Summary of freshwater inflows to the Mt. Hope Bay Estuarine System to be sampled weekly for nutrients, general locations are shown in Figures 3-5. Shaded rivers (MHB F,G,H) are on-going as part of 604(b) grant number DEP#2006-04/604.

Freshwater Inflow	**Station I.D.**	**Particulate Nitrogen & Carbon (PN/PC)**	**Dissolved Organic Nitrogen (DON)**	**Nitrate + Nitrite (NOx)**	**Ammonium (NH^{+}_{4})**
Taunton River	MHB-A	X	X	X	X
Three Mile River	MBH-B	X	X	X	X
Segreganset River	MBH-C	X	X	X	X
Assonet River	MBH-D	X	X	X	X
Quequechan River	MBH-E	X	X	X	X
Lewins Brook to Lee River	MBH-F				
Cole Brook to Cole River	MBH-G				
Heath Brook to Kickamuit River	MBH-H				

Table 4. Mt. Hope Bay System stream sampling station locations and depth of collection for nutrient (i.e. all chemical analyses) and dissolved oxygen samples. The presented coordinates for these stations were those being used for the years of stream sampling (2004-2005) under the multiple 604(b) Grants.

Station	**(North) Lat**	**(West) Lon**	**Sta Depth (meters)**	**Nutrient Sampling Depths**			**D.O. Sampling Depths**		
				Surf	**2 m**	**Btm**	**Surf**	**Mid**	**Btm**
MHB-A	41° 53' 09.57	71° 05' 22.03	grab	**X**			**NA**		
MHB-B	41° 51' 20.94	71° 06' 59.17	grab	**X**			**NA**		
MHB-C	41° 49' 23.61	71° 07' 30.33	grab	**X**			**NA**		
MHB-D	41° 47' 37.67	71° 04' 04.18	grab	**X**			**NA**		
MHB-E	41° 42' 13.15	71° 09' 38.38	grab	**X**			**NA**		

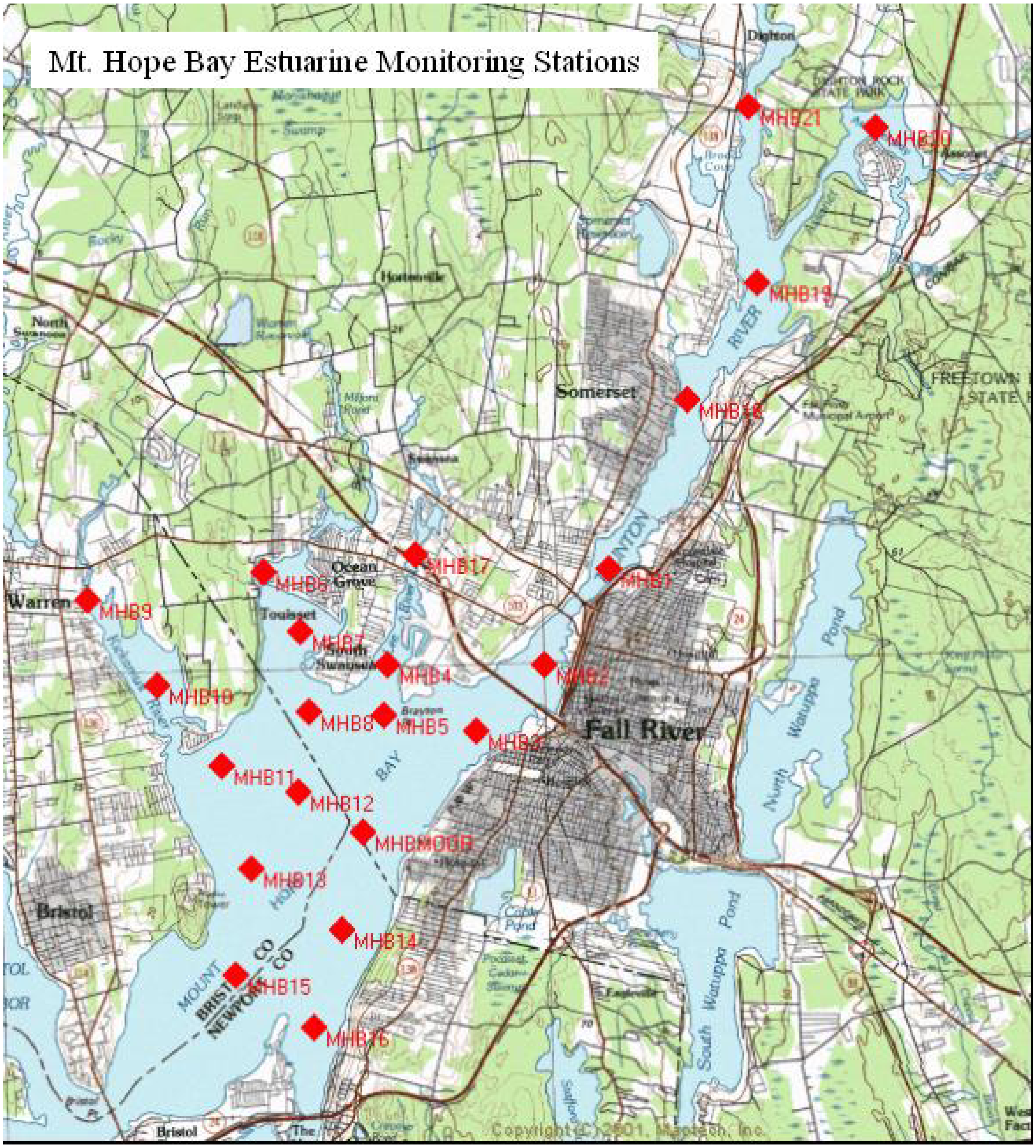

Figure 2. Water quality sampling stations within Mt. Hope Bay and the Taunton River (estuarine region). The stations are positioned to support future application of the MEP Linked Watershed-Embayment Management Model.

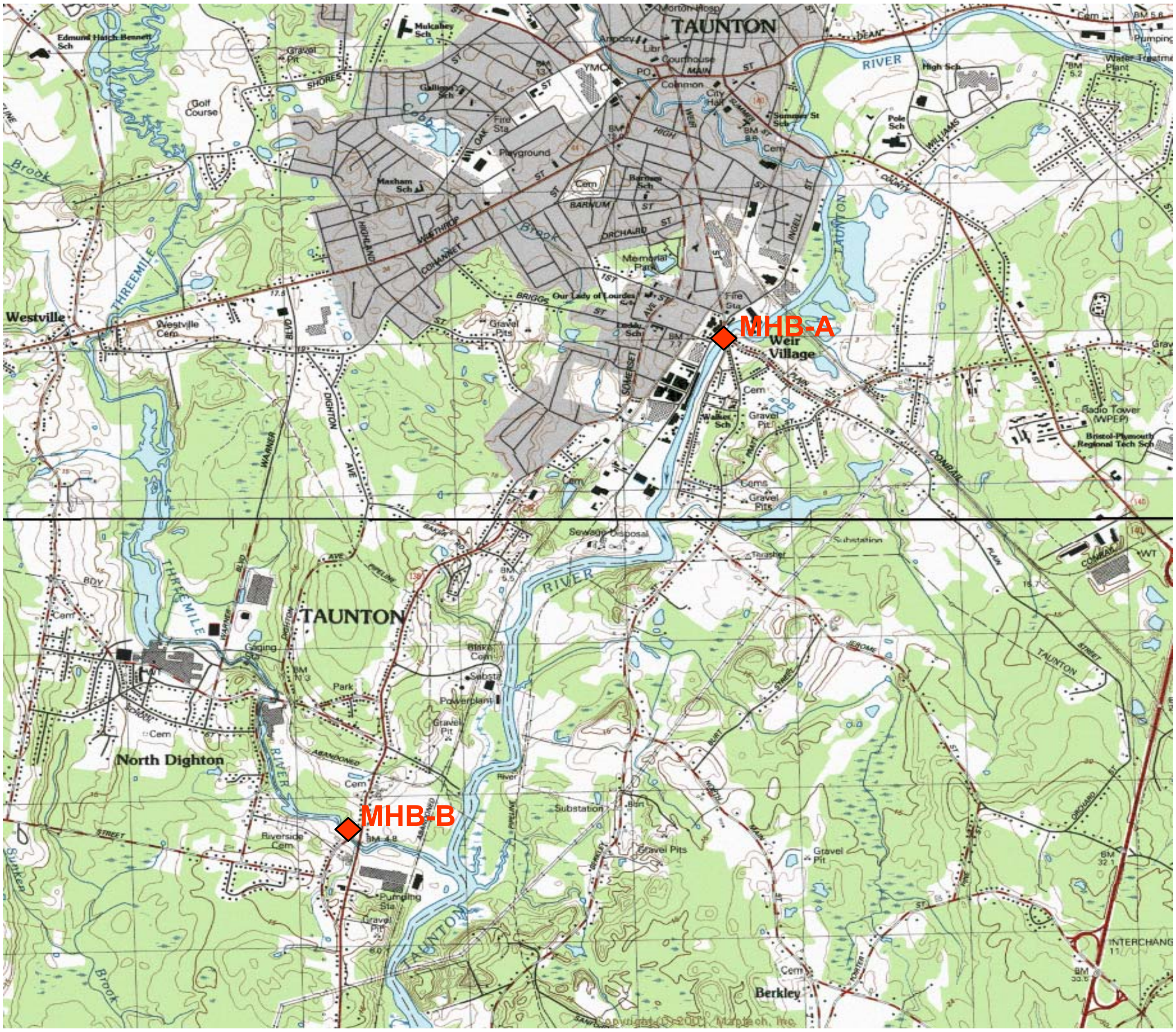

Figure 3. Stream gauging and nitrogen sampling stations on the Taunton River (MBH-A) and Three Mile River (MBH-B). These freshwaters discharge to the headwaters of the Taunton River Estuary

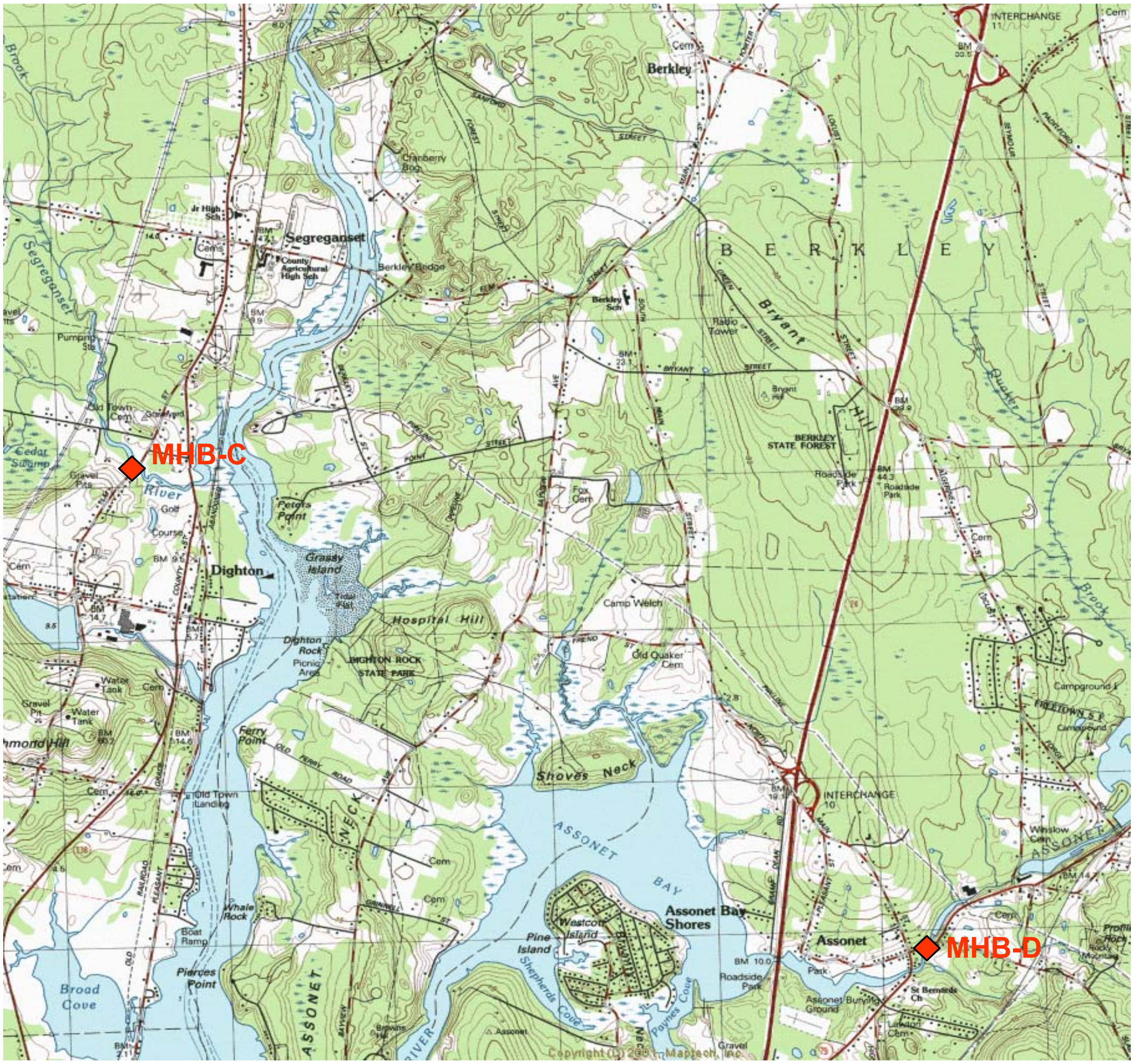

Figure 4. Stream gauging locations on the Segreganset River (MBH-C) and Assonet River (MBH-D). These freshwaters discharge to the headwaters of the Taunton River Estuary

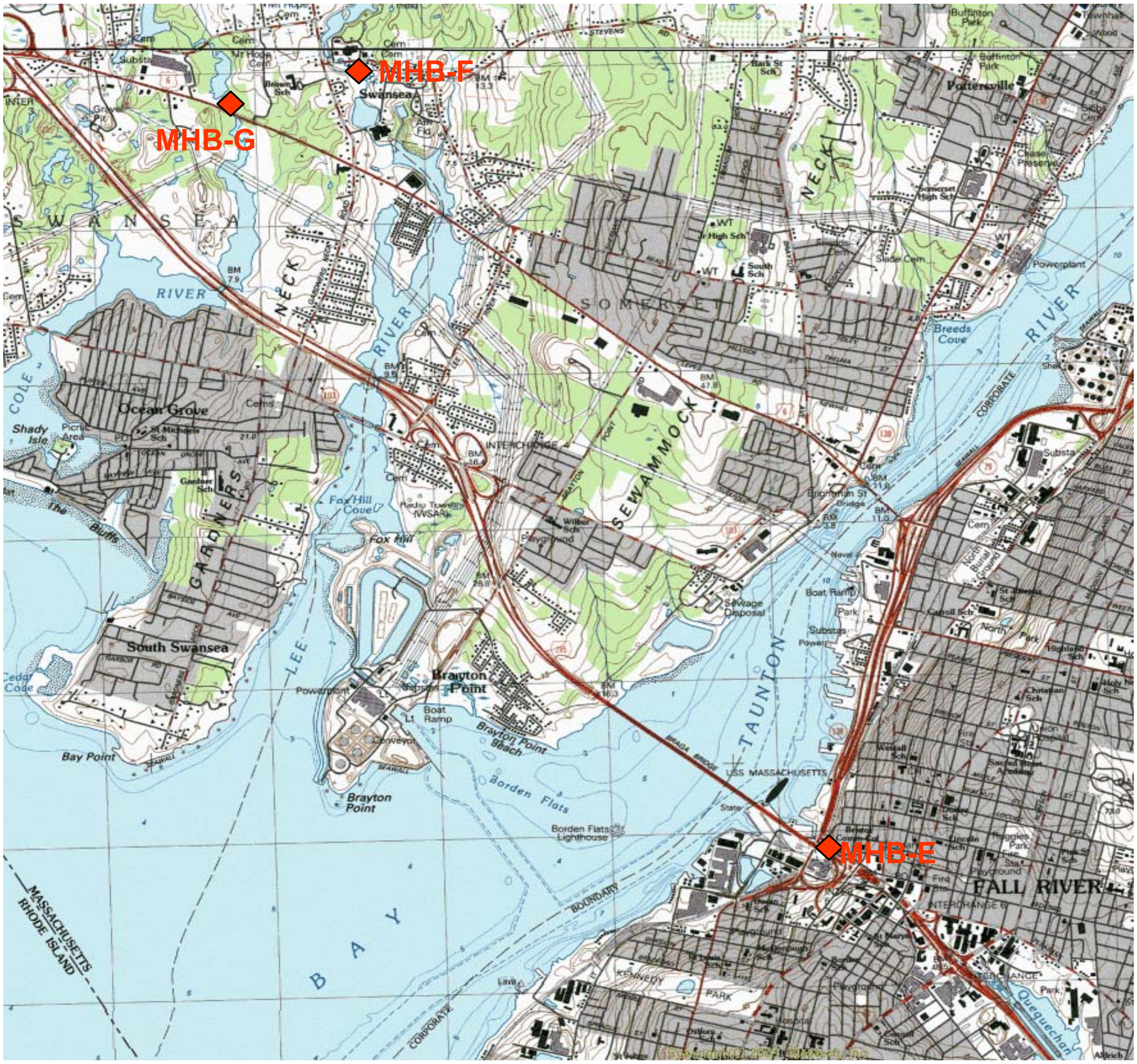

Figure 5. Stream gauging locations on the Quequechan River (MBH-E), Lewins Brook to Lee River (MBH-F, on-going) and Cole Brook to Cole River (MBH-G, on-going). These freshwater inflows transport nutrients to the upper portion of the Mt. Hope Bay basin

3.0 RESULTS AND DISCUSSION

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 glacial outwash aquifers, such as the south coast of Massachusetts, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer mineral. Since throughout southeastern Massachusetts 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 these oxygenated groundwater systems. 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 and salt ponds tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters. The Mt. Hope Bay – Taunton River Estuarine System which exchange tidal waters with Narragansett Bay and Rhode Island Sound follow this general pattern, although their upper-most reaches can have excess inorganic nitrogen levels due to localized loading of nitrates at their headwaters (see below). The lower reaches of these estuaries are nitrogen limited based upon their inorganic N to P ratios (<<16) and these regions would be expected to expand inland if nitrogen loading in the upper reaches were to be reduced. However, the primary nutrient of eutrophication in these systems is nitrogen, similar to most other estuaries in Massachusetts.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal salt ponds and embayments, because of their shallow nature 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 world-wide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. As nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

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. This effort is ongoing throughout southeastern Massachusetts (e.g. Massachusetts Estuaries Project). The general approach focuses on changes in nitrogen loading from watershed to embayment, and determination of the changes in habitat health for incremental increases or decreases in nitrogen inputs, hence nitrogen concentrations within the receiving waters. The MEP approach depends upon estimates of nitrogen inputs and embayment recycling of nitrogen, circulation within the embayment; and assessments of habitat quality. The MEP approach requires a sound baseline (not less than 3 years) of nitrogen related water quality monitoring. This latter monitoring is fulfilled for the Mt. Hope Bay – Taunton River Estuarine System by the funded 604(b) grants obtained from the MassDEP over the past 3 years. However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" will require the MEP assessment, modeling and analysis (i.e. the "MEP approach").

The following assessments are based upon the 3 summers of watercolumn monitoring obtained via 604(b) grant funding and will be refined as additional water quality data is collected up until the MEP is undertaken in this system. Additional levels of analysis of the overall system will be achievable with the "higher level" analysis by the MEP. However, some general conclusions relative to estuarine water quality (Section 3.1) and major stream inputs (Section 3.2) can be made at this time. Note also that the following is meant to be a brief analysis focusing on the nutrient related health of this regions most significant coastal system, Mt. Hope Bay – Taunton River.

3.1 Estuarine Water Quality Monitoring Data

Overall, the Taunton River - Mount Hope Bay estuarine complex appears to be representative of a large nitrogen enriched embayment system that is driven by riverine inputs. The expansive watershed which encompasses large suburban and urban areas carries significant nitrogen loading to the estuary, which coupled with local point and non-point discharges from the lower watershed areas, appears to be above the nitrogen loading threshold of this basin. Nitrogen related habitat impairment is exacerbated by the periodic stratification of Mt. Hope Bay, which results in prolonged oxygen depletion (~4 mg l^{-1}) of bottom waters. As it appears that nitrogen management is the only approach for habitat restoration within this estuary, the elemental ratio method (Redfield molar ratio of N/P <16, indicating N as the management focus) was employed as a check on N vs. P limitation of primary production in this basin. The N/P molar ratios did support the contention that Mt. Hope Bay and the Taunton River estuary are N limited. The average ratio of inorganic nitrogen to inorganic phosphorus (N/P) was quite low, <3, at all stations within the Bay, although the Taunton River estuarine stations showed consistently higher ratios (5-10) as presented in Table 5. While this is only an approximate method, it is consistent with other studies documenting nitrogen limitation in estuaries throughout southeastern Massachusetts. In addition, it is consistent with established theories of nitrogen limitation in temperate estuaries. The conclusion supports the targeting of nitrogen as the key nutrient for management of the habitat quality of these estuarine systems.

Taunton River/Mt. Hope Bay System: The Taunton River/Mt. Hope Bay System is composed of a large riverine estuary discharging to a large open embayment with relatively deep waters (ca. 5-12 m at mid tide) and moderate to high salinity waters throughout (Table 5). The estuary shows a moderate salinity gradient. With the exception of the upper reaches nearest the freshwater entry, almost all of the waters ranged from 19 ppt to 28 ppt nearest the channel at Bristol Point. The salinity gradient results from the high predominantly riverine freshwater inflow and the high tidal flushing of this enclosed basin. Only the stations directly influenced by the Taunton River (MHB19-21) and the Kickamuit River (MHB-9) showed significant dilution of the main Bay. However, freshwater does have a major structuring effect on the habitat quality of the Mt. Hope Bay System. During summer, the Mt. Hope Bay water column frequently has fresher water at the surface than at the bottom. The effect is to reduce vertical mixing of the waters. Since the Bay is nutrient enriched, and therefore supports organic matter production by phytoplankton, there appears to be significant oxygen demand in the water column and sediments. Chlorophyll a levels throughout this system are generally high in the summer, >11 ug L^{-1}, supporting the assessment of a nutrient enriched estuary and indicating that organic matter production is capable of supporting a high level of oxygen demand. As this production settles to the bottom water and sediments and stimulates respiration, the effect of reducing vertical mixing allows oxygen demand below the pycnocline to deplete the bottom water oxygen pool result in periodic hypoxia and stress to benthic animal communities and fish. These low oxygen conditions are primarily found in the upper portion of the main Mt. Hope Bay basin and in the Taunton River estuarine reach (Table 7). Complete data files for dissolved oxygen, salinity as well as nutrients and physical parameters have been sent to MassDEP in digital format under separate cover (as indicated in Appendix D). With regard to the stream gage stations sampling, secchi depth and dissolved oxygen measurements are not taken at the stream stations and as such no data (ND) was presented in the spreadsheet containing the raw water quality data.

Given the high population within the watershed and resultant N loading to this down gradient estuary and the observed high chlorophyll levels and oxygen depletions, it is not surprising that nitrogen levels are moderately to highly enriched over offshore waters. The Taunton River estuarine reach, as the focus of upper watershed N loading, showed very high total nitrogen levels (TN) in its upper reach (1.058 mg N L^{-1}) and maintained high levels throughout most of its reach (>0.6 mg N L^{-1}). The main basin of Mt. Hope Bay supported lower TN levels primarily as a result of mixing with incoming waters (generally 0.5-0.6 mg N L^{-1}). This is consistent with the observed oxygen depletions and infauna animal communities. The highest (Moderate) water quality was found at the stations in the main basin and lower reaches of Mt Hope Bay out to the channels to lower Narragansett Bay and the Sakonet River (Figure 6).

From the water quality data, it appears that the smaller rivers discharging to Mt. Hope Bay had a minor localized effect on water quality in their lower drown river valley basins, due to their relatively small flows (compared to Taunton River) and mixing with waters of the Mt. Hope Bay (Section 3.2). However, it should be noted that although there only appeared to be a localized water quality "effect", the N load from these rivers is proportionately responsible for the impaired nutrient related habitat quality of the Mt. Hope Bay basin.

The water quality data can be used to generate a Bay Health Index as developed and refined by the Buzzards Bay Project, Coalition for Buzzards Bay's Bay Watcher Program and SMAST. The concept is to integrate the basic water quality monitoring parameters (dissolved inorganic nitrogen, total organic nitrogen, chlorophyll a pigments, Secchi depth and lowest 20% of Dissolved Oxygen measures) into a single index that can be plotted to show the spatial pattern of nitrogen related water quality within an embayment. While the result is general and qualitative, the patterns are useful in gauging overall habitat quality and guiding more detailed quantitative habitat assessments as undertaken by the Massachusetts Estuaries Project Approach. The reference values used in generating the index are shown in Table 6.

Using the Bay Health Index for the Mt. Hope Bay/Taunton River estuarine complex illustrates the overall spatial pattern discussed above (Figure 6). In general, the Taunton River Estuary, with its large watershed N load and high TN levels, is showing poor water quality due to its high chlorophyll and oxygen depletions. The main basin of Mt. Hope Bay, with its greater flushing and access to higher quality waters of the lower Bay, is showing less impairment with moderate water quality. Finally, the lower basin of Mt. Hope Bay, nearest the tidal "inlet", is generally showing moderate water quality. This pattern is consistent with the structure of the watershed and the tidal flushing of estuarine waters resulting, in part, from the moderate tide range. The impaired waters in the regions nearest the river discharges most likely result from their lower flushing rates and from nitrogen loads. In these drowned river valley basins thorough assessments of ecological impairment requires additional habitat parameters before habitat impairments can be firmly documented. However, these data collected via the 604(b) grant program indicate that additional sampling in the basin in the lower region of Mt. Hope Bay, near the tidal inlets, may be warranted. In addition, these data indicate that the MEP analysis of this system should focus on restoration of the main basin of Mt. Hope Bay and the Taunton River estuarine reach, and that it is likely that restoration of the Taunton River Estuary will have a significant positive effect on the habitat quality of the main basin of Mt. Hope Bay.

Overall, it appears that the MEP analysis is warranted for the Mount Hope Bay/Taunton River estuarine complex as assessed by the water quality monitoring data and that the water quality monitoring partnership that has been developed under this 604(b) grant, provides a viable stepping stone for stewardship of this large and complex estuarine system.

Table 5. Summary of average levels of primary nutrient related water quality parameters measured in the summers of 2004, 2005 and 2006 in Mount Hope Bay by SMAST Coastal Systems staff.

Station	Total Depth (m)	20% Low* D.O. (mg/L)	Sal (ppt)	PO4 (mg/L)	NH4 (mg/L)	NOX (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TN (mg/L)	DIN/DIP Molar Ratio	Total Chl a (ug/L)
MHB1	10.0	5.02	23.3	0.054	0.052	0.095	0.147	0.299	0.155	0.601	6	11.75
MHB2	8.9	4.94	26.1	0.052	0.047	0.043	0.090	0.312	0.170	0.572	4	13.50
MHB3	5.2	5.49	26.0	0.051	0.037	0.035	0.072	0.282	0.163	0.517	3	14.32
MHB4	3.5	5.61	25.7	0.052	0.026	0.017	0.043	0.308	0.173	0.525	3	14.71
MHB5	5.6	5.20	26.2	0.050	0.029	0.020	0.050	0.294	0.169	0.512	2	14.53
MHB6	3.9	5.09	24.1	0.061	0.049	0.030	0.079	0.359	0.168	0.606	3	12.87
MHB7	4.5	5.94	25.5	0.049	0.023	0.016	0.039	0.308	0.189	0.536	2	17.46
MHB8	5.1	4.93	25.8	0.046	0.022	0.019	0.041	0.280	0.165	0.486	2	15.84
MHB9	ND	ND	19.7	0.062	0.049	0.040	0.089	0.453	0.263	0.805	3	14.02
MHB10	3.2	5.86	25.7	0.048	0.017	0.012	0.027	0.314	0.167	0.508	1	14.11
MHB11	4.9	5.02	26.2	0.043	0.017	0.012	0.029	0.268	0.175	0.472	1	16.23
MHB12	5.0	5.36	26.4	0.049	0.020	0.021	0.040	0.284	0.168	0.493	2	16.12
MHB13	5.9	6.00	26.8	0.045	0.020	0.013	0.033	0.282	0.158	0.473	2	15.40
MHB14	6.5	5.34	27.0	0.044	0.024	0.009	0.033	0.289	0.197	0.519	2	16.78
MHB15	12.9	6.46	27.9	0.035	0.021	0.009	0.029	0.273	0.143	0.445	2	12.68
MHB16	11.2	6.33	27.7	0.043	0.028	0.012	0.039	0.265	0.157	0.461	2	13.02
MHB17	ND	ND	24.6	0.064	0.057	0.026	0.083	0.404	0.181	0.669	3	11.81
MHB18	6.7	4.96	22.3	0.062	0.061	0.136	0.197	0.300	0.156	0.652	7	11.44
MHB19	4.0	4.93	18.7	0.058	0.074	0.201	0.275	0.342	0.178	0.799	10	12.27
MHB20	1.8	5.09	17.5	0.054	0.063	0.144	0.207	0.372	0.192	0.771	8	13.59
MHB21	2.6	4.60	14.2	0.061	0.066	0.350	0.415	0.420	0.219	1.058	15	13.34
MHBMOOR	6.3	5.85	26.8	0.045	0.025	0.013	0.038	0.284	0.181	0.503	2	15.57

* Average of the lowest 20% of recorded values

Table 6 Reference values used in the Bay Health Index. Scores are generated for each parameter and the mean score computed. In some cases where Secchi data is not available, the mean of the other 4 parameters may be used.

Score	Secchi Depth M	Oxygen Saturation %	Inorganic N mg/L	Total N mg/L	Total Chlorophyll a Pigments ug/L
0%	0.6	0.40	0.140	0.600	10.0
100%	3.0	0.90	0.014	0.280	3.0

The relationship between 0% to 100% for each parameter is logrithmic.

Table 7 Trophic health index scores and status for water quality monitoring stations, Mt. Hope Bay, 2004-2006 (described in Howes et al. 1999 and also at www.savebuzzardsbay.org.)

Station	Secchi SCORE	Low20% Oxsat SCORE	DIN SCORE	TON SCORE	T-Pig SCORE	EUTRO Index	Health Status
MHB1	52.2	57.8	0.0	36.5	0.0	29	Fair/Poor
MHB2	67.7	58.5	19.3	28.7	0.0	35	Mod/Fair
MHB3	62.1	79.4	29.0	39.1	0.0	42	Mod
MHB4	62.0	79.0	51.5	28.7	0.0	44	Mod
MHB5	61.2	71.8	44.9	34.2	0.0	42	Mod
MHB6	65.7	73.5	24.9	17.0	0.0	36	Mod/Fair
MHB7	61.5	87.9	55.4	24.8	0.0	46	Mod
MHB8	61.7	65.3	53.5	39.1	0.0	44	Mod
MHB9	ND	ND	19.6	0.0	0.0	ND	ND
MHB10	60.4	89.4	70.7	29.1	0.0	50	Mod
MHB11	61.6	66.2	68.5	39.8	0.0	47	Mod
MHB12	58.5	78.2	54.1	37.1	0.0	46	Mod
MHB13	57.4	89.9	63.4	40.6	0.0	50	Mod
MHB14	58.8	73.0	63.3	27.5	0.0	45	Mod
MHB15	68.6	92.8	68.3	48.1	0.0	56	Mod
MHB16	65.6	95.5	55.8	45.9	0.0	53	Mod
MHB17	ND	ND	22.5	3.3	0.0	ND	ND
MHB18	47.1	58.0	0.0	36.1	0.0	28	Fair/Poor
MHB19	36.9	54.6	0.0	19.1	0.0	22	Fair/Poor
MHB20	30.5	60.7	0.0	8.1	0.0	20	Fair/Poor
MHB21	24.1	43.5	0.0	0.0	0.0	14	Fair/Poor
MHBMOOR	57.4	84.0	57.1	33.3	0.0	46	Mod

High Quality = >69; High/Moderate = 61-69; Moderate = 39-61; Moderate/Fair = 31-39; Fair/Poor = <31

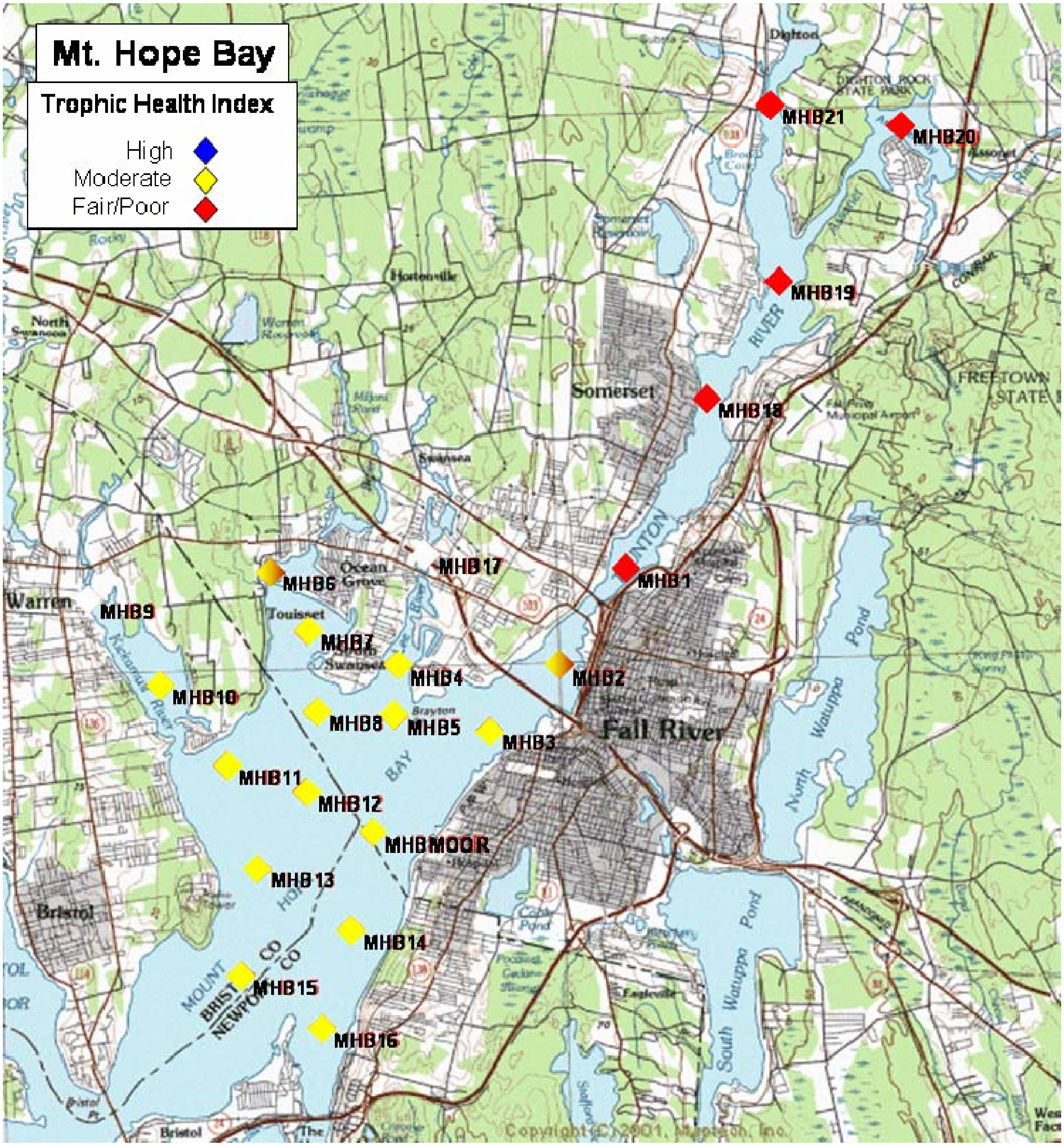

Figure 6 Nutrient Related Water Quality of Mt. Hope Bay – Taunton River Estuary based upon monitoring data from stations in Figure 2. The Health Index was developed for Buzzards Bay

3.2 Stream Discharge and Water Quality Monitoring Data

With regard to the stream gaging and stream water quality monitoring component of the 604(b) grant objectives for the Mt. Hope Bay – Taunton River Estuarine Water Quality Monitoring Project, the stream related tasks where initiated to ultimately generate the data necessary to support critical elements of the Massachusetts Estuaries Project (MEP) Linked Watershed- Embayment Modeling Approach. The MEP is structured to generate site specific embayment nutrient thresholds that serve as targets for watershed wide nutrient load reductions that would be protective or restorative of the habitat quality in any given embayment. As such, MEP modeling and prediction of change in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land area (watershed). This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out, sewering analysis, enhanced flushing, pond/wetland restoration for natural attenuation, etc.) to changes in water quality and habitat health of the estuarine receiving water. Therefore, in the context of the MEP nutrient threshold analysis, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Though the complete nitrogen land use load analysis (watershed-wide) undertaken by the MEP has many more dimensions than those just mentioned, a critical element of the MEP land use load analysis rests on the accurate determination of stream discharges and the associated attenuated nitrogen loads to the embayment being analyzed. The 604(b) grant project for the Mt. Hope Bay – Taunton River embayment system has allowed for the development of daily stream flow values and associated N-loads based on the stream gaging and weekly stream water quality data collection undertaken as part of the 604(b) grant. This effort has yielded a significant data set directly applicable to the objectives to be met by the MEP in the Mt. Hope Bay embayment system.

Surfacewater transport and Nitrogen Load Determination

Measured rates of nitrogen loading from streams discharging to the Mt. Hope Bay embayment system (Taunton River, Three Mile River, Segreganset River, Assonet River, Quequechan River) being investigated under this set 604(b) grants (DEP#2004-04/604, DEP#2005-04/604) were based on long term measurements of stage in each of the mentioned surface waters as well as collection of weekly water quality sampling at each gage location. Ultimately, this data will be merged with the MEP watershed based nutrient loading analysis which is based upon the delineated watersheds to the stream gages in order to determine levels of nitrogen attenuation occurring in the watersheds to each stream. As such, the truest estimate of actual nitrogen loads being discharged from the watershed to Mt. Hope Bay can be determined and utilized in embayment water quality modeling. The complete MEP watershed loading analysis combined with the measured stream loads obtained under the 604(b) grant program will enable the development by the MEP of the embayment specific nitrogen threshold for restoration of Mt. Hope Bay.

If all of the nitrogen applied or discharged within a watershed (based on MEP land use analysis) reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport from source to estuarine waters is through groundwater flow in glacial 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 path to the adjacent 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 by natural biological processes that represent removal (not just temporary storage). However, this natural attenuation of nitrogen load is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes. In the case of the Mt. Hope Bay – Taunton River embayment system watersheds, most of the freshwater flow and transported nitrogen passes through a surface water system and frequently multiple systems prior to entering the estuaries, producing the opportunity for significant nitrogen attenuation.

Failure to determine the attenuation of watershed derived nitrogen overestimates the nitrogen load to receiving estuarine waters. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal). In addition to attenuation by freshwater ponds, attenuation in surface water flows is also important. An example of the significance of surface water nitrogen attenuation relating to embayment nitrogen management was seen in the Agawam River, where >50% of nitrogen originating within the upper watershed was attenuated prior to discharge to the Wareham River Estuary (CDM 2001). Similarly, MEP analysis of the Quashnet River indicates that in the upland watershed, which has natural attenuation predominantly associated with riverine processes, the integrated attenuation was 39% (Howes et al. 2004). In addition, a preliminary study of Great, Green and Bournes Ponds in Falmouth, measurements indicated a 30% attenuation of nitrogen during stream transport (Howes and Ramsey 2001). An example where natural attenuation played a significant role in nitrogen management can be seen relative to West Falmouth Harbor (Falmouth, MA), where ~40% of the nitrogen discharge to the Harbor originating from the groundwater effluent plume emanating from the WWTF was attenuated by a small salt marsh prior to reaching Harbor waters. Similarly, the small tidal basin of Frost Fish Creek in the Town of Chatham showed ~20% nitrogen attenuation of watershed nitrogen load prior to discharge to Ryders Cove. Clearly, proper development and evaluation of nitrogen management options requires determination of the nitrogen loads reaching an embayment, not just those loaded to the watershed. As such, the 604(b) grant program has help to develop the necessary stream flows and nitrogen loads to be able to do the comparison with the MEP developed land use based load values and obtain a percent attenuation for nitrogen flowing to the embayment system.

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements of nitrogen loading and stream flow was undertaken as part of the 604(b) grant objectives. These measurements were conducted in each of the 5 major surface water flow systems discharging to the Mt. Hope Bay embayment system (e.g. Taunton River, Three Mile River, Segreganset River, Assonet River, Quequechan River). The location of the stream gages placed in each of the surface water systems mentioned above are depicted above (Figures 3 – 5).

Quantification of watershed based nitrogen attenuation is contingent upon being able to compare nitrogen load to the embayment system directly measured in freshwater stream flow (or in tidal marshes, net tidal outflow) to nitrogen load as derived from the detailed land use analysis (MEP analysis). Measurement of the flow and nutrient load associated with the Taunton River (at Weir Village bridge crossing), Three Mile River (immediately up gradient of Route 139 bridge), Segreganset River (at Elm Street immediately up gradient of the Route 139), Assonet River (at the Route 79 bridge crossing) and the Quequechan River (at the rail road bridge up gradient of Battleship Cove) provide a direct integrated measure of all of the processes presently attenuating nitrogen in the sub-watersheds up gradient from the gauging sites. Flow and nitrogen concentration were measured at the gages on the Taunton River, Three Mile River, Segreganset River, the Assonet River and the Quequechan River for a total 20 to 22 months of record depending on the gage location.

During the study period, velocity profiles were completed on each river every month to two months in order to ultimately develop a rating curve (stage – discharge relation) that could be utilized to convert measured stream stages into daily flows. 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 made 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.

Periodic measurement of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges. Water level data obtained every 10-minutes was averaged to obtain hourly stages for a given river. 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 annual flow.

In the case of tidal influence on stream stage, the diurnal low tide stage value was extracted on a day by day basis in order to resolve the stage value indicative of strictly freshwater flow. The lowest low tide stage values for any given day were entered into the stage – discharge relation in order to compute daily flow. A complete annual record of stream flow (365 days) was generated for each of the surface water discharges flowing into the Mt. Hope Bay – Taunton River embayment system.

The annual flow record for each surface water flow was merged with the nutrient data sets generated through the weekly water quality sampling to determine nitrogen loading rates to the tidally influenced portion of the Taunton River and Mt. Hope Bay. Nitrogen discharge from a given stream was calculated using the paired daily discharge and daily nitrogen concentration data to determine the mass flux of nitrogen through the gaging sites.

For a given gaging location, weekly water samples were collected (at low tide for a tidally influenced stage) 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 the embayment system as appropriate. Ultimately, by comparing these measured nitrogen loads based on stream flow and water quality sampling to predicted loads based on the land use analysis to be performed by the MEP, the degree to which natural biological processes within the watershed to each embayment reduces (percent attenuation) nitrogen loading will be determined.

Surface water Discharge and Watershed Nitrogen Load: Taunton River to Mt. Hope Bay

Stream gaging on the Taunton River provides for a direct measurement of the nitrogen loading to the Mt. Hope Bay embayment system. The combined rate of nitrogen attenuation by watershed-wide biological processes will be determined in the future by comparing the present predicted nitrogen loading (to be determined by the MEP) to the sub-watershed region contributing to the Taunton River above the gauge site and the measured annual discharge of nitrogen to the tidal portion of the Taunton River as determined under the 604(b) grant.

At the Taunton River gauge site, a continuously recording vented calibrated water level gauge was installed to yield the level of water in the freshwater portion of the Taunton River that carries the flows and associated nitrogen load to Mt. Hope Bay. As the Taunton River is tidally influenced up gradient of the Weir Village bridge, the gage was located such that it be above the influence of saltwater at low tide. In this manner, flow measurements conducted at low tide would be a measure of freshwater being discharged from the Taunton River at the gage. To confirm that freshwater was being measured at low tide, salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average low tide salinity was determined to be 0.2 ppt therefore, the gauge location was deemed acceptable for making freshwater flow measurements. Additionally, prior to deployment of the gage a detailed salinity profile was conducted across the stream section where flow measurements would be undertaken for development of the rating curve for the site. This was to check that there was no stratification of the water column at the site and that freshwater would be measured exclusively under both neap and spring tide conditions. The salinity profiling confirmed the lack of water column stratification at the site thus eliminating the concern over measuring a combination of fresh and brackish water which would result in an over estimate of flow. Calibration of the gauge was checked monthly. The gauge on the Taunton River was installed on May 19, 2004 and operated continuously for 20 months such that one summer season would be captured in the flow record. The gage was retrieved from the field in December 2005. During the period of deployment there was one period of instrument failure (approximately 3 weeks October 2004-November 2004) during which time invalid stage data was generated by the instrument. Since no stage data was generated during that period it was not possible to calculate daily flows for that period using the rating curve discussed above. For the period of instrument failure, an assumed stage that split the difference between the last record stage and the stage at the time of the new instrument deployment as used in order to fill the gap in the daily flow record develop under the 604(b) grant project. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season and extends from September of 2004 to the end of August 2005 (one complete hydrologic year).

River flow (volumetric discharge) was measured at low tide every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Taunton River gage based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Before using the continuously measured stage data to determine volumetric flow, tidal influence on stage was filtered out of the record by examining stage at ebb slack tide. Based on the daily flows obtained from the Taunton River stage record, measured flows, and the rating curve, the annual freshwater flux was determined to be 1,172,417,821 m^3/yr with an average daily discharge of 3,212,104 m^3/d to the embayment system (Figure 7). Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets will allow for the future determination of nitrogen mass discharge to the estuarine portion of Mt. Hope Bay.

Total nitrogen concentrations within the Taunton River outflow were relatively high, average of 1.39 mg N L^{-1}, where as Nitrate + Nitrite (NOx) was on average 0.748 mg N L^{-1}. In the Taunton River, nitrate was the predominant form of nitrogen (54 %), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. Dissolved inorganic nitrogen (DIN) which includes NOx was the next most abundant nitrogen specie with an average of 0.792 mg N L^{-1} (57 % of the Total Nitrogen pool) followed by dissolved organic nitrogen (DON) with an average concentration of 0.488 mg N L^{-1} (35 % of the Total Nitrogen pool). Particulate organic nitrogen (PON) represented a small fraction of the TN pool with an average concentration of 0.111 mg N L^{-1} (8 % of the Total Nitrogen pool). Figures 8 and 9 depicts the daily freshwater flow in the Taunton River relative to the concentrations of Total Nitrogen (TN) and Nitrate + Nitrite (NOx) as determined from the weekly water quality sampling at the gage as supported by the 604(b) grant.

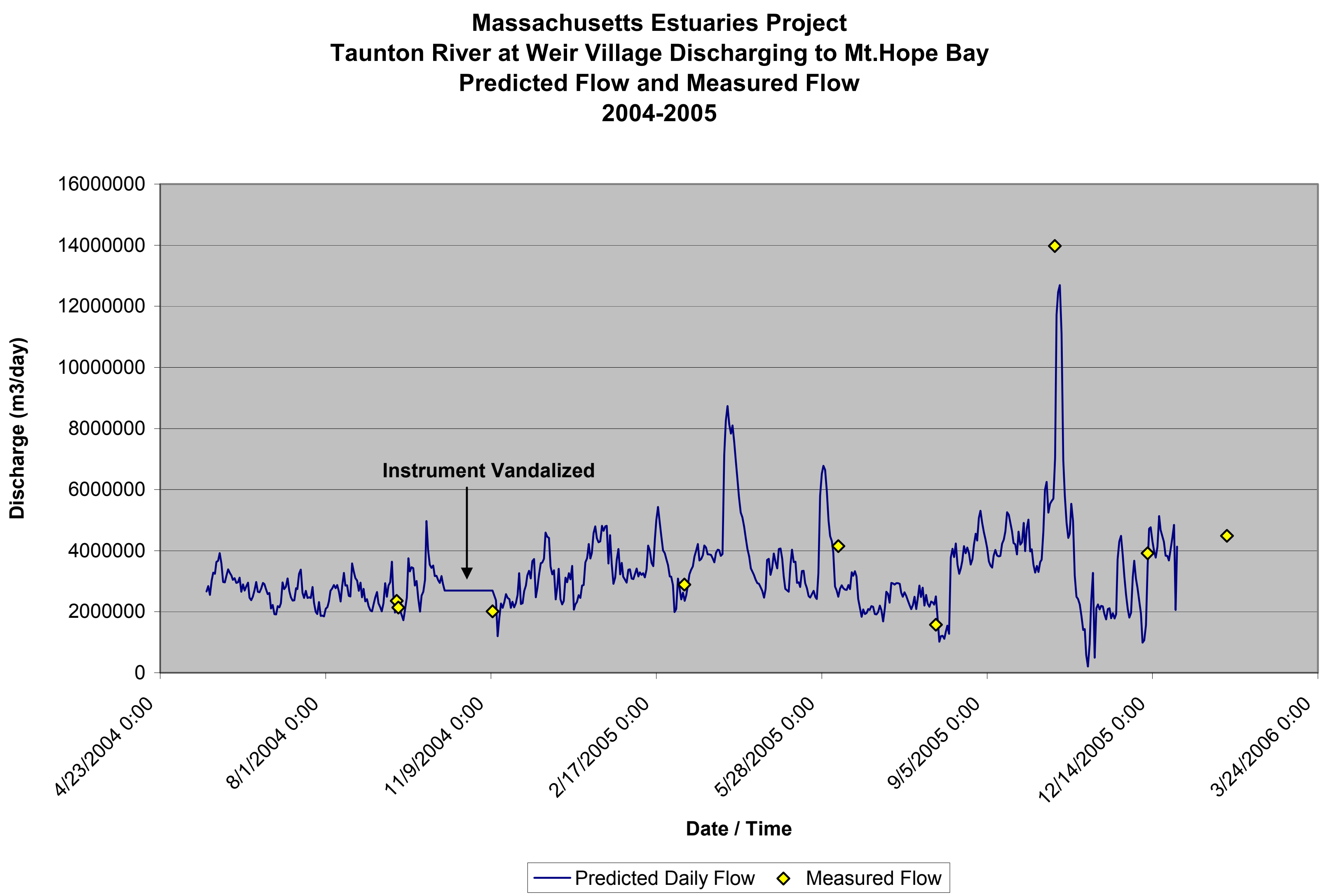

Figure 7 – Predicted daily discharge for the Taunton River discharging to Mt. Hope Bay.

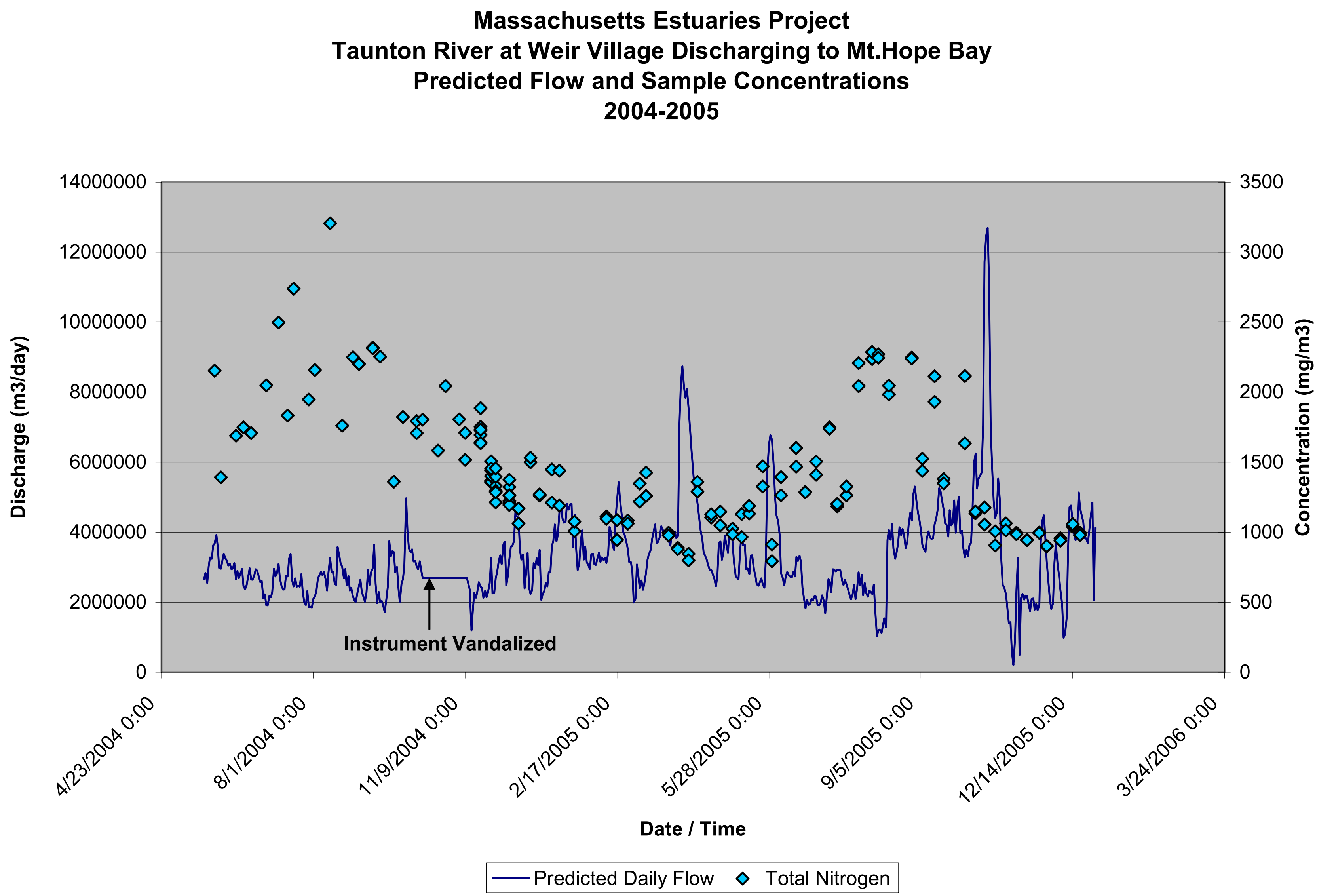

Figure 8 - Predicted daily discharge and Total Nitrogen (TN) concentrations for the Taunton River discharging to Mt. Hope Bay

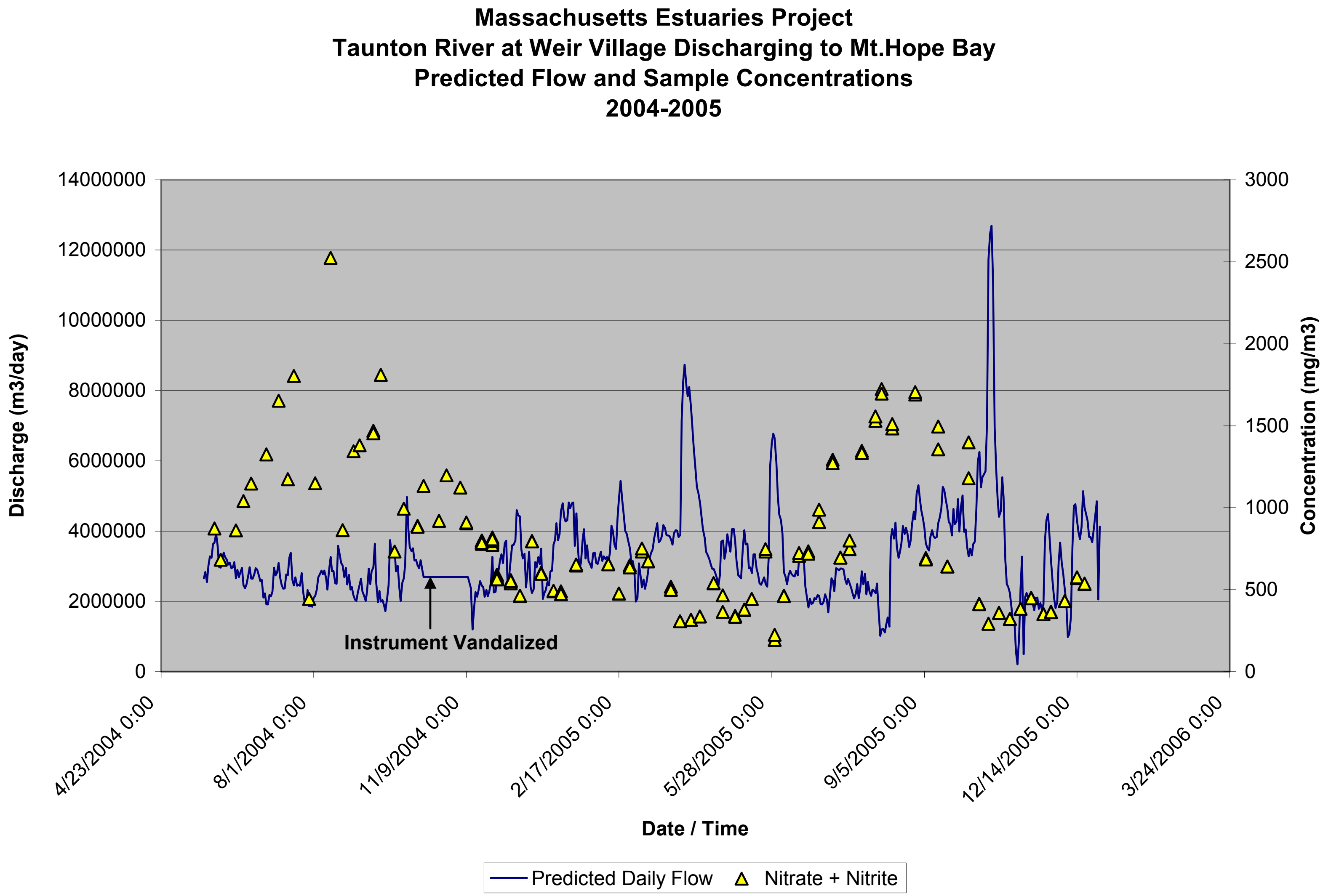

Figure 9 – Predicted daily discharge and Nitrate + Nitrite (NOx) concentrations for the Taunton River discharging to Mt. Hope Bay.

Surface water Discharge and Watershed Nitrogen Load: Three Mile River to Taunton River Estuarine Reach

Stream gaging on the Three Mile River provides for a direct measurement of the nitrogen loading to the estuarine reach of the Taunton River and ultimately, the Mt. Hope Bay embayment system. The combined rate of nitrogen attenuation by watershed-wide biological processes will be determined in the future by comparing the present predicted nitrogen loading (to be determined by the MEP) to the sub-watershed region contributing to the Three Mile River above the gauge site and the measured annual discharge of nitrogen from the Three Mile River as determined under the 604(b) grant.

At the Town Brook gauge site, a continuously recording vented calibrated water level gauge was installed to yield the level of water in the freshwater portion of the Three Mile River that carries the flows and associated nitrogen load to the estuarine reach of the Taunton River enroute to Mt. Hope Bay. To confirm that freshwater was being measured at low tide, salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average low tide salinity was determined to be 0.2 ppt therefore, the gauge location was deemed acceptable for making freshwater flow measurements.

Based on flow measurements taken throughout the gage deployment period and the detailed stage record, a rating curve relating stage to flow was developed in order to determine predicted daily flows in the Three Mile River. Predicted daily flows agree favorably with measured flows used in the development of the rating curve. Calibration of the gauge was checked monthly. The gauge on the Three Mile River was installed on May 19, 2004 and operated continuously for 19 months such that one summer season would be captured in the flow record. The gage was retrieved from the field in November 2005 due to vandalism. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season and extends from September of 2003 to the end of August 2004 (one complete hydrologic year).

River flow (volumetric discharge) was measured at low tide every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Three Mile River gage was based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Based on the daily flows obtained from the Three Mile River stage record, measured flows, and the rating curve, the annual freshwater flux was determined to be 233,887,161 m^3/yr with an average daily discharge of 640,787 m^3/day to the estuarine reach of the Taunton River and Mt. Hope Bay (Figure 10). Integrating the flow and nitrogen concentration datasets discussed below will allow for the future determination of nitrogen mass discharge to the estuarine portion of Mt. Hope Bay.

Water samples were collected weekly for nitrogen analysis. Total nitrogen concentrations within the Three Mile River outflow were relatively high, 1.096 mg N L^{-1}, where as Nitrate + Nitrite (NOx) and dissolved inorganic (DIN) was 0.648 mg N L^{-1} and 0.671 mg N L^{-1} respectively. In the Three Mile River, nitrate + nitrite was the predominant forms of nitrogen (59 %), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was not completely taken up by plants within the pond or stream ecosystems. Dissolved organic nitrogen (DON) was clearly a less abundant nitrogen specie with an average of 0.357 mg N L^{-1} (33 % of the Total Nitrogen pool) followed by particulate organic nitrogen (PON) with an average concentration of 0.068 mg N L^{-1} (6 % of the Total Nitrogen pool). Figures 11 and 12 depict the daily freshwater flow in the Three Mile River relative to the concentrations of Total Nitrogen (TN) and Nitrate + Nitrite (NOx) as determined from the weekly water quality sampling at the gage as supported by the 604(b) grant.

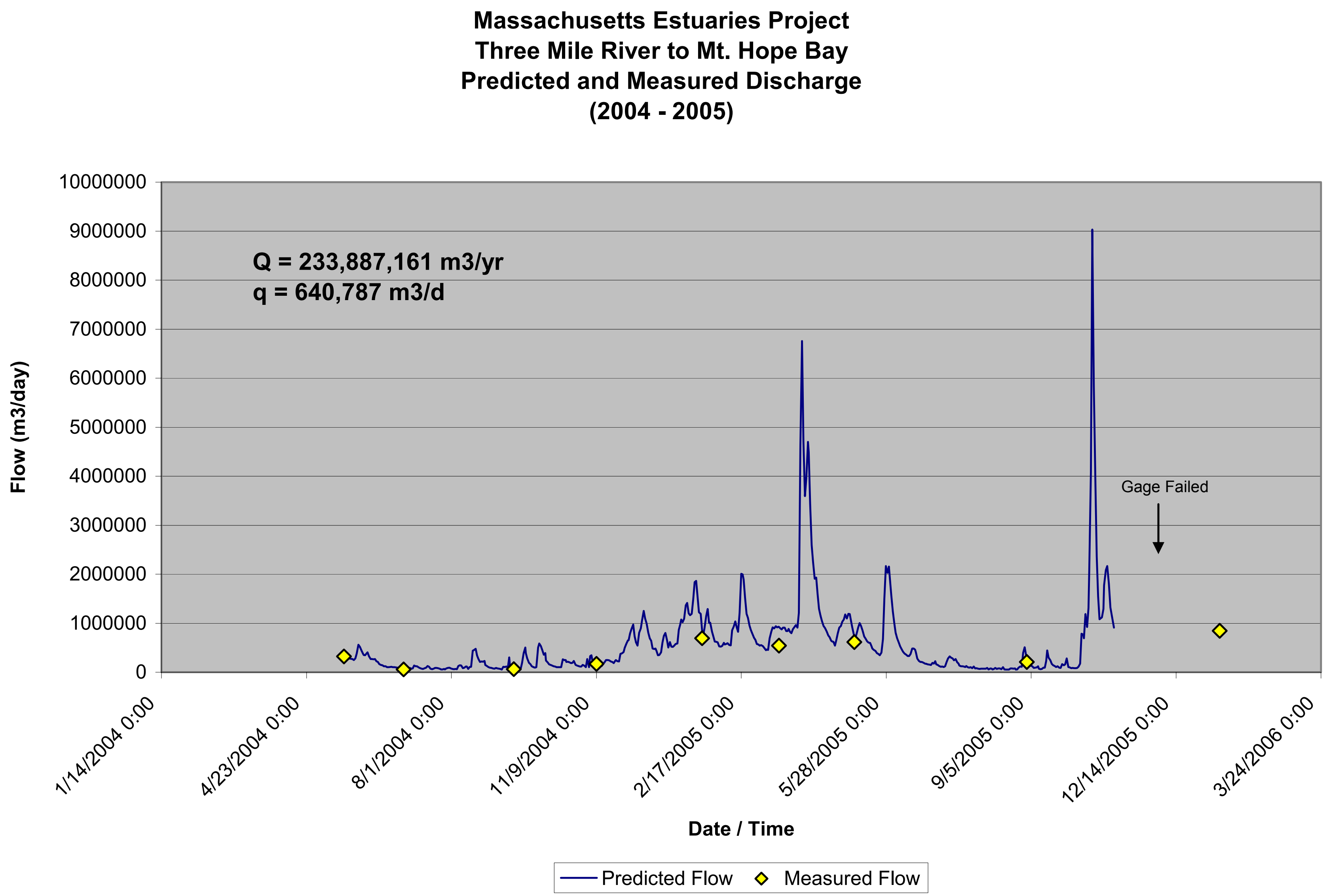

Figure 10 - Predicted daily discharge for the Three Mile River discharging to the estuarine reach of the Taunton River.

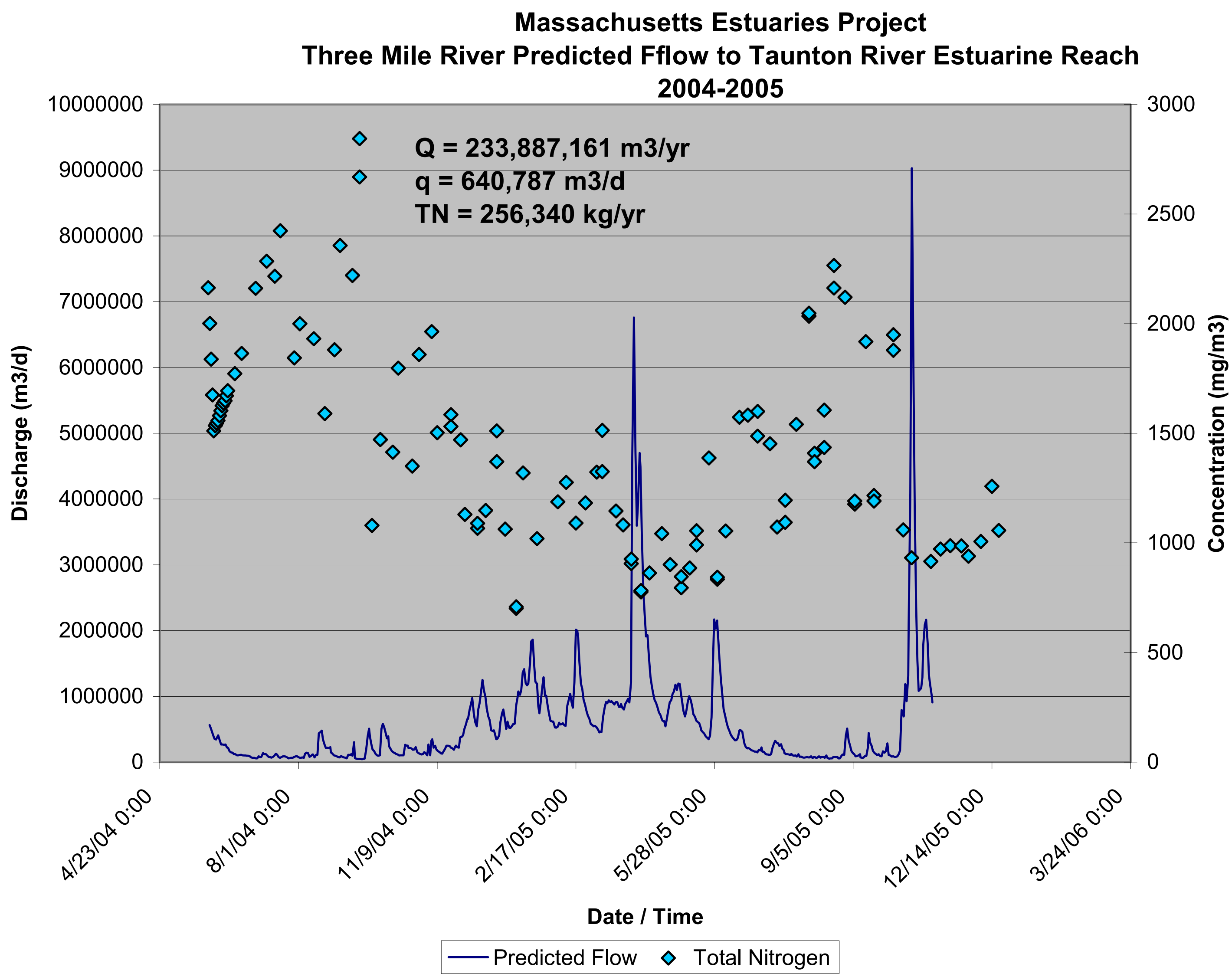

Figure 11 - Predicted daily discharge for Three Mile River relative to Total Nitrogen (TN) concentrations.

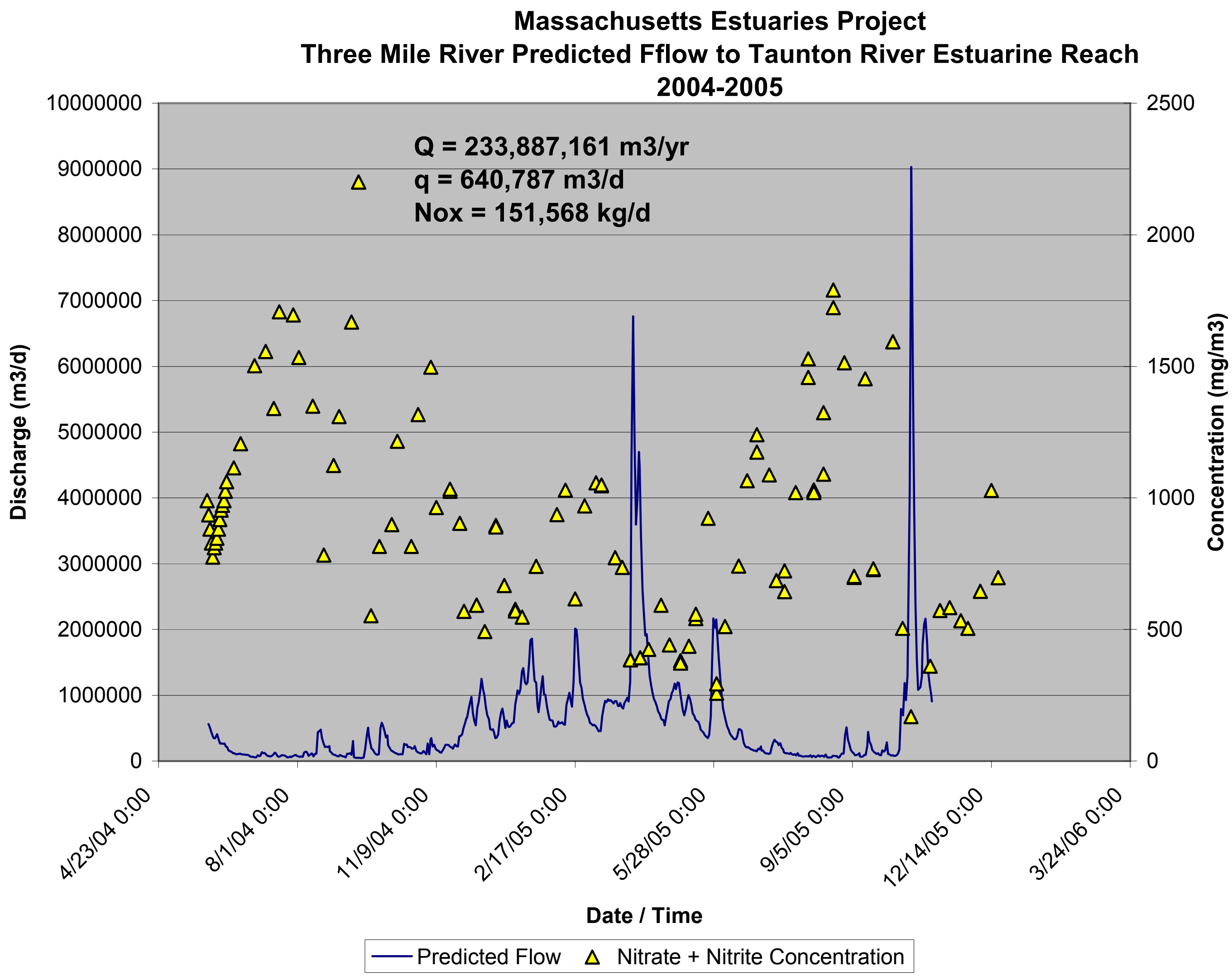

Figure 12 - Predicted daily discharge for Three Mile River relative to Nitrate + Nitrite (NOx) concentrations.

Surface water Discharge and Watershed Nitrogen Load: Segreganset River to Taunton River Estuarine Reach

Stream gaging on the Segreganset River provides for a direct measurement of the nitrogen loading to the estuarine reach of the Taunton River discharging to the Mt. Hope Bay embayment system. The combined rate of nitrogen attenuation by watershed-wide biological processes will be determined in the future by comparing the present predicted nitrogen loading (to be determined by the MEP) to the sub-watershed region contributing to the Segreganset River above the gauge site and the measured annual discharge of nitrogen to the tidal portion of the Segreganset River as determined under the 604(b) grant.

At the Segreganset River gauge site, a continuously recording vented calibrated water level gauge was installed to yield the level of water in the freshwater portion of the Segreganset River that carries the flows and associated nitrogen load to the estuarine reach of the Taunton River. As the Segreganset River is tidally influenced down gradient of the Elm Street bridge, the gage was located such that it be above the influence of saltwater at low tide. In this manner, flow measurements conducted at low tide would be a measure of freshwater being discharged from the Segreganset River at the gage. To confirm that freshwater was being measured at low tide, salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average low tide salinity was determined to be 0.5 ppt therefore, the gauge location was deemed acceptable for making freshwater flow measurements. Additionally, daily flows calculated using the rating curve developed under the 604(b) grant were confirmed relative to measured flows at the stream gage. Predicted daily flows agree favorably with measured flows used in the development of the rating curve. Calibration of the gauge was checked monthly.

The gauge on the Segreganset River was installed on May 19, 2004 and operated continuously for 21 months such that one summer seasons would be captured in the flow record. The gage was retrieved from the field in March 2006. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season and extends from September of 2004 to the end of August 2005 (one complete hydrologic year).

River flow (volumetric discharge) was measured at low tide every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Segreganset River gage based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Before using the continuously measured stage data to determine volumetric flow, tidal influence on stage was filtered out of the record by examining stage at ebb slack tide. Based on the daily flows obtained from the Segreganset River stage record, measured flows, and the rating curve, the annual freshwater flux was determined to be 41,288,006 m^3/yr yielding a daily discharge of 113,118 m^3/day (Figure 13). Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets will allow for the future determination of nitrogen mass discharge to the estuarine portion of the Taunton River and Mt. Hope Bay.

Total nitrogen concentrations within the Segreganset River outflow were moderate, on average 0.751 mg N L^{-1}, where as average Nitrate + Nitrite (NOx) concentration was 0.249 mg N L^{-1} (33 % of the Total Nitrogen pool). Additionally, particulate organic nitrogen (PON) with an average concentration of 0.061 mg N L^{-1} represented 8 % of the total nitrogen pool. In the Segreganset River, dissolved organic nitrogen (DON) with an average concentration of 0.264 mg N L^{-1} was as prevalent a form of nitrogen (35% of the Total Nitrogen pool) as NOx, indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was significantly taken up by plants within the pond or stream ecosystems prior to discharging to the Lower Taunton River system. Figures 14 and 15 depict the daily freshwater flow in the Segreganset River relative to the concentrations of Nitrate + Nitrite (NOx) and Total Nitrogen (TN) as determined from the weekly water quality sampling at the gage as supported by the 604(b) grant.

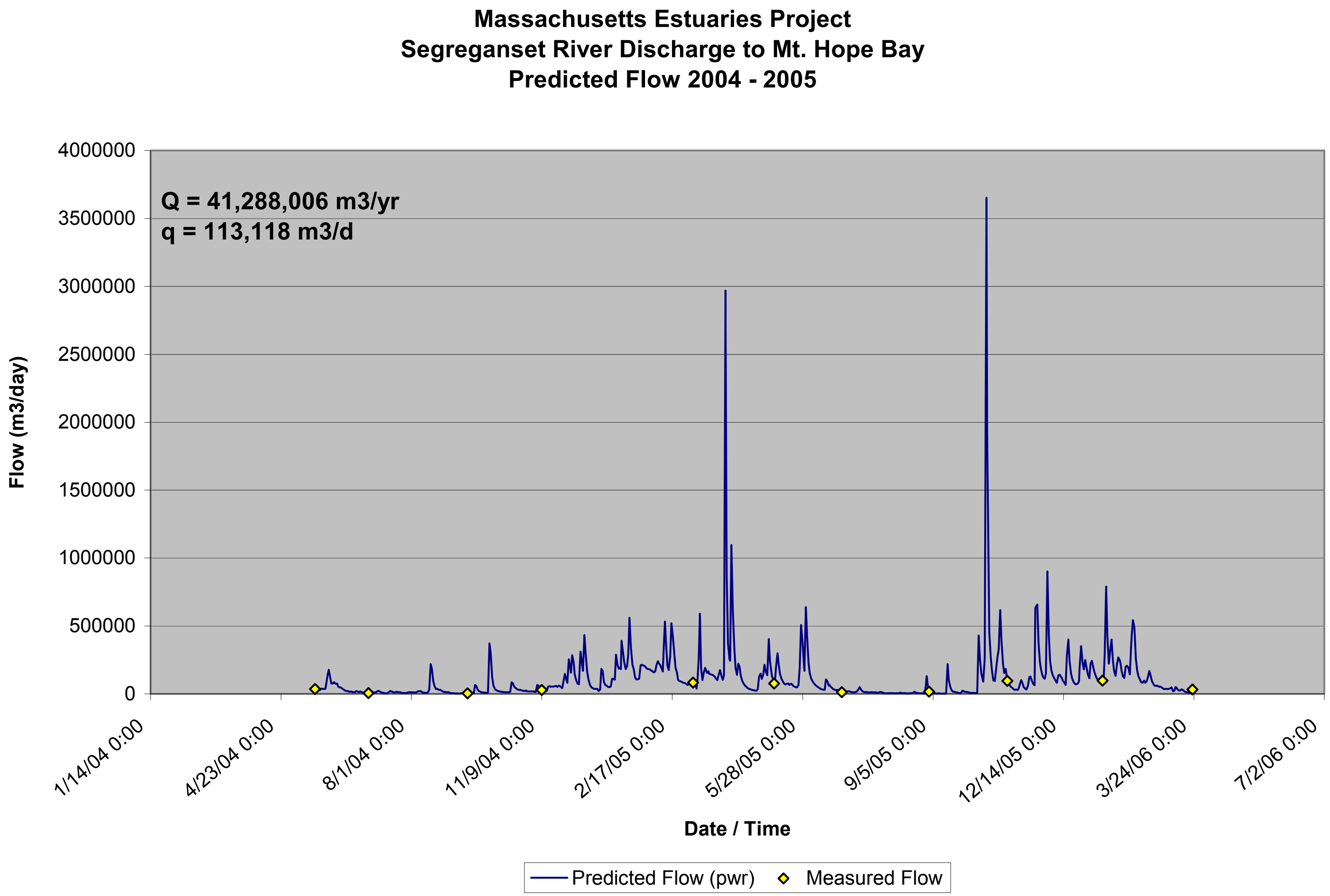

Figure 13 – Predicted daily discharge in the Segreganset River discharging to estuarine reach of the Taunton River.

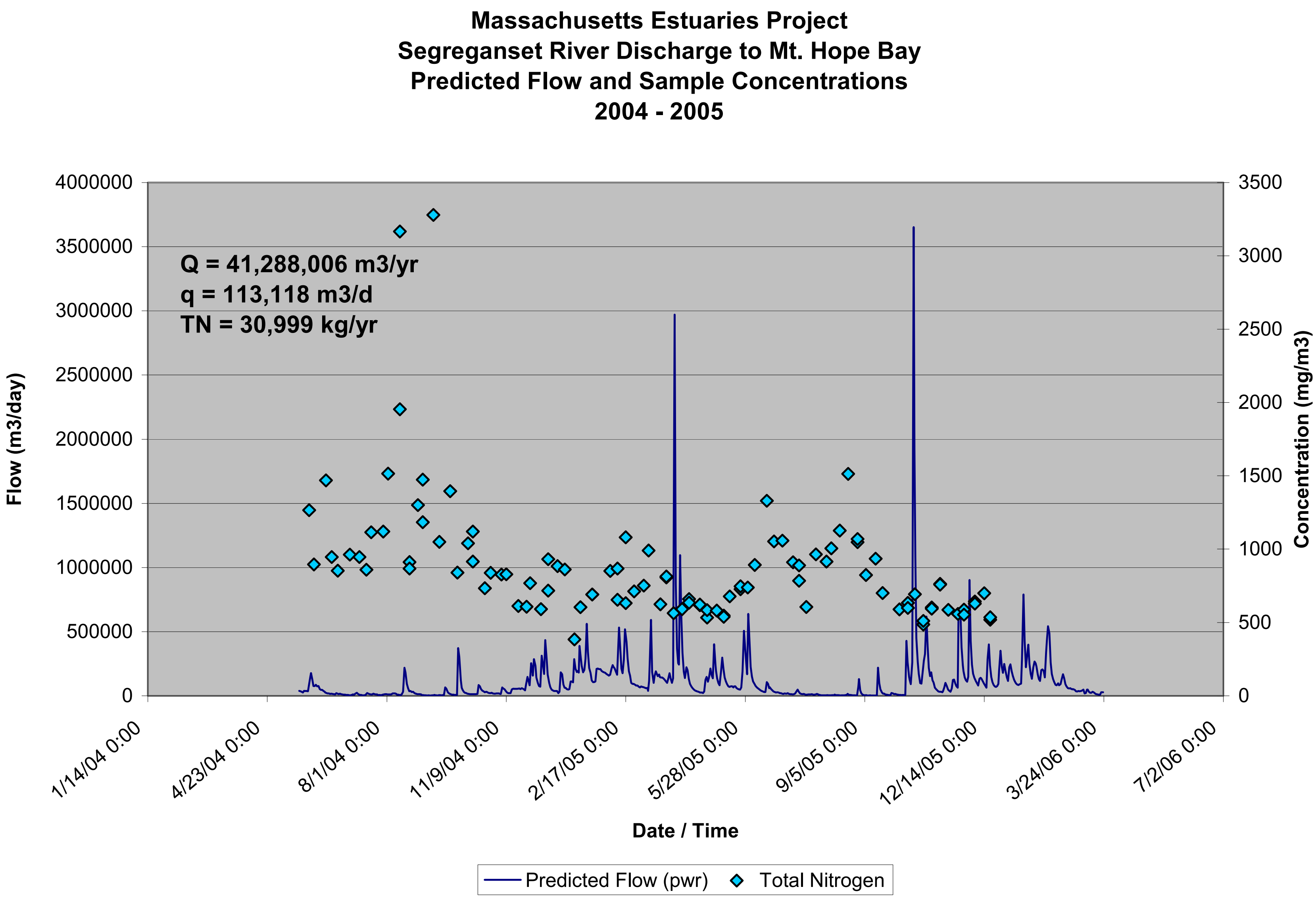

Figure 14 - Predicted daily discharge for the Segreganset River relative to Total Nitrogen (TN) concentrations

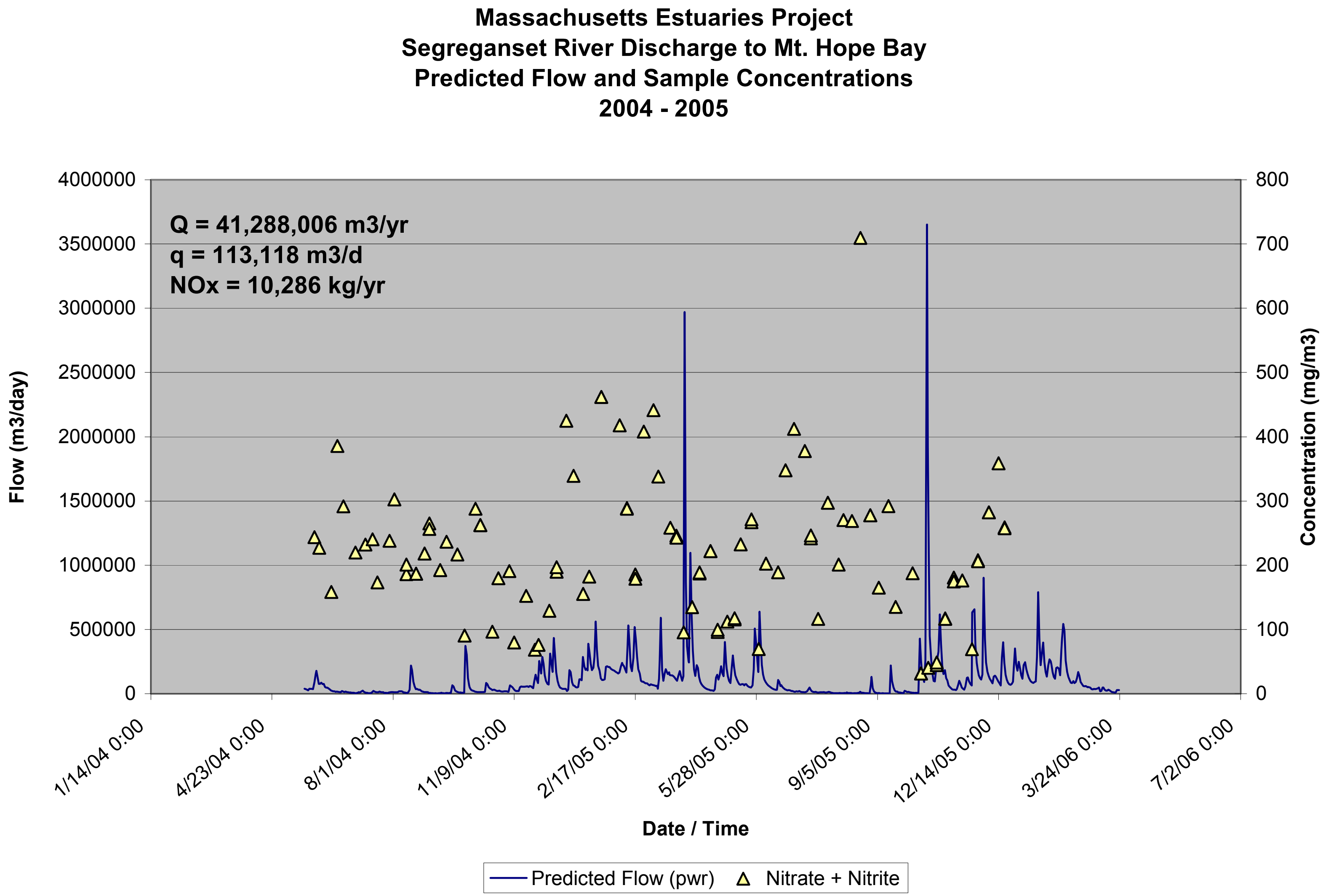

Figure 15 - Predicted daily discharge for the Segreganset River relative to Nitrate + Nitrite (NOx) concentrations.

Surface water Discharge and Watershed Nitrogen Load: Assonet River discharge to Mt. Hope Bay

Stream gaging on the Assonet River to the estuarine reach of the Taunton River provides for a direct measurement of the nitrogen loading to the Mt. Hope Bay embayment system. The combined rate of nitrogen attenuation by watershed-wide biological processes will be determined in the future by comparing the present predicted nitrogen loading (to be determined by the MEP) to the sub-watershed region contributing to the Assonet River above the gauge site and the measured annual discharge of nitrogen to the tidal portion of the Assonet River system as determined under the 604(b) grant.

At the Assonet River gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the Assonet River that carries the flows and associated nitrogen load to the estuaine reach of the Taunton River and ultimately, Mt. Hope Bay. As the Assonet River is tidally influenced down gradient of the Route 79 bridge crossing, the gage was located such that it be above the influence of saltwater at low tide. In this manner, flow measurements conducted at low tide would be a measure of freshwater being discharged from the Assonet River at the gage. To confirm that there was not tidal influence at the gage, salinities where measured for indication of freshwater flow at the gage. Salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average salinity was determined to be 0.3 ppt therefore, the gage location was deemed acceptable for making freshwater flow measurements. Additionally, daily flows calculated using the rating curve developed under the 604(b) grant were confirmed relative to measured flows used in the development of the rating curve. As depicted in Figure 16, predicted flows agree well with measured flows obtained during the deployment period. Calibration of the gauge was checked monthly. The gage on the Assonet River was installed on May 20, 2004 and operated continuously for 21 months such that one summer seasons would be captured in the flow record. The gage was retrieved from the field in March 2006. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season and extends from mid September of 2004 to mid September of 2005 (one complete hydrologic year).

River flow (volumetric discharge) was measured at low tide every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Assonet River gage based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Before using the continuously measured stage data to determine volumetric flow, tidal influence on stage was filtered out of the record by examining stage at ebb slack tide. Based on the daily flows obtained from the Assonet River stage record, measured flows, and the rating curve, the annual freshwater flux was determined to be 106,115,523 m^3/yr yielding a daily discharge of 290,727 m^3/day (Figure 20). Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets will allow for the future determination of nitrogen mass discharge to the estuarine portion of Mt. Hope Bay.

Total nitrogen concentrations within the Assonet River outflow were moderate, on average 0.717 mg N L^{-1}, where as Nitrate + Nitrite (NOx) was on average 0.083 mg N L^{-1} (12% of the Total

Nitrogen pool). In the Assonet River, dissolved organic nitrogen (DON) was by far the predominant form of nitrogen relative to the Total Nitrogen pool (76%), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was significantly taken up by plants within the pond or stream ecosystems prior to discharging to the estuarine reach of the Taunton River. Figures 17 and 18 depict the daily freshwater flow in the Assonet River relative to the concentrations of Total Nitrogen (TN) and Nitrate + Nitrite (NOx) as determined from the weekly water quality sampling at the gage as supported by the 604(b) grant.

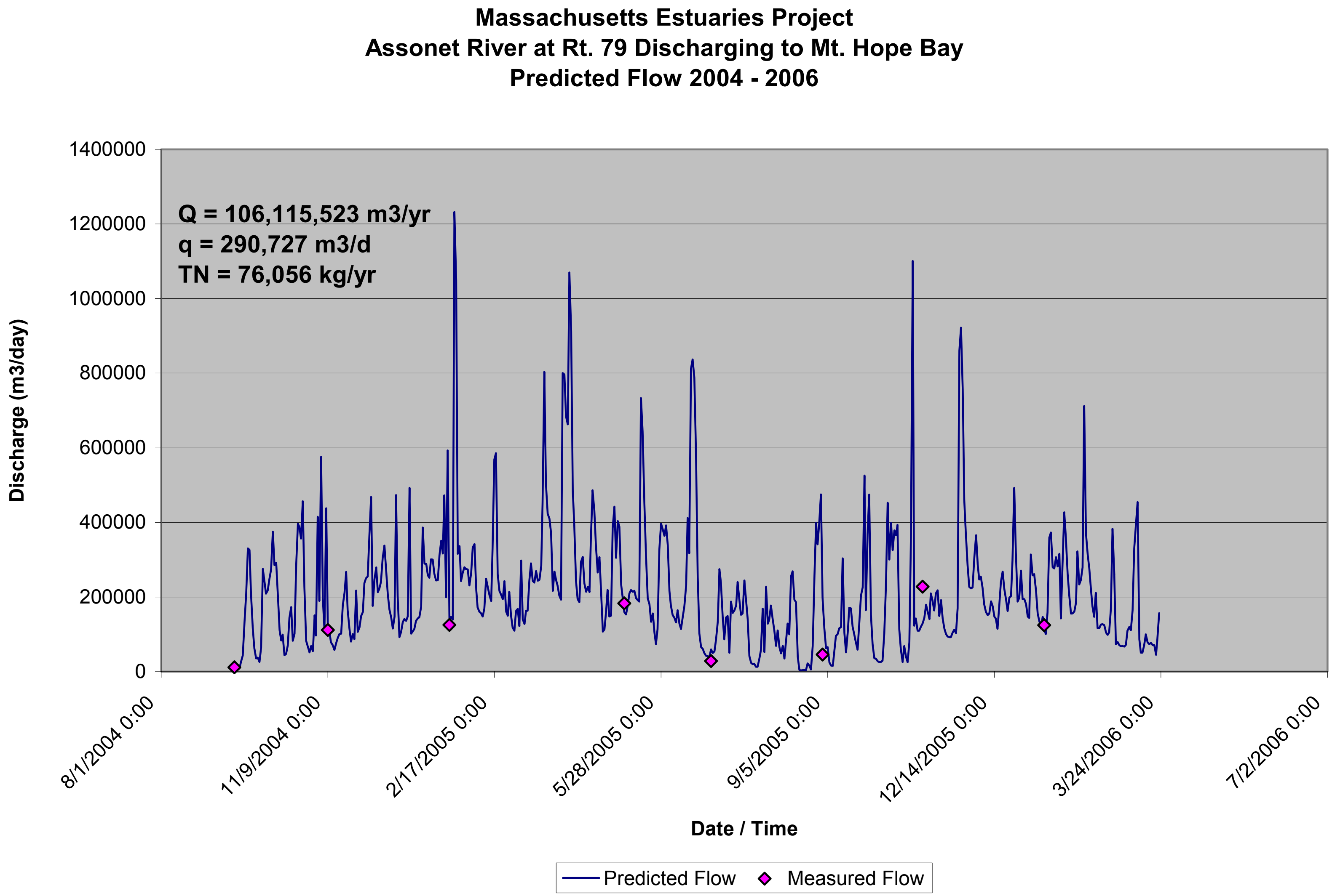

Figure 16 – Predicted daily discharge for the Assonet River discharging into the estuarine reach of the Taunton River.

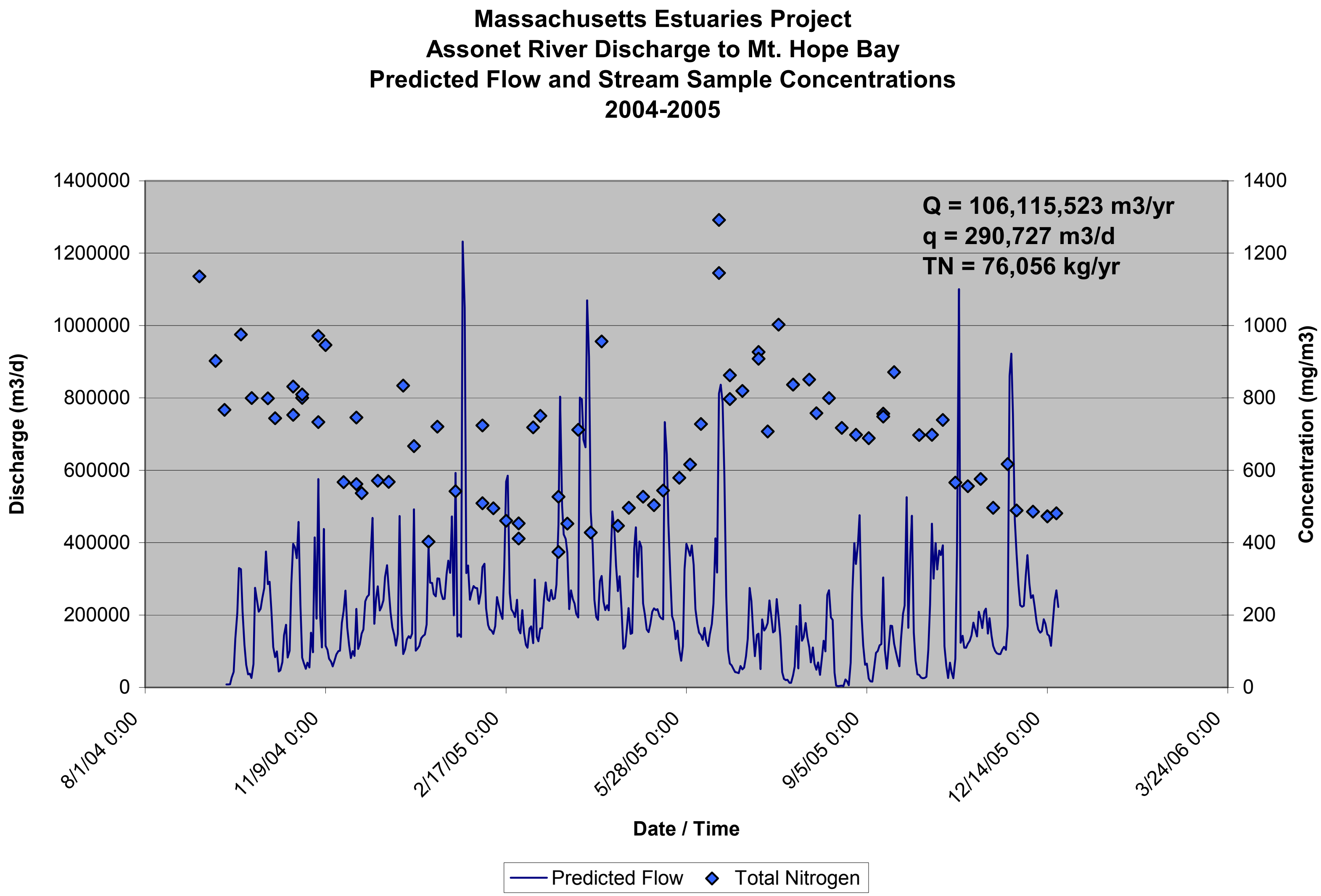

Figure 17 – Predicted daily discharge relative to Total Nitrogen (TN) concentrations for the Assonet River discharging to the estuarine reach of the Taunton River.

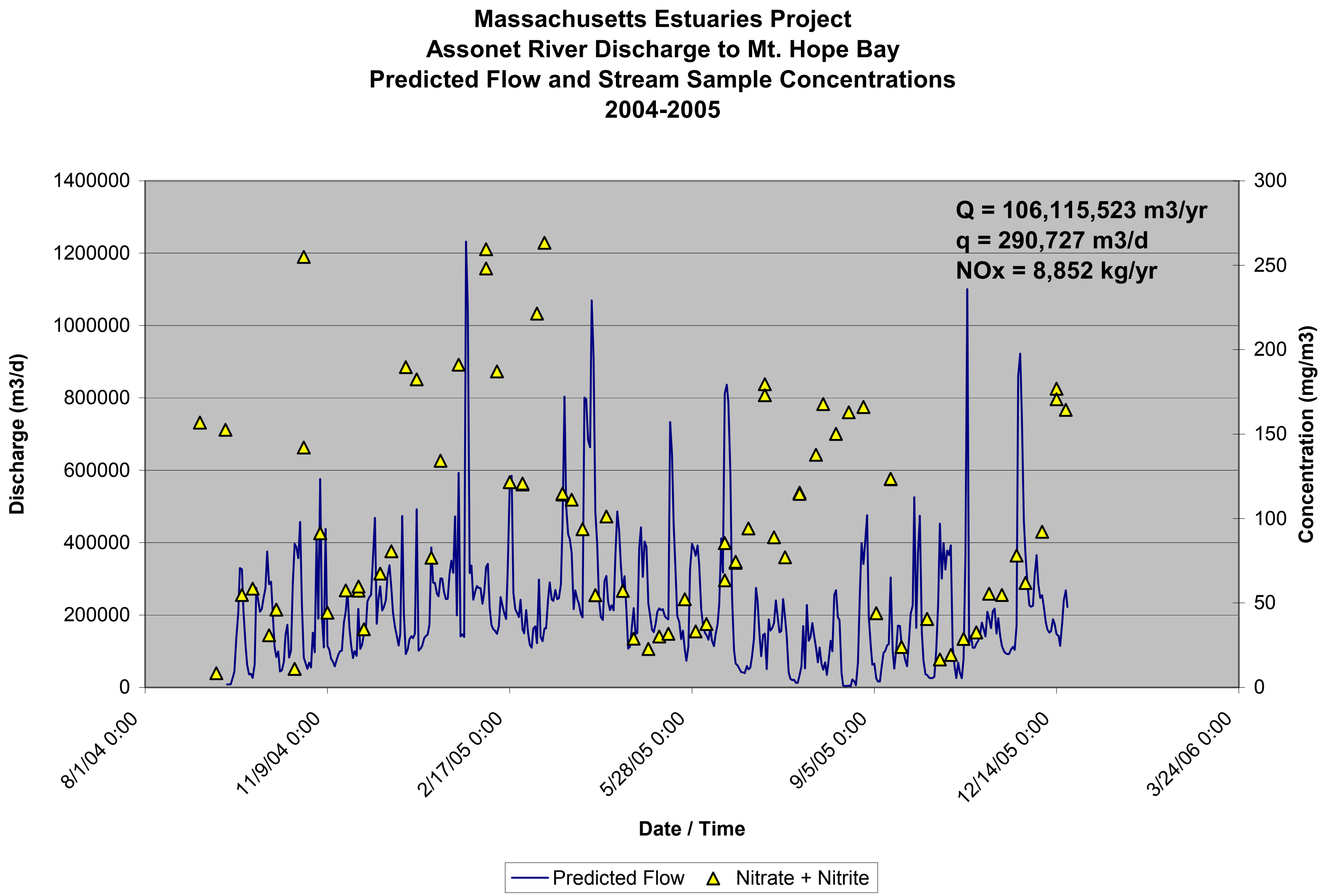

Figure 18 – Predicted daily discharge relative to Nitrate + Nitrite (NOx) concentrations for the Assonet River discharging to the estuarine reach of the Taunton River.

Surface water Discharge and Watershed Nitrogen Load: Quequechan River discharge to Mt. Hope Bay

Stream gaging on the Quequechan River to lower estuarine reach of the Taunton River (Battleship Cove) provides for a direct measurement of the nitrogen loading to the Mt. Hope Bay embayment system. The combined rate of nitrogen attenuation by watershed-wide biological processes will be determined in the future by comparing the present predicted nitrogen loading (to be determined by the MEP) to the sub-watershed region contributing to the Quequechan River above the gauge site and the measured annual discharge of nitrogen to the tidal portion of the lower Taunton River system as determined under the 604(b) grant.

At the Quequechan River gage site, a continuously recording vented calibrated water level gage was installed to yield the level of water in the freshwater portion of the Quequechan River that carries the flows and associated nitrogen load to the lower Taunton River. As the Quequechan River is tidally influenced down gradient of the rail road bridge crossing, the gage was located such that it be above the influence of saltwater at low tide. In this manner, flow measurements conducted at low tide would be a measure of freshwater being discharged from the Quequechan River at the gage. To confirm that there was not tidal influence at the gage, salinities where measured for indication of freshwater flow at the gage. Salinity measurements were conducted on the weekly water quality samples collected from the gauge site. Average salinity was determined to be 0.5 ppt therefore, the gage location was deemed acceptable for making freshwater flow measurements. Additionally, daily flows calculated using the rating curve developed under the 604(b) grant were confirmed relative to measured flows used in the development of the rating curve. As depicted in Figure 19, predicted flows agree well with measured flows obtained during the deployment period. Calibration of the gauge was checked monthly. The gage on the Quequechan River was installed on May 21, 2004 and operated continuously for 21 months such that one summer season would be captured in the flow record. The gage was retrieved from the field in March 2006. The 12-month uninterrupted record used in this analysis encompasses the summer 2004 field season and extends from September of 2004 to the end of August 2005 (one complete hydrologic year).

River flow (volumetric discharge) was measured at low tide every 4 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the Quequechan River gage based upon these flow measurements and measured water levels at the gage site. The rating curve was then used for conversion of the continuously measured stage data to obtain daily freshwater flow volume. Before using the continuously measured stage data to determine volumetric flow, tidal influence on stage was filtered out of the record by examining stage at ebb slack tide. Based on the daily flows obtained from the Quequechan River stage record, measured flows, and the rating curve, the annual freshwater flux was determined to be 45,351,644 m^3/yr yielding a daily discharge of 124,251 m^3/day (Figure 20). Water samples were collected weekly for nitrogen analysis. Integrating the flow and nitrogen concentration datasets will allow for the future determination of nitrogen mass discharge to the estuarine portion of Ellisville Harbor.

Total nitrogen concentrations within the Quequechan River outflow were moderately high, on average 0.805 mg N L^{-1}, where as Nitrate + Nitrite (NOx) was on average 0.143 mg N L^{-1} (18% of the Total Nitrogen pool) In the Quequechan River, dissolved organic nitrogen (DON) was a prevalent fraction of the total nitrogen pool (52%) indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the freshwater ponds and to the river was significantly taken up by plants within the pond or stream ecosystems prior to discharging to the lower Taunton River and the Mt. Hope Bay system. Figures 20 and 21 depict the daily freshwater flow in the Quequechan River relative to the concentrations of Total Nitrogen (TN) and Nitrate + Nitrite (NOx) as determined from the weekly water quality sampling at the gage as supported by the 604(b) grant.

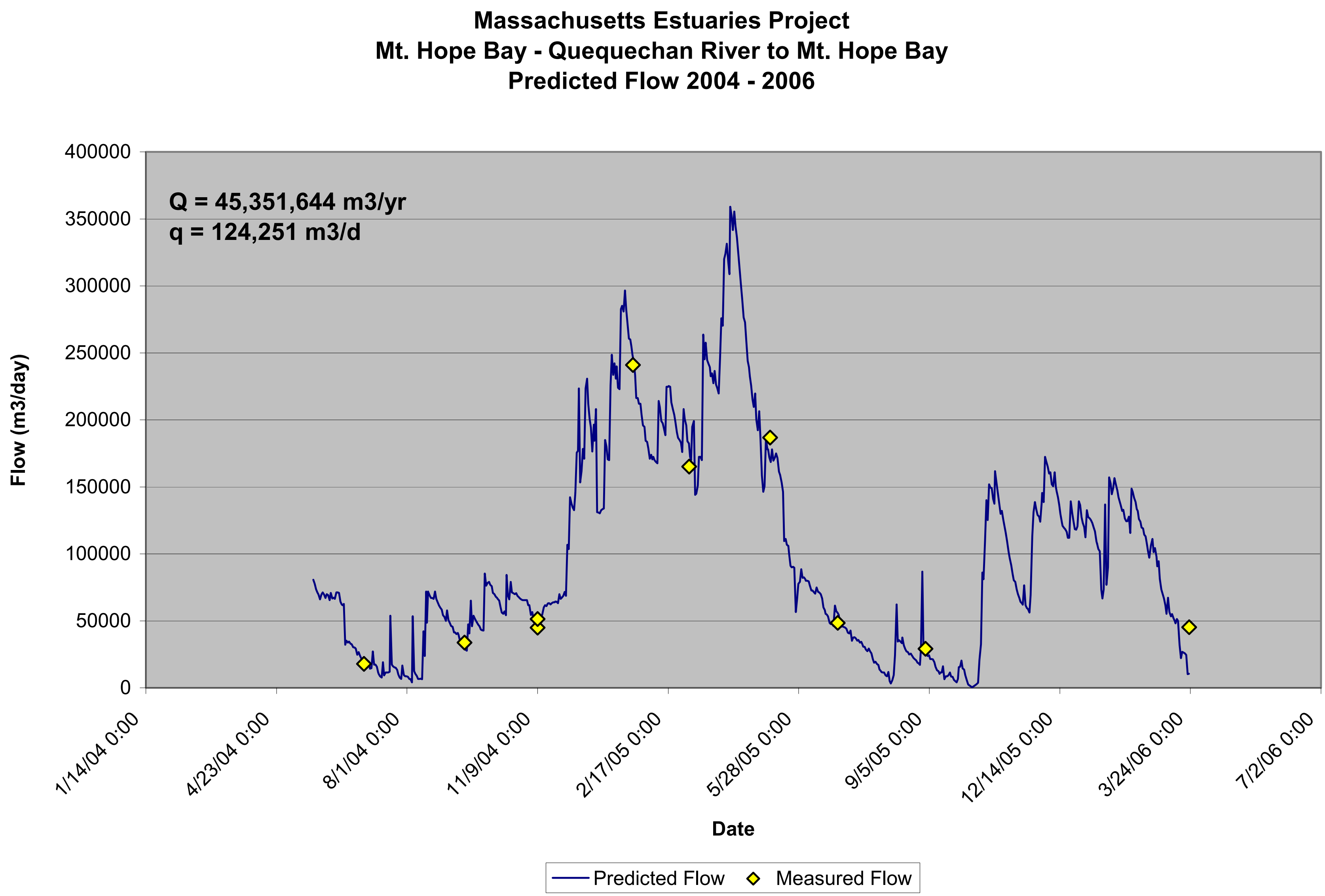

Figure 19 – Predicted daily discharge for the Quequechan River discharging into the estuarine reach of the Taunton River.

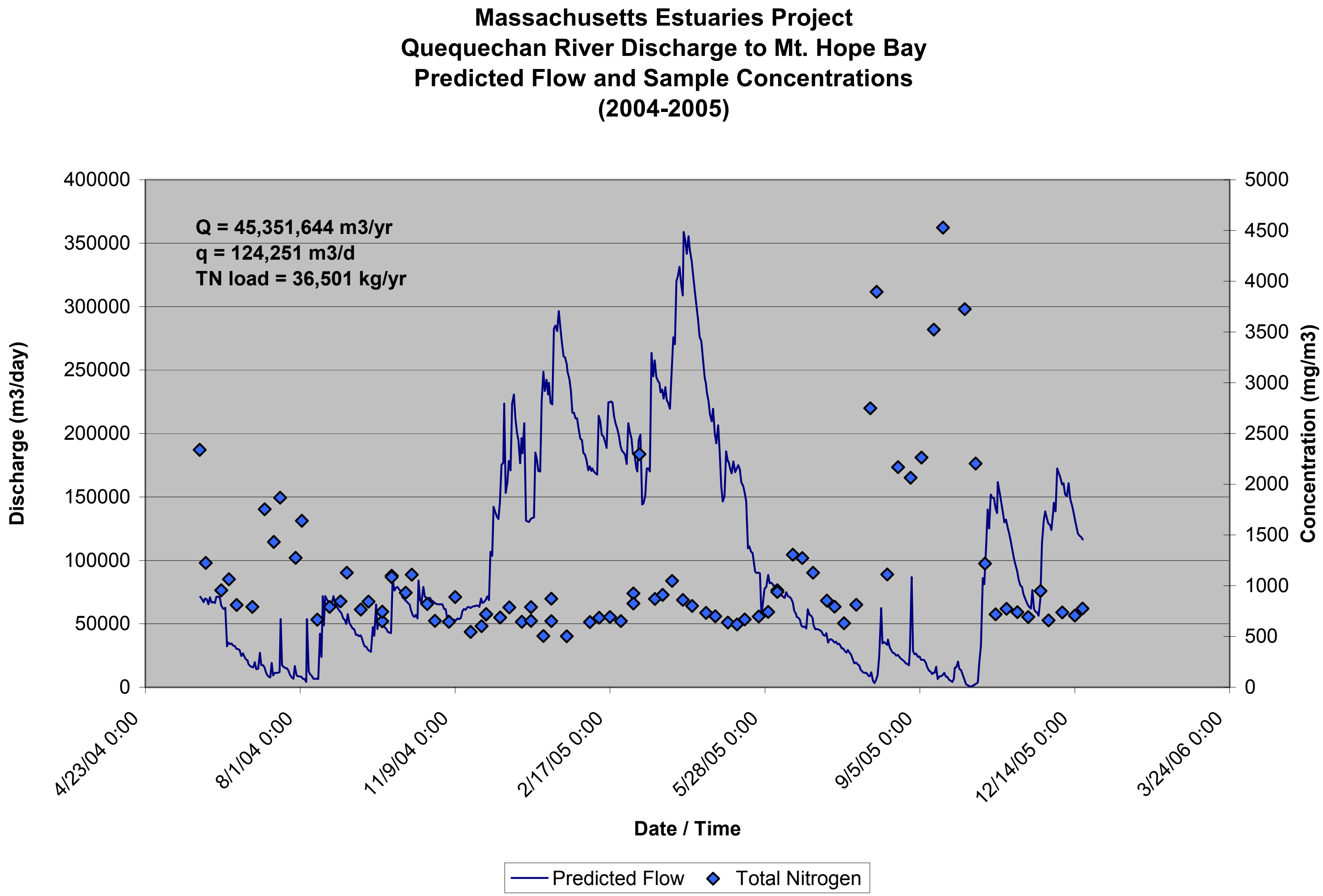

Figure 20 – Predicted daily discharge relative to Total Nitrogen (TN) concentrations for the Quequechan River discharging to the estuarine reach of the Taunton River.

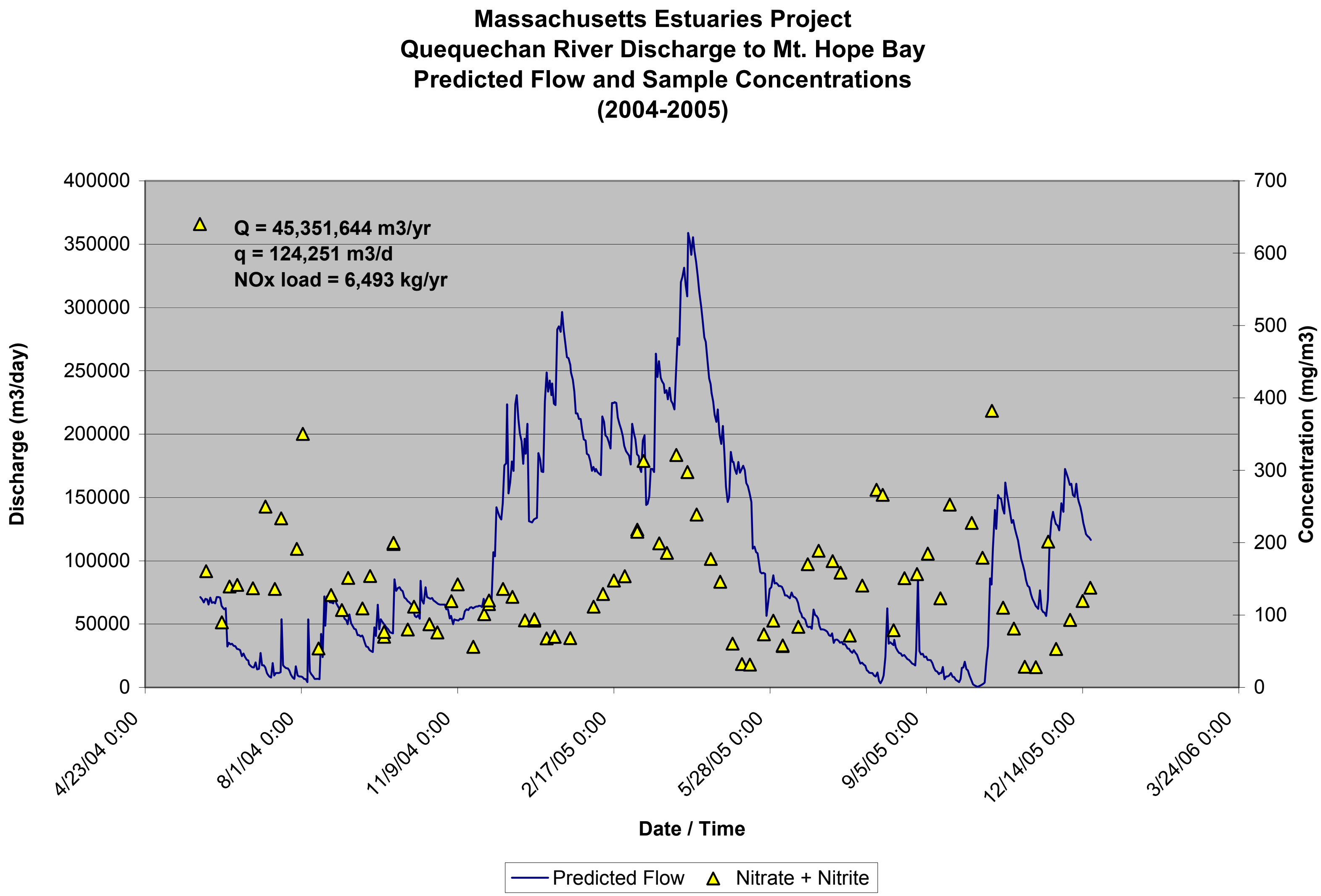

Figure 21 – Predicted daily discharge relative to Nitrate + Nitrite (NOx) concentrations for the Quequechan River discharging to the estuarine reach of the Taunton River.

EMBAYMENT SYSTEM	PERIOD OF RECORD	DISCHARGE (m3/year)	ATTENUATED LOAD (Kg/yr)	
			Nox	TN
Taunton River at Weir Village Bridge	**September 1, 2004 to August 31, 2005**	**1172417821**	**876951**	**1629974**
Three Mile River at Route 139	**September 1, 2004 to August 31, 2005**	**233887161**	**151568**	**256340**
Segreganset River at Elm Street	**September 1, 2004 to August 31, 2005**	**41288006**	**10286**	**30999**
Assonet River at Route 79 Bridge	**September 15, 2004 to September 14, 2005**	**106115523**	**8852**	**76056**
Quequechan River at Rail Road Bridge (Battleship Cove)	**September 1, 2004 to August 31, 2005**	**45351644**	**6493**	**36501**

Table 8 – Summary of stream flows and nutrient loads to the estuarine reach of the Taunton River discharging to Mt. Hope Bay.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, it appears that the Massachusetts Estuaries Project (MEP) analysis is warranted for both estuarine systems (Taunton River estuarine system and Mt. Hope Bay embayment system) monitored under these 604(b) projects and that water quality monitoring needs to continue in order to develop the best baseline possible to invoke the MEP nutrient threshold analysis.

With regards to the specifics of each embayment monitored under the 604(b) grant program, certain water quality characteristics have become apparent as follows:

- The N/P molar ratios did support the contention that Mt. Hope Bay and the Taunton River estuary are N limited. The average ratio of inorganic nitrogen to inorganic phosphorus (N/P) was quite low, <3, at all stations within the Bay, although the Taunton River estuarine stations showed consistently higher ratios (5-10).

- The estuary shows a moderate salinity gradient. With the exception of the upper reaches nearest the freshwater entry, almost all of the waters ranged from 19 ppt to 28 ppt nearest the channel at Bristol Point. The salinity gradient results from the high predominantly riverine freshwater inflow and the high tidal flushing of this enclosed basin. Only the stations directly influenced by the Taunton River (MHB19-21) and the Kickamuit River (MHB-9) showed significant dilution of the main Bay.

- Chlorophyll a levels throughout this system are generally high in the summer, >11 ug L^{-1}, supporting the assessment of a nutrient enriched estuary and indicating that organic matter production is capable of supporting a high level of oxygen demand.

- The Taunton River estuarine reach, as the focus of upper watershed N loading, showed very high total nitrogen levels (TN) in its upper reach (1.058 mg N L^{-1}) and maintained high levels throughout most of its reach (>0.6 mg N L^{-1}).

- The main basin of Mt. Hope Bay supported lower TN levels primarily as a result of mixing with incoming waters (generally 0.5-0.6 mg N L^{-1}). This is consistent with the observed oxygen depletions and infauna animal communities.

- The highest water quality was found at the stations nearest the channels to lower Narragansett Bay and the Sakonet River (MHB-15, 16).

- The Taunton River Estuary, with its large watershed N load and high TN levels, is showing poor water quality due to its high chlorophyll and oxygen depletions.

- The main basin of Mt. Hope Bay, with its greater flushing and access to higher quality waters of the lower Bay, is showing less impairment.

- The lower basin of Mt. Hope Bay, nearest the tidal "inlet", is generally showing moderate to high water quality. The impaired waters in the regions nearest the river discharges most likely result from their lower flushing rates and from nitrogen loads.

- The data collected via the 604(b) grant program indicate that additional sampling in the basin in the lower region of Mt. Hope Bay, near the tidal inlets, may be warranted. In addition, these data indicate that the MEP analysis of this system should focus on restoration of the main basin of Mt. Hope Bay and the Taunton River estuarine reach. It is likely that restoration of the Taunton River Estuary will have a significant positive effect on the habitat quality of the main basin of Mt. Hope Bay

- Overall, it appears that the MEP analysis is warranted for the Mount Hope Bay/Taunton River estuarine complex as assessed by the water quality monitoring data

5.0 DATA QUALITY ASSURANCE AND CONTROL

The lab data will be reviewed by Dr. Brian Howes to assure that the data meets SMAST Quality Assurance requirements. At this stage, the source identity of blind duplicate samples will reside solely with Dr. David White, Project QA Officer. The resulting data will then be evaluated by Dr.s White and Howes to compare blind duplicate results with their source samples to assess the accuracy of the lab analyses. The level of repeatability of the data collected by the monitoring program and the chemical assays conducted by the SMAST Coastal Systems Analytical Facility are presented in Table B.1-4 of the approved over-arching Massachusetts Estuaries Project QAPP (June 13, 2003). As stated in the MEP QAPP, in some cases these data acceptance criteria are more rigorous than minimum requirements put forth in Tables B.1-1 and B.1-2. If acceptance criteria are not met, a detailed field study will have to be undertaken to determine if the cause of the difference between replicate samples is due to the hydrodynamics of the system or sampling and analysis procedures. Since duplicates are collected on consecutive casts, there is a possibility that patchiness in the water column is being seen in the data. Significant difference in a single duplicate sample is not sufficient to trigger action. The acceptability of the data is assessed based upon the overall pattern of agreement between blind duplicates.

Lab results will be scrutinized both for each station over the course of the sampling program and for all stations within the embayment system during each sampling round. The data will be compared to identify suspicious outliers that will be assessed first by examining the lab accuracy for that date and then by considering the setting at the sample site to determine any unique conditions that might cause the observed results. Possible causative factors for data outliers are anticipated to include: proximity to a fresh water discharge; location within a poorly circulated recess of the estuary; recent rainfall (collected from National Weather Service station at the New Bedford Municipal Airport); handling or collection errors; and lab error as indicated by blind duplicate results for that date.

Record keeping of Quality Assured (QAed) data will follow the Coastal Systems Program Analytical Facility Laboratory Quality Assurance Plan which has been submitted and accepted by the MA DEP and is available for DEP internal use only. Hard copy data such as raw data books, field data sheets, and chain of custody forms are all held by the Laboratory Manager in data notebooks. Analytical data sheets, field data sheets, COC's, electronic spreadsheets, calculation sheets are annotated with personnel's name and date when they were created and modified (when and by whom). Electronic databases are held both on the access protected hard drives of the Laboratory Manager and/or the QA Manager. In addition, immediate backup is held on the SMAST central computer which is maintained by professional full-time CIT staff. CD copies are also generally created for larger projects. Synthesized data will be reported to the Southeast Regional Planning and Economic Development District (SRPEDD) in a technical report developed by Dr.s White and Howes discussing the details of the sampling program, water quality data presented in tabular format, discussion of water quality trends, flow and nutrient loads from freshwater inputs, and a discussion of seasonal differences. A summary will be provided describing the general state of the embayment systems relative to the water quality data collected under this monitoring program. Data submittals will include field data, laboratory analyses and duplicates.

APPENDIX – A

FIELD SAMPLING PROTOCOL (NUTRIENTS)

MEP FIELD SAMPLING PROTOCOLS: NUTRIENTS

5.1 Nutrient Sample Collection Overview (MEP QAPP Appendix B-1, H)

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 occur during the last three hours of an outgoing tide. Through training sessions, hands-on instruction and sampling tips, we will provide sampling teams with the information necessary to ensure efficiency and accuracy in the measurements. Please call (Sara Sampieri) 508-910-6352) 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: dissolved oxygen (milligrams per liter), water temperature, specific conductance, 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
Dissolved Organic N	Total Phosphorus (streams only)	Specific Conductance/Salinity
Total Suspended Solids		

5.2 Arriving On Station

The on-shore landmarks will be used to approximate sample station location, with final sample station determined by GPS. However, it is anticipated that, for the stream stations and nearshore marine stations, that landmarks or navigational bouys will provide sufficient location information once sampling is underway. All stations will be located by GPS so that future sampling programs can easily return to them. The boat will be anchored so that it remains in a fixed position while samples are collected and profile readings taken. The boat should approach the sample location moving into the current to minimize sediment disturbance for all sample stations but particularly for shallow stations (anticipated water depth less than 1 meter).

5.3 Order of Data Collection on Station

In order to avoid bottom disturbance, the following data collection order will be followed:

- Use Secchi disk to determine light penetration and to determine exact depth from stern of boat and wait until after touching bottom (5 minutes) before proceeding
- Collect meter data in vertical profile using depth information to collect data to within 0.5 meters of the bottom (from side or bow of boat)
- Collect water samples (from the side or bow of boat)

5.4 General Information and Weather (Appendix A also MEP QAPP Append B-1 H)

The following parameters will be recorded on the 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 (collected by SMAST from NOAA weather station located at New Bedford Regional Airport, Lat. 41 40 31N Lon. 070 57 25W, in New Bedford, MA.).
* Any unusual natural or man-made conditions.
*Fill out each field data sheet with the pond, station number, time, cloud cover and wind direction and speed and wave height if it has changed from the previous station.

5.5 Dissolved Oxygen, Field Data Collection with YSI-55 Meter and Probe

The meter is calibrated each day on shore before starting the sampling. Calibration is described in Appendix B. Once calibrated, the meter should be left on throughout the course of the sampling day. If turned off, it must be re-calibrated for Dissolved Oxygen prior to proceeding with data collection. The meter provides readings of: dissolved oxygen milligrams per liter and temperature (percent saturation can be calculated combining these data with the laboratory assays of specific conductance). When arriving on station, once the boat is secured with the anchor, remove the probe from its protective housing and place it into the surface water to allow it to equilibrate with the surface water temperature.

The meter data should be collected in the same order as listed above (Section 5.3). At each depth interval, record the data on the field data sheets. The meter cable is marked in 10 cm intervals. At each depth, the probe should be moved in an up and down manner over a distance of several inches to circulate water over the probe. Wait to record data until the reading for each parameter has stabilized. If the water depth is <1.5 meter, samples should be collected at mid water, if 1.5-3.5 meter, then samples should be collected at surface (15 cm) and bottom (0.30-0.5 meter above sediment) and if >3.5 meter at surface, 2 meters and bottom. If the D.O. reading from the YSI 55 is less than 5 mg/L, collect a water sample for dissolved oxygen by Winkler analysis.

5.6 Nutrient & Chlorophyll Sample Collection Protocol (MEP QAPP Appendix B-1, H)

Sample collection should proceed in the up-current or up-wind direction from the meter readings and only after any suspended bottom sediments have settled. Each task described herein will be performed at each station in the embayment beginning in the inner portion and moving outward (toward the inlet). Samples are collected by Niskin Bottle. If the water depth is <1.5 meter, samples should be collected at mid water, if 1.5-3.5 meter, then samples should be collected at surface (15 cm) and bottom (0.30-0.5 meter above sediment) and if >3.5 meter at surface, 2 meters and bottom.

5.7 Water Quality Sampling Protocol: Nutrients, Oxygen, Physical Parameters:

1. The day before

(a) Review Checklist for all equipment – Call for replacements.
(b) Label all bottles with Station ID, Date and Depth (Top, Middle or Bottom).
(c) Mount filters in filter holders.
(d) Put ice packs in freezer.
(e) Add capped waste bottle, paper towels & wash bottle w/distilled water to kit.

MAKE SURE ICE IS IN COOLER

2. Anchor at Sampling Station & Record Station Observation Data including:
Sampler Names, Station Number, Date & Time, Wind Info, Weather Conditions.

3. Collect Depth & Secchi Disk Information

(a) Lower Secchi disk until it just disappears from view. Read & record depth at waterline.
(b) Lower Secchi disk further then raise until just visible. Read & record depth at waterline.
(c) Average 2 Secchi disk readings & record.
(d) Lower Secchi disk to bottom & record total depth.

4. Collect Nutrient and Chlorophyll a Samples.

(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 Niskin Bottle to 15 cm below the surface and pull stopper, bring to surface, shake and dump to rinse bottle; reset and repeat at appropriate depths. If a sample is collected for dissolved oxygen Winkler analysis, the sample will be collected first and processed as in Section 7.5, below.
(c) Add about 50 mL to 1L nutrient (white) bottle, cap, shake and dump out, repeat. Then fill bottle to shoulder then put in cooler, and shut cooler lid.
(d) Repeat rinse and filling procedure with 1 liter brown Chlorophyll bottle, cap and put in cooler.

PUT NUTRIENT AND CHLOROPHYLL SAMPLES IN COOLER IMMEDIATELY

(e) A filtered sample needs to be processed as indicated in the next section (Section 6).

Note: Surface samples can be taken by hand if desired. If taking samples by hand you must hold the open bottle in an inverted vertical position while submerging to the desired depth and then tip upright to fill.

6.0 FIELD SAMPLE PROCESSING (on station filtering)

Samples will be prepared for dissolved nutrient analyses by filtration. Samples for dissolved nutrient analyses will be filtered through a 0.45-micron cellulose acetate filter 47 millimeters in diameter into a 60 cc acid-leached plastic bottle.

- **TO BE DONE AS SOON AS POSSIBLE AFTER COLLECTION (<1 hr)**
- Filtered samples are to be shipped in the small white 60 cc plastic bottle (these bottles are acid leached and provided by SMAST)

Filtering for Dissolved Nutrients Procedure (MEP QAPP Appendix B-1, H):

1. Remove white 1 liter sample bottle from cooler, one station bottle at a time.
2. Label a 60cc bottle with identical station information:
    a. Embayment abbreviation name
    b. Station ID
    c. Sample Depth (in meters)
    d. Date (mo/dy/yr)

3. Place filter (using provided forceps) in clear plastic filter holder. (white filter, not the blue paper).
4. Vigorously 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.

Place samples in cooler with 1 Liter bottles for transport.

7.0 SAMPLING USING DISSOLVED OXYGEN (D.O.) METER – YSI 55

7.1 Instrument Warmup

Turn on D.O. meter and allow 10 minutes for meter to stabilize. Ensure that the sponge in calibration/storage chamber is moist and the probe is inserted in the calibration chamber.

7.2 Calibration

(a) If reading is in mg/l, **Hit Mode key to put in % saturation mode** before entering calibration mode.
(b) **Press UP ARROW & DOWN ARROW** at same time to enter calibration menu.
(c) Now in Altitude menu. **Put at 0** using up or down arrows and hit enter key (left arrow).
(d) Now in % saturation menu. Make sure the D.O. reading in large display is **stable** and **Hit Enter** key.
(e) Now in salinity menu. **Enter 0** salinity (salinity will be corrected for during data processing).
(f) **Hit Enter** key.
(g) Meter now ready to take readings but need to return to mg/l mode, so **Hit Mode** key.

If temperature units need to be changed (F to C), press Down Arrow & Mode key at same time.

CALIBRATION IS NOW COMPLETE.

7.3 Initial Reading

At each station, record dissolved oxygen (mg/l) and temperature while the probe is still in the calibration chamber. This is called Initial Reading on Data Sheet.

7.4 Data Reading and Recording

Remove the probe and take Dissolved Oxygen and Temperature readings at depths required for your station, i.e. surface, mid-depth and bottom. Readings will vary slightly because the probe consumes oxygen so **jiggle the probe** while reading the instrument to expose the probe to new water. Read to nearest tenth of mg/l.

After each station, rinse probe and return it to the calibration chamber. The probe does not stay in the storage/calibration chamber very well because of the weight of the cable so be careful that the probe doesn't fall out on deck when moving the meter about the boat.

If dissolved oxygen readings are less than 5 mg/L, you must take a 300 mL BOD Bottle for Winkler DO Assay. Please collect QA sample by Modified Winkler Method, below.

DO NOT RECALIBRATE. **LEAVE D.O. METER ON until the day's sampling is completed.

7.5 Dissolved Oxygen (D.O.) Sample Collection/Analysis Modified Winkler Method

Note to YSI meter Teams: If the D.O. reading from the YSI 55 is less than 5 mg/L, collect a water sample for dissolved oxygen by Winkler analysis, that sample will be collected first. All other Teams collect Winkler D.O. samples at each location.

D.O. Sample by Winker Analysis Procedure

(a). Label one 300 mL glass Winkler bottle with station I.D., date, and depth.

(b). Using Niskin Bottle collect sample from depth and bring to surface.

(c). Remove glass stopper from 300 mL Winkler bottle
(d). Lower rubber tube from Niskin Bottle to the bottom of the glass reagent bottle from the blue oxygen kit.
(e). Drain ¾ of the Niskin Bottle through the glass Winkler bottle, overflowing the glass bottle.
(f). Gently tap glass bottle to insure that no bubbles stick to sides.
(g). As volume reaches ¾ of the Niskin, 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.

Now: Fix the sample for transport to the lab, as follows:

(h). Open Reagent packet #1 (use the scissors in your kit);
(i). Open Reagent packet #2
(j). Remove glass stopper from glass oxygen reagent bottle;
(k). Pour Reagent #1 into bottle and then add reagent packet #2 to bottle.
(l). Replace glass stopper, careful not to trap bubbles.
(m). Mix bottle for 45 seconds by turning bottle upside down & rightside up. A little left over reagent on the bottom is OK.
(m). Let bottle sit for 2 minutes then mix again for 45 seconds. Put water into bottle lip.
(n). Allow floc to settle until below half way in the glass 300 mL BOD bottle, usually takes ~5 min
(o). Add reagent 3 to the 300 mL glass BOD bottle & replace stopper with no bubbles. Mix until ALL reagent dissolved. Water will now be yellow/amber.
(p). Put some water in bottle lip and put on snap cap. Place in cooler with the other sample bottles to be sent back to SMAST for titration.

8.0 EQUIPMENT CLEANUP FOR STORAGE

(a) Rinse sampling pole and Secchi disk with fresh water.
(b) Rinse D.O. glassware and filter holders with distilled water & dry before returning to sampling kit.
(c) Rinse D.O. probe with distilled water and return to storage/calibration chamber.

SHIPPING AND HANDLING

All samples will be transported to the Coastal Systems Analytical Facility by SMAST technical personnel involved in the field program. The SMAST person transporting the samples will check the Chain of Custody and verify that the samples are as stated before accepting them for transport. After collection, samples will be kept continuously on ice or in refrigeration. Samples will be shipped in heavy-duty styrofoam coolers with ice or cold packs adequate to maintain cold internal temperatures. All shipments will be accompanied by a Chain of Custody (sample in Appendix B).

APPENDIX – B

CHAIN OF CUSTODY AND FIELD DATA SHEETS

SRPEDD-SMAST

Mt. Hope Bay Estuarine Monitoring Program – Water Sampling Data Sheet 2004,05,06

General Conditions

MBH- ____ Station ID. Embayment ___________________________

___________ Sample Date Volunteers Names ______________________

___________ Beaufort Scale (Force# 0 - 12)

___________ E / F Ebb (outgoing) or Flood (incoming) tide

Time of nearest LOW tide ________am / pm (refer to your tide table)

#_________ Weather Conditions: (choose one) 1. Cloudless 2. Pt. Cloudy 3 Overcast 4. Rain 5. Fog/Haze 6. Drizzle 7. Intermit. Rain

#_________ 24 hour Precipitation (choose one) 1 None 2 Light 3 Heavy

___________ Wind direction (ie. SE, NW)

Secchi Depth __________(m)Disappearance/descending

__________(m)Reappearance/ascending

__________(m) Average

___________(meter) Total water depth at station

Observations: Birds ______ # , _________type; Moorings _________ #

Swimming ________yes/ no ; Shellfishing ________ yes / no

Please continue comments on back

Oxygen Meter **Initial Reading**		**D.O. (mg/L)**		**Temp (°C)**		

Depth Specific Parameters

	SURFACE **15 cm below**		MID see protocol		BOTTOM **40 cm from bottom**	
Collection Time						
Collection Depth		**Meters**		**Meters**		**Meters**
Oxygen Reading		**mg/L**		**mg/L**		**mg/L**
Temperature Reading		°C		°C		°C
Oxygen - Winkler Bottle if Meter < 5 mg/L						check if bottle is filled

Did you collect a 1 L Brown, 1 L Clear and 60cc bottle at each nutrient depth?

Return data sheet with samples to Coastal Systems Program, SMAST c/o Dr. Brian Howes, 706 S. Rodney French Blvd., New Bedford, MA 02744.

COASTAL SYSTEMS GROUP
Chain of Custody Record

Personnel Contacts

RECEIVED		RECEIVED	
name		name	
date	time	date	time
COLLECTED		**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				

This form is to be completed and signed at sample transfer to the Coastal Systems Analytical Facility at SMAST.
706 Rodney French Blvd., New Bedford, MA 02649; 508-910-6352

APPENDIX – C

EQUIPMENT TO BE USED AND CALIBRATION

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 nd 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. The display will then read SAVE and return automatically to the Normal Operation Mode.

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 – D

NUTRIENT WATER QUALITY DATA

(Data Transmitted Electronically as Excel Files)

55 Village Square Drive, South Kingstown, RI 02879, USA
T +1 401 789-6224 F +401 789-1932 W www.rpsgroup.com | www.asascience.com

Analysis of Changes in Temperature Regime in Mt. Hope Bay With and Without Brayton Point Station in Operation with Resulting Effects on Saturated Dissolved Oxygen Levels

Craig Swanson; Ph.D.; Senior Associate
RPS ASA Project 14-472

13 January 2015

Executive Summary

The thermal effects from the discharge of the Brayton Point Station on Mt. Hope Bay was assessed using a calibrated hydrothermal model applied under the auspices of various state and federal agencies, the Station operator, and other interested parties. A series of model runs were made which predicted the temperature regime in the Bay both with and without the Station in operation. These temperature predictions provided the information necessary to estimate the change in dissolved oxygen from existing conditions present in the mid-2000s when water quality data was acquired to when the plant is scheduled to go offline in 2017.

The average baywide temperature decrease was predicted to be 1.24°C. Using the relation between saturated DO concentration and temperature, the average baywide increase is 0.24 mg/L or 2.67% over permitted operations at the time. This increase is important since it comprises approximately one half of the DO deficit (~0.4 mg/L) measured in the mid-2000s in the upper Taunton estuary. Further DO improvements are also anticipated because other temperature dependent oxygen demanding components will create less DO consumption under a reduced temperature regime. This simplified temperature effects modeling approach could have been used in the draft permit for the Taunton WWTF to provide a meaningful estimate of the likely DO conditions when the Station went offline. In fact the sister water quality model, BFWASP, to the hydrothermal model, BFHYDRO, could have been used to definitively estimate resulting DO levels and confirm the significance of nutrients on the DO regime .

Finally, the use by USEPA of a sentinel station located in the far southeast corner of the Bay is not an appropriate methodology to predict DO conditions and nutrient reduction requirements in the Taunton Estuary since the hydrodynamics and therefore the transport and flushing at this site are significantly different from the rest of the Bay. Consequently, there is no reasonable basis to anticipate that nitrogen levels at the sentinel site provide a basis for predicting DO or algal growth potential at the other sites further up in the Bay or the Taunton River.

Background

RPS ASA (formerly Applied Science Associates) has performed field programs and modeling studies for the Brayton Point Station since 1996 as part of the Station's efforts to renew their permit from the U.S. Environmental Protection Agency for discharge of cooling water to Mt. Hope Bay. Subsequent to a recent change in ownership it was announced the Station will cease operations in 2017.

RPS ASA has performed a series of modeling studies that evaluated the thermal regime in the Bay using a sophisticated hydrothermal model calibrated, verified and optimized with extensive field observations. The model was accepted in September 2000 by the Brayton Point Station Technical Advisory Committee (TAC), consisting of state and federal agencies (including the USEPA) and other interested parties, as suitably calibrated for use in predicting the thermal structure of the Bay. The subsequent studies included modeling the three-dimensional, time varying temperature distribution for a series of Station operational alternatives including the case without the Station operating, i.e., ambient environmental background forcing only. These studies have been documented in a variety of publications authored by RPS ASA staff with the most recent being Swanson et al. (2006).

The City of Taunton, MA is seeking a permit renewal from the USEPA for the discharge of treated effluent from its wastewater treatment plant (WWTP). The new draft permit incorporates limits on total nitrogen (TN) concentrations in the discharge which attempts to improve dissolved oxygen (DO) levels in the Bay located 21 km (13 mi) south of the WWTP. The draft permit relies on data collected during the period 2004-2006 (SMAST, 2007) which indicates DO below the minimum level of 5 mg/L. Since temperature affects the saturation of DO in the Bay, the removal of the heat load from the Station will result in a reduction in temperature that will increase the dissolution potential of the waters of the Bay for DO. RPS ASA was asked to perform an analysis of the expected increase in the Bay DO concentration levels based on the cessation of operations of the Station.

The following tasks were performed for this effort:

- Identify model results from the earlier studies that predict the temperature distributions in the Bay for both the Station in operation as well as no Station operation.
- Calculate the resulting saturated concentration levels of DO for both operational scenarios and the DO concentration difference between the two.
- Assess the reasonableness of the USEPA-selected sentinel station that was used to characterize the waters downstream of the Taunton WWTF discharge.

Temperature Analysis for Mt. Hope Bay

Hydrothermal Model Application

A three-dimensional time-dependent hydrothermal computer model was used to assess the thermal effects of the Station discharge on the Bay. The system, known as WQMAP, was developed by RPS ASA and the University of Rhode Island (Spaulding et al., 1999). The system includes a suite of integrated environmental models, including a boundary-conforming grid generation model, BFGRID; the three-dimensional hydrothermal model, BFHYDRO; a set of pollutant transport and fate models (single- and multiple-constituent [BFMAX] and WASP5 (Water Quality Analysis Simulation Program) kinetics [BFWASP]). It should be noted that BFWASP is capable of simulating the DO concentration levels in the Bay using the BFHYDRO model output and appropriate rates required in the WASP5 kinetics. All operate on a boundary-conforming grid system and are supported by an embedded geographic information system and environmental data management tools.

The BFHYDRO model was applied by dividing the Bay into over 1000 three-dimensional grid cells where temperature, salinity, and velocities were calculated within each cell. It was successfully calibrated, verified and optimized with TAC oversight using an extensive set of observations collected in the Bay over a number of years as discussed in Swanson et al. (1998, 1999, and 2001) and summarized in Swanson et al. (2006).

Model Results

Two cases from the extensive modeling of various plant operational alternatives were chosen for the present analysis. First a No Plant (NoPlt) case was selected where the Station was not in operation and with the model run only with natural environmental forcing. The year 1999 was chosen as a reasonable worst-case warm-water year since there was concern about the potential for warm year biological impacts. The plant operational case, MOAII, was chosen since that was based on the interim permit levels documented but the second Memorandum of Agreement among the Station, various Massachusetts and Rhode Island state agencies, and the U.S. Environmental Protection Agency (1997). The MOAII restricted operations through all of the 2000s until closed cycle cooling began operations in 2011.

The selected model output was processed by taking the daily averaged temperatures over the simulated year (1999) for each grid cell whose volume was known so that the cumulative percent of the volume of the Bay that was greater than a specific temperature could be generated. This result was documented in various reports including the chapter appearing the journal *Northeast Naturalist* (Swanson et al., 2006). These results are repeated as Figure 1 below. The figure indicates temperature ranges from 0 to 27 °C with the NoPlt case always cooler than MOAII as expected. The difference in volume between the cases at a given temperature is not large, however. For example, at 5C, the NoPlt case shows 72% of the Bay volume is greater than this temperature compared to 82% for the MOAII case.

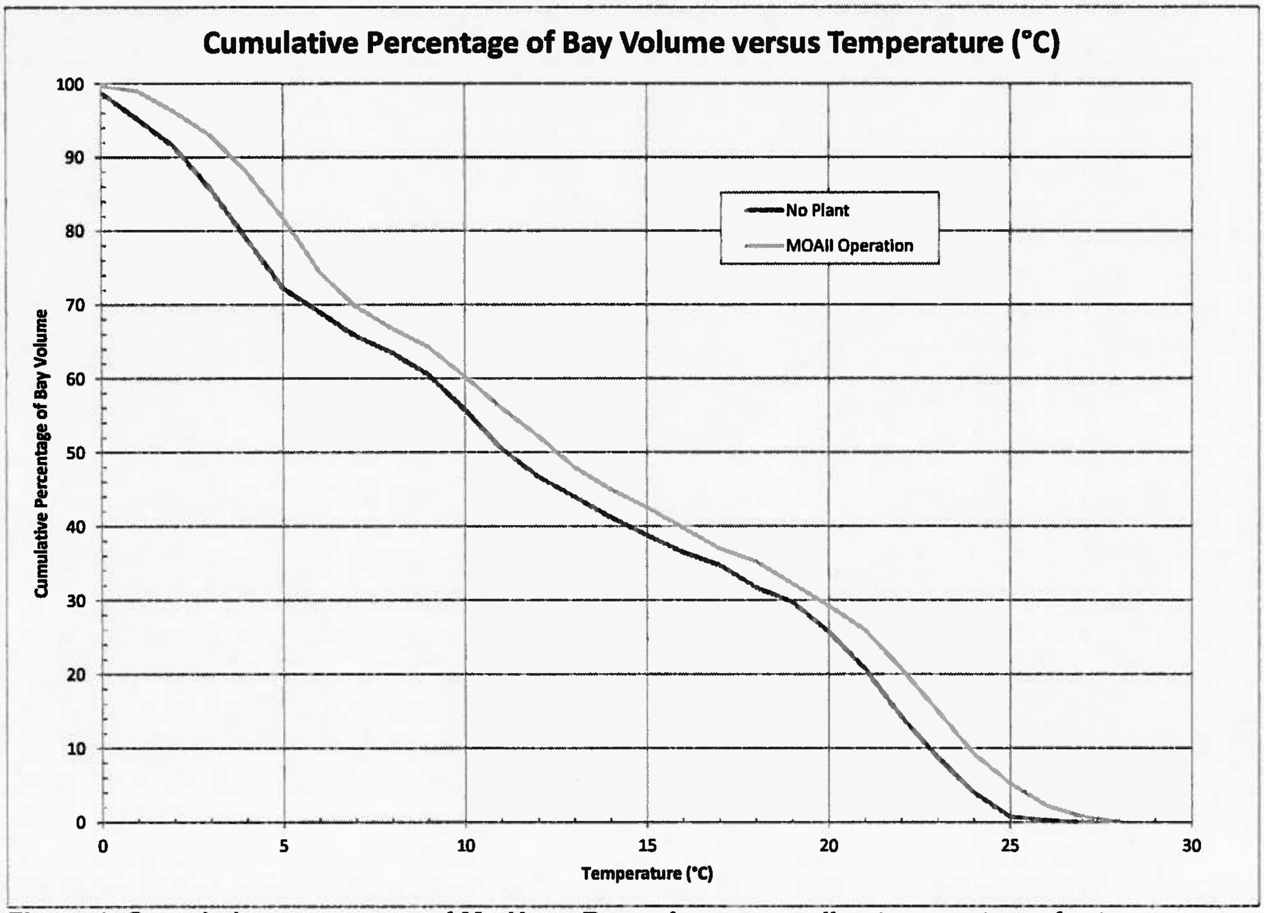

Figure 1. Cumulative percentage of Mt. Hope Bay volume exceeding temperatures for two modeled scenarios.

Dissolved Oxygen Analysis for Mt. Hope Bay

Estimates of Saturated DO Concentrations

The saturated DO concentrations decrease with both increasing temperature and salinity. A mean salinity of 30 psu was conservatively estimated based on previously collected data. Figure 2 shows the relationship between temperature and DO for a 30 psu salinity taken from the USGS website: http://water.usgs.gov/software/DOTABLES/. There is a 46% drop in saturated DO concentration levels between 0 and 30 °C, from 11.85 to 6.41 mg/L.

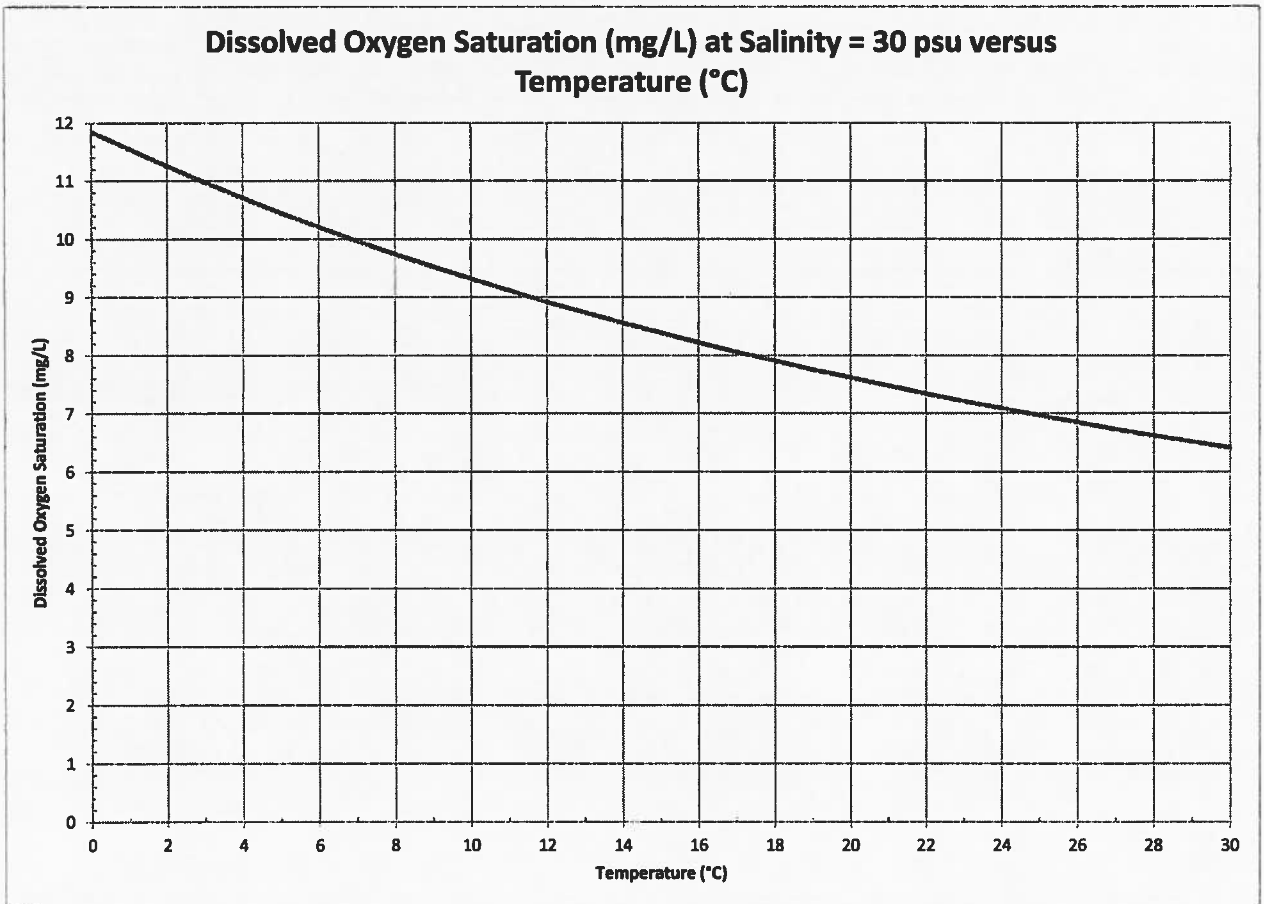

Figure 2. Variation of dissolved oxygen with respect to temperature for approximate mean the Bay salinity of 30 psu.

Figure 3 shows the relationship between cumulative percentage volume and DO in a manner similar to Figure 1 for cumulative percentage volume versus temperature. The figure indicates saturated DO for the NoPlt case always higher than MOAII as expected. The difference in volume between the cases at a given DO saturation concentration is not large, however. For example, at 10 mg/L, the NoPlt case shows 70% of the Bay cumulative volume is greater than this saturated DO level compared to 66% for the MOAII case.

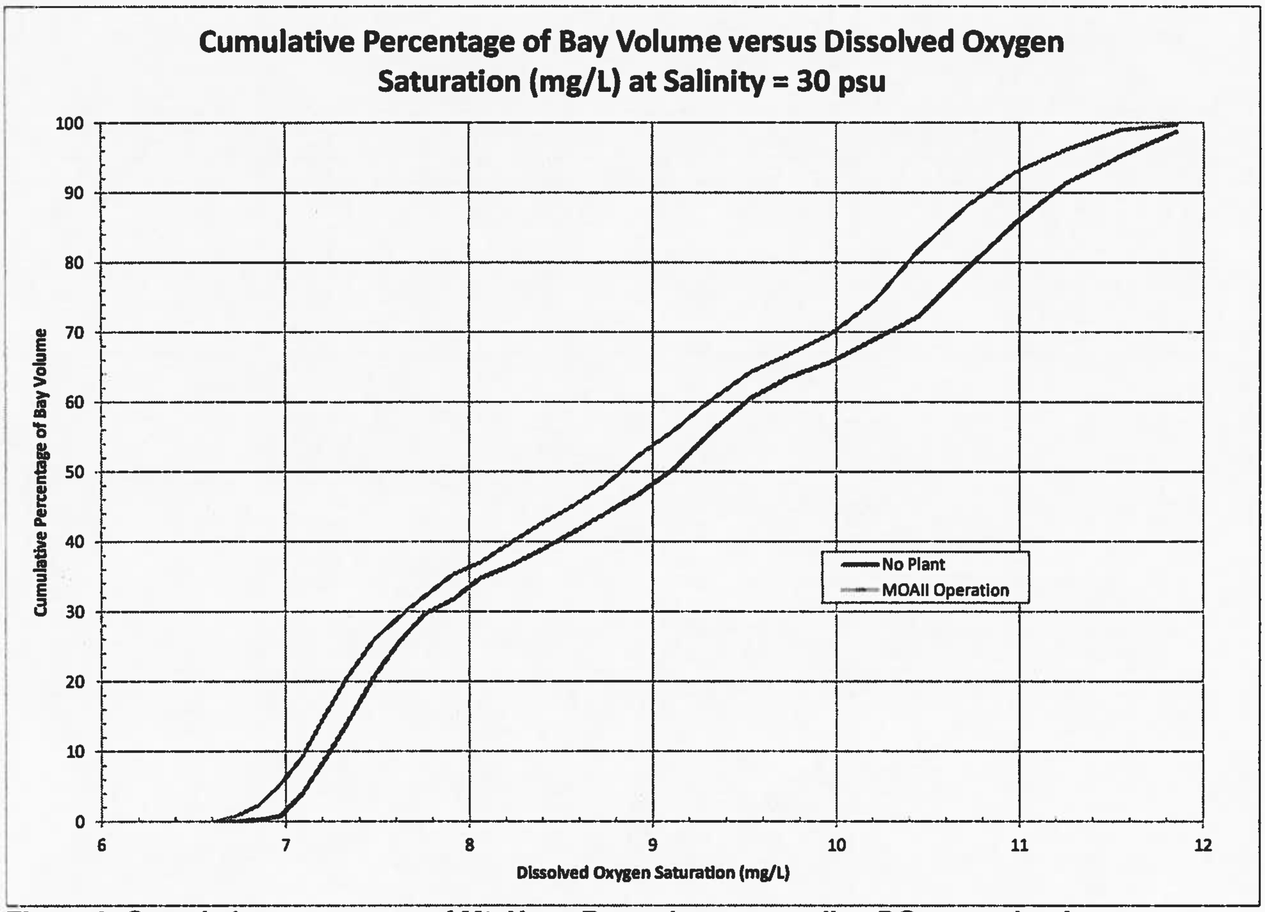

Figure 3. Cumulative percentage of Mt. Hope Bay volume exceeding DO saturation for two modeled scenarios.

Instead of cumulative volume percentage a more detailed approach is to evaluate the volume percentage change in 5% volume increments. Table 1 shows the change in saturated DO concentration between the NoPlt case and the MOAll case. Temperatures are shown for each increment for reference. The DO increases for the increments range from 0.13 to 0.37 mg/L with an average of 0.24 mg/L or 2.7%. Larger differences are seen for the colder waters, consistent with the relation between saturated DO concentration and temperature.

Table 1. Change in saturated DO concentration between the NoPlt and MOAll cases in 5% the Bay **volume increments.**

Volume % Lo	Volume % Hi	NoPlt T (°C)	MOAll T (°C)	NoPlt DO (mg/L)	MOAll DO (mg/L)	ΔDO (mg/L)	% Dif
0	5	24.84	26.47	6.99	6.79	0.20	2.89%
5	10	23.27	24.46	7.18	7.04	0.14	2.02%
10	15	22.40	23.46	7.29	7.15	0.13	1.86%
15	20	21.54	22.56	7.40	7.27	0.14	1.90%
20	25	20.61	21.60	7.53	7.40	0.14	1.88%
25	30	19.49	20.45	7.69	7.56	0.13	1.78%
30	35	17.60	18.91	7.97	7.77	0.20	2.54%
35	40	15.42	16.92	8.32	8.07	0.25	3.06%
40	45	13.56	14.90	8.64	8.41	0.23	2.77%
45	50	11.89	13.24	8.94	8.70	0.24	2.81%
50	55	10.67	11.86	9.19	8.95	0.24	2.65%
55	60	9.65	10.64	9.39	9.19	0.20	2.20%
60	65	8.27	9.42	9.68	9.44	0.24	2.57%
65	70	6.57	7.88	10.07	9.77	0.31	3.14%
70	75	5.16	6.47	10.41	10.10	0.32	3.12%
75	80	4.26	5.61	10.64	10.30	0.34	3.28%
80	85	3.53	4.87	10.84	10.48	0.35	3.38%
85	90	2.69	4.04	11.07	10.70	0.37	3.42%
90	95	1.63	2.92	11.37	11.00	0.36	3.30%
95	100	0.06	1.15	11.83	11.51	0.33	2.83%

Other Temperature Dependent Parameters Influencing the DO Regime

As noted above, temperature will be decreasing throughout the Bay due to the closure of the Station. Consequently, all temperature–dependent oxygen demanding processes are also projected to occur at a more reduced rate (algal growth, sediment oxygen demand, organic decay in the water column). Thus, the overall DO improvement in the system will be greater than projected simply from the saturation DO improvement.

Suitability of Sentinel Station Located at MHB16

A sentinel station approach was used by USEPA as part of its analysis of Total Nitrogen (TN) impacts from the Taunton WWTF discharge. A station included in the SMAST (2007) field program conducted in 2004-2006, MHB16, was chosen by EPA as the sentinel station. This station is located in the extreme southeast corner of the Bay just north of the connection of the Bay with the Sakonnet River, one of two connections (the other being to the East Passage of Narragansett Bay) to Rhode Island Sound and the Atlantic Ocean. From the perspective of the hydrodynamics in the Bay this is an unsupportable approach. The flow through the Sakonnet River Narrows is only 10 to 20% (Kincaid, 2006) of the flow through the main interface to Narragansett Bay so the flushing characteristics and factors influencing the DO regime would be entirely different from most of the rest of the Bay and certainly differ dramatically from conditions occurring in the Taunton Estuary. Consequently, one could not reasonably anticipate that the hydrodynamic conditions (including stratification) or algal growth influencing the DO regime at this location would be similar to the conditions controlling DO in the Taunton estuary that is subject to an entirely different set of oxygen demanding inputs and physical conditions.

References

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Assessment of the Scientific Basis of the Taunton Wastewater Treatment Plant Draft NPDES Permit (MA0100897)

by

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September 4, 2014

I have developed the following report as an assessment of the technical analyses used as the basis for establishing total nitrogen reduction requirements for the Taunton Wastewater Treatment Plant Draft NPDES Permit. In particular, my focus is on the scientific basis of (1) the total nitrogen concentration a (TN) criterion which was established as a target for bringing the system to acceptable water quality, and (2) the modeling methodology employed to generate the TN effluent limitations for discharges to the system's watershed. My review is based on careful reading of the permit and supporting documentation as well as a number of other relevant documents cited in the reference list at the end of this document. I begin with a summary of my understanding of the approach outlined in the permit. This is followed by a critique of specific aspects of the methodology. The report concludes with my overall assessment. My general conclusion is that the methods employed for developing the TN reduction requirements are not scientifically defensible and not consistent with the generally accepted methods used for assessing DO-related issues in estuaries. None of the important site-specific physical, chemical and biological factors influencing whether and how TN may affect the DO regime by stimulating excessive plant growth in the Taunton estuary were evaluated in the Region's analyses. Because overly simplistic, unreliable methods were employed in developing the permit requirements, there is no reasonable basis to conclude that the TN reduction requirements are either necessary or sufficient to ensure DO criteria compliance in the estuary. Consequently, absent a more complete and competent analysis that accounts for well-known factors influencing the DO regime in estuarine settings, the ecological benefits associated with TN reduction cannot be determined for this system.

OVERVIEW OF APPROACH

Three types of empirical analyses are conventionally employed to derive numeric criteria for natural receiving waters (primarily lakes, rivers and estuaries): (1) the reference condition approach, (2) stressor-response analysis, and (3) mechanistic modeling (US EPA 2000a, 2000b, 2001, 2010b). In brief:

- The *reference condition approach* derives candidate criteria from observations collected in reference waterbodies representing least disturbed and/or minimally disturbed conditions within a region (Stoddard et al. 2006) that support designated uses.

- A *stressor-response analysis* is used when data are available to accurately estimate a relationship between nutrient concentrations and a response measure that is directly or indirectly related to a designated use of the waterbody. Then, a nutrient concentration that is protective of designated uses can be derived from the estimated relationship.
- *Mechanistic modeling* is used to predict specific constituents based on a series of equations and algorithms that represent physical, chemical, biological, and ecological processes. Thus, in contrast to the other two methodologies, which are empirical, the mechanistic models are based on scientific principles.

The Taunton TN nutrient criterion is based on a hybrid of the reference condition and stressor-response analysis, whereas a mechanistic model of sorts (albeit a very simple one) is used for the effluent limit calculation. For the former, a single "sentinel" station was chosen in Mount Hope Bay where DO criteria were met, and assumed that whatever TN level occurs at that location is what is the factor controlling the DO regime and therefore required to meet DO objectives throughout the system, including the Taunton estuary (many miles away). Thus, as with the reference condition approach, the current methodology uses data from a location that is deemed to have acceptable water quality and the physical factors influencing the DO regime are considered identical in all other locations. As with the stressor-response approach, the method is based on the implicit assumption that response (DO concentration) is well correlated with the stressor (TN concentration) and that no other significant factors are controlling the resultant water column DO.

Once the TN nutrient criterion was established, an estimate for the allowable TN loading was computed with a mass-balance. A very simple model was employed for this purpose. It was assumed that the entire estuary system was well-mixed and at a steady state. Given estimates of freshwater inflow rate and salinity concentrations, a salinity balance was then used to estimate exchange with the ocean. Given the ocean exchange, the model could then be used to compute the TN concentration of the freshwater inflow needed to achieve the TN concentration target. The product of the inflow rate times the inflow TN concentration then yields the allowable TN loading. Aside from its simplicity, the most noteworthy feature of the model is that it treats total nitrogen as a conservative substance.

CRITIQUE

The methodology has many critical flaws which render its results thoroughly unreliable. These are the same type of fundamental flaws which were identified in the development of TN reduction requirements for the Great Bay estuary (Bierman, et al – 2014)) and which were identified by EPA's Science Advisory Board in 2010 (US EPA 2010a) in reviewing the use of simplified regression methods to predict water quality and ecological changes due to ambient nutrient levels. Many of these deficiencies have already been identified by Hall and Associates (2014) with which I am in general agreement. Consequently, rather than reiterate the same points, my critique will focus on the flaws I found to be the most serious and fundamentally significant.

Inappropriateness of Sentinel Method

There are a number of reasons why the sentinel method employed to come up with the nutrient criteria is fundamentally flawed and ultimately I have no expectation that meeting the ambient criteria chosen via this method will result in acceptable water quality throughout the system. First, it needs to be understood that this approach created to derive the Taunton permit requirements is novel and not specified as a scientifically defensible method for addressing DO-related problems in any published literature that I am familiar with in my 42 years of conducting water quality impact assessments. TN is not a pollutant that directly controls water column DO in estuarine systems. Therefore, as an initial point, the claim that simply controlling to achieve a specific TN level will produce a specific DO response is simply a false and scientifically incorrect assumption.

Second, both the reference condition and the stressor-response approaches are typically based on data from a number of similar systems. Statistical techniques are then employed to determine the most likely value of the nutrient criteria that correlates with acceptable water quality, after making sure that the system locations and physical factors are similar. The use of multiple systems and screening to ensure similar habitat and physical conditions (hydrodynamics and hydrology), greatly increases the reliability that the resulting nutrient criteria is generally valid and not the result of an outlier. In contrast, the use of a single station by the present study without any documentation that the other locations of the estuary are similar in hydrology/hydrodynamics and other critical factors (e.g., stratification and sources of DO demand) provides little confidence that the oxygen objective will be met at all (or even any) locations in the system. This is precisely the type of simplified analyses that EPA's Science Advisory Board informed the Agency was not sufficient or scientifically defensible in developing nutrient criteria and nutrient management approaches:

> "*For criteria that meet EPA's stated goal of "protecting against environmental degradation by nutrients," the underlying causal models must be correct. Habitat condition is a crucial consideration in this regard (e.g., light [for example, canopy cover], hydrology, grazer abundance, velocity, sediment type) that is not adequately addressed in the Guidance. Thus, a major uncertainty inherent in the Guidance is accounting for factors that influence biological responses to nutrient inputs. Addressing this uncertainty requires adequately accounting for these factors in different types of water bodies. (SAB report at 38) … Numeric nutrient criteria developed and implemented without consideration of system specific conditions (e.g., from a classification based on site types) can lead to management actions that may have negative social and economic and unintended environmental consequences without additional environmental protection.*" *(SAB at 38)* (US EPA 2010a)

The sentinel approach is predicated on the assumption that the total nutrient concentration at a single location provides a valid predictor of the dissolved oxygen concentration directly below that location and is similarly controlling the DO regime in other locations. Even for standing waters, like lakes, where vertical transport usually dominates, this is a tenuous assumption. For a flowing system such as an estuary, it is ludicrous. As is well documented in the literature, the oxygen at any estuarine location depends on a variety of factors including oxygen reaeration, depth, sediment oxygen demand, sediment-water exchange of nutrients, nitrification and denitrification, point source carbonaceous and nitrogenous loadings, degree of vertical mixing, horizontal transport from both upstream and downstream directions, algal productivity, hydrolysis, organic carbon and organic nitrogen loads from allochthonous sources in the watershed, etc., etc., etc. The failure to evaluate and consider any of these factors renders the present assessment pure speculation, which is, in an event, demonstrably in error. TN could not possibly be the single factor controlling the DO regime in the Taunton estuary given the numerous non-nutrient factors known to influence this and other estuarine systems.

Choice of TN as stressor

The use of total nutrients as a stressor dates back to the early years of eutrophication modeling when Richard Vollenweider hypothesized that the spring total phosphorus concentration in a lake could be used as a predictor of summer eutrophication symptoms such as average chlorophyll *a*, Secchi depth, and hypolimnetic dissolved oxygen demand (Vollenweider 1968, 1969, 1975). This made some sense for stratified lakes with low to moderate summer flushing rates as the lake's surface layer could be viewed as a batch reactor. However, Vollenweider and other water-quality experts recognized that although the approach could be used for crude screening analysis of stratified lakes, more sophisticated methodologies would be required for actual management of other water bodies such as shallow lakes, and flowing systems such as rivers and estuaries.

Because they are subject to strong advective water motion, flowing systems (such as rivers and estuaries) are the antithesis of batch systems and hence, the idea that a total nutrient will ultimately and predictably yield a particular level of water quality at a point in space and time is again patently ludicrous. I have included an appendix at the end of this document, where I use simple mathematical models to illustrate why this is true.

Oversimplistic Modeling

As mentioned previously, no water quality modeling was employed to establish the reliability of the TN criterion. At a minimum, the analysis should have demonstrated how TN influenced phytoplankton growth at the various locations, since this is a prerequisite for causing effects on the DO regime. No such analysis exists. Because of the complexity of this system and its economic and environmental value the absence of any serious modeling to support nutrient criteria development verges on negligent.

Further, even when modeling is employed to establish the TN effluent limitations, it is ludicrously simplistic and based on completely undocumented assumptions, rather than scientific fact or an exercise of reasonable scientific judgment. First, the system is clearly not completely mixed with gradients occurring longitudinally, laterally and vertically. Second, eutrophication is not a steady-state problem as is clearly demonstrated by the time series plots contained in the permit document. The very fact that phytoplankton "blooms" occur establishes that the systems water quality is dynamic. Third, the assumption that TN is conservative is absolutely erroneous. Although it is clearly more stable than its component species (e.g., ammonia, nitrate, etc.), a number of source and sink processes act to increase and reduce the total nitrogen pool at different rates in different locations in the system. Notable among these are sediment-water interactions (settling, resuspension, sediment nutrient release) and denitrification. Finally, there is no rational basis to presume that the important hydrodynamic conditions controlling the DO regime and how TN may influence that regime are identical in Mount Hope Bay and the upper reaches of the Taunton estuary. This is pure speculation which is, once again, demonstrably incorrect as the hydrodynamic and hydrologic conditions in these two areas are obviously quite different as would be expected by simply looking at a map of the estuary and given a rudimentary understanding of coastal hydrodynamics (one is the closed end of the Taunton estuary affected by fresh water inputs, the other would be primarily influenced by higher tidal exchange from the ocean). In short, the "modeling" has no credible scientific basis.

SUMMARY

In summary, I have concluded that the technical analysis underlying the permit is severely flawed, and does not reflect the current or accepted state of the science for making such assessments. It is based on naïve and simplistic reasoning that is weak and clearly not consistent with the available information or expected conditions controlling the DO regime in estuarine settings. No published EPA guidance document on assessment of DO and nutrient conditions in estuarine settings indicates that this is an accepted method of analysis.

I have critiqued many water quality plans and management schemes as an environmental engineer and water-quality expert and I must state that this is the most technically weak effort I have examined over my 42 year career. (See attached curriculum vitae). And lest my comments be considered biased, I should state that beyond my scientific background, I am a dedicated environmentalist who was drawn to this field because of my love of the outdoors. I have fished the New England coastline from Long Island Sound off New London to north of Cape Ann in Massachusetts and I believe that Narragansett Bay is one of the real jewels of our region. So it really matters to me that the stewardship of systems such as the Taunton River Estuary and Mount Hope Bay be based on the best available science. Because this is not the case, I have absolutely no confidence that the remedial measures suggested by the permit will have the desired effect of maintaining healthy water quality in the system.

Steven C. Chapra _______________ **Sept. 5, 2014**

Steven C. Chapra, Ph.D., F.ASCE, F.AEESP

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APPENDIX 1. Why TP Concentration Standards are Inappropriate for Managing Phytoplankton Biomass in Flowing Systems

This appendix attempts to address the question of why anyone would ever suggest that a total phosphorus criterion would represent a sensible strategy for managing flowing systems such as rivers or estuaries. In brief, I believe that the idea of singular total phosphorus criteria for flowing natural waterbodies originates from the misguided notion that effective lake management approaches can be seamlessly (and thoughtlessly) transferred to rivers and streams. Although the following focuses on phosphorus in rivers, the conclusions are directly transferable to nitrogen-limited tidal rivers and estuaries.

In the late 1960’s and early 1970’s, several limnologists suggested that total phosphorus concentration could serve as an effective trophic state indicator. In particular, Richard Vollenweider posited that lakes with total phosphorus concentrations less than 10 μgP/L would tend to be oligotrophic whereas those with greater than 20 μgP/L would tend be eutrophic.

Although Vollenweider himself repeatedly stated that these were approximate guidelines and not hard thresholds, the values were adopted by many lake managers as quantitative goals for managing lake eutrophication. And in fact, the approach has been a useful component of nutrient remediation schemes for a number of important systems including the Laurentian Great Lakes.

So why might the approach work for lakes and not for streams? The answer to this question lies in fundamental differences between these two types of natural waters.

In effect, the viability of the Vollenweider approach is predicated on the functioning of the particular lakes he studied. In particular, the approach was developed for deep, stratified, phosphorus-limited, North-temperate lakes with long residence times (i.e., greater than a year). In such lakes, Vollenweider (and others) assumed that the spring total phosphorus concentration was a prime determinant of plant production over the ensuing summer growing season.

For this assumption to strictly hold, once the lake stratifies in late spring, the epilimnion must essentially behave as a batch or closed system. Thus, plant growth over the ensuing summer is primarily dictated by the finite store of nutrient represented by the spring phosphorus concentration rather than by external loads. The average summer level of biomass is then determined by the recycle of this pool between inorganic and organic forms. Empirical support for the approach was provided by a number of empirical correlations. The chief examples of these were logarithmic plots suggesting strong correlations between summer average chlorophyll *a* concentrations and spring total phosphorus concentration.

A simple computation can be used to illustrate how such an approach breaks down in rivers and streams. First, total phosphorus can be divided into three components

$$TP = p_p + p_i + p_o \tag{1}$$

where p_p = phytoplankton phosphorus (μgP/L), p_i = inorganic phosphorus (μgP/L), and p_o = non-phytoplankton organic phosphorus (μgP/L). If the chlorophyll *a* to phosphorus ratio is assumed to be 1 μgA/μgP, this means that p_p can be directly interpreted as a measure of phytoplankton biomass.

The river can be idealized as a steady-state, plug-flow system with a single point source of phosphorus (Figure 1). Further it is assumed that the river has uniform, steady flow and constant hydrogeometric properties (i.e., depth, width, etc.). For such cases, velocity will be constant and travel time and distance are linearly related (i.e., distance = velocity times travel time). Under these conditions, the following mass-balances can be written for each phosphorus component

$$\frac{dp_p}{dt} = k_g \frac{p_i}{k_{sp} + p_i} p_p - k_r p_p - k_d p_p - k_s p_p \tag{2}$$

$$\frac{dp_i}{dt} = -k_g \frac{p_i}{k_{sp} + p_i} p_p + k_r p_p + k_h p_o \tag{3}$$

$$\frac{dp_o}{dt} = k_d p_p - k_h p_o \tag{4}$$

where t = travel time (d), k_g = maximum growth rate at constant light and temperature (/d), k_{sp} = phosphorus half-saturation constant (μgP/L), k_r = respiration/excretion rate (/d), k_d = death rate (/d), k_s = settling rate (/d), and k_h = hydrolysis rate (/d).

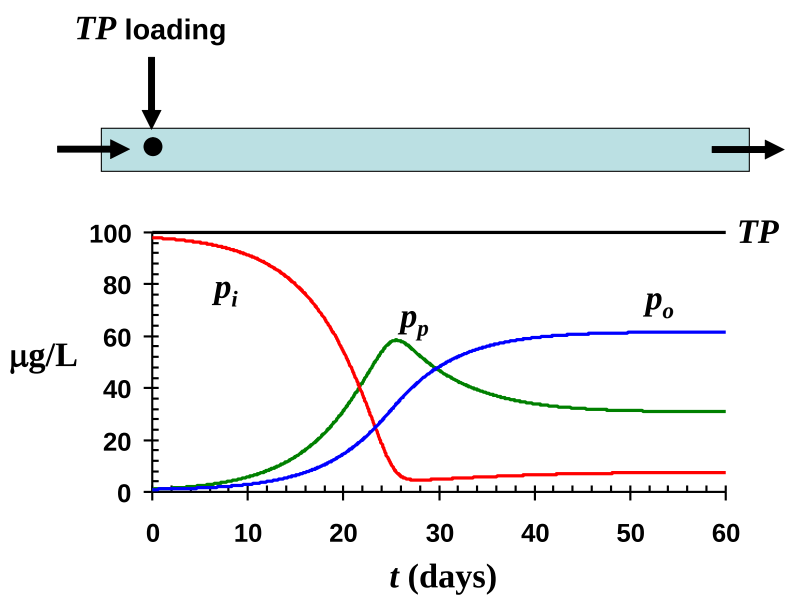

Figure 1 Simulation of phytoplankton, inorganic and organic phosphorus downstream from a point source.

Given reasonable values for the parameters and a set of initial conditions at the mixing point (Table 1), these equations can be integrated numerically to simulate how the various phosphorus species change as the water travels downstream. For the present example, the initial conditions are set so that the river has a high level of available, inorganic nutrient at the mixing point as would be the case for a high phosphorus discharge into an effluent-dominated river. In addition, the phytoplankton settling velocity is set to zero.

Table 1 Parameters and initial conditions used to simulate phytoplankton and phosphorus concentrations below a single point source to a one-dimensional river.

Parameter	Value	Units
k_g	0.5	d^{-1}
k_{sp}	5	$\mu gP\ L^{-1}$
k_r	0.2	d^{-1}
k_d	0.1	d^{-1}
k_s	0	d^{-1}
k_h	0.05	d^{-1}
Initial conditions:		
p_p	1	$\mu gP\ L^{-1}$
p_i	98	$\mu gP\ L^{-1}$
p_o	1	$\mu gP\ L^{-1}$

The results are displayed in Figure 1. Because the inorganic P concentration is well above the half-saturation constant, the phytoplankton initially grow rapidly as the inorganic phosphorus is efficiently converted to phytoplankton biomass. Growth continues until the inorganic phosphorus level approaches the half saturation constant whereupon a peak is reached. At this point, growth has become sufficiently limited that it is exactly balanced by the respiration and death losses. Thereafter, the phytoplankton levels decline until the solution approaches a stable steady state. This asymptote represents the point at which phytoplankton growth exactly balances phosphorus recycle.

Note that because of the assumption of zero settling, the total P concentration is constant. This allows the component concentrations at the stable steady state to be computed exactly as

$$p_i = \frac{k_r + k_d}{k_g - (k_r + k_d)} k_{sp} \quad (5)$$

$$p_o = \left(1 - \frac{k_h}{k_d + k_h}\right)(TP - p_i) \quad (6)$$

$$p_p = \frac{k_h}{k_d + k_h}(TP - p_i) \quad (7)$$

Thus, we see that the ultimate inorganic phosphorus concentration is equal to the half saturation constant multiplied by the ratio of the phytoplankton loss rates ($k_r + k_d$) to the maximum net phytoplankton growth rate ($k_g - k_r - k_d$). The organic P and phytoplankton

P concentrations are then dictated by the product of the total organic P (i.e., organic P and phytoplankton P) and a dimensionless number quantifying the relative values of the hydrolysis and death rates.

Although this is a very simple model, it dramatically illustrates why specifying a phosphorus concentration standard for rivers is ill-founded. Notice that until the asymptote is approached, there is no direct correlation between phytoplankton biomass and the total phosphorus concentration (as well as with any of the individual phosphorus species).

Just as is the case for BOD and oxygen, although phosphorus certainly causes increased phytoplankton biomass, there is absolutely no direct spatial correlation between in-stream TP and biomass. Hence, whereas a phosphorus standard makes some sense for a long residence-time, stratified lake, it falls apart for a plug-flow system like a river (or a mixed-flow system such as an estuary).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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FACT SHEET

DRAFT NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMIT TO DISCHARGE TO WATERS OF THE UNITED STATES

NPDES PERMIT NO: **MA0100897**

NAME AND ADDRESS OF APPLICANT:

The City of Taunton
Department of Public Works
90 Ingell Street
Taunton, MA 02780-3507

NAME AND ADDRESS OF FACILITY WHERE DISCHARGE OCCURS:

Taunton Wastewater Treatment Plant (WWTP)
825 West Water Street
Taunton, MA 02780

The municipalities of Raynham and Dighton are co-permittees for specific activities required by the permit, as set forth in Section VIII of this Fact Sheet and Sections 1.B and 1.C. of the Draft Permit. The responsible municipal departments are:

Town of Raynham Sewer Dept 416 Titicut Road Raynham, MA 02767	Town of Dighton Sewer Dept P.O. Box 229 North Dighton, MA 02764

RECEIVING WATER: **Taunton River** (Taunton River Basin - MA62-02)

CLASSIFICATION: **Class SB – Shellfishing (R) and CSO**

TABLE OF CONTENTS

Fact Sheet Attachments:

I. PROPOSED ACTION, TYPE OF FACILITY AND DISCHARGE LOCATION

The above named applicant has applied to the U.S. Environmental Protection Agency for the re-issuance of its National Pollutant Discharge Elimination System (NPDES) permit to discharge into the designated receiving water. The current permit became effective on March 27, 2001. The permit expired on March 27, 2006 and has been administratively continued pursuant to 40 C.F.R. 122.6.

A draft permit was placed on public notice in 2007. Upon reviewing the public comments received on the draft permit, EPA determined that substantial new questions had been raised regarding the need for nutrient limits in the permit. EPA has conducted further research and analysis regarding the setting of nutrient limits for this facility, and has developed a new draft permit for the Taunton Wastewater Treatment Plant (WWTP) containing nutrient limits as well as new collection system operation and maintenance requirements, changes to the indicator organism for bacteria limits, and other changes. Given the need to update a number of provisions to reflect changes in standard permit language, as well as the time that has passed since the first draft, EPA is issuing a complete new draft permit and is accepting public comment on all aspects of the draft permit. This new draft permit supersedes the 2007 draft and all comments on the 2007 draft are also superseded. New comments must be filed during this public comment period for those comments to be addressed in the issuance of the Final Permit.

The Taunton WWTP is an advanced secondary treatment plant that is currently authorized to discharge a flow of 8.4 mgd. The treatment plant discharges to the Taunton River (Outfall 001). There is one combined sewer overflow (CSO) that also discharges to the Taunton River (Outfall 004). The locations of the outfalls are shown on Figure 1.

The treatment plant and Taunton collection system are owned by the City of Taunton and are currently operated under contract by Veolia Water (formerly PSG/USFilter). Veolia submitted the application for renewal of the NPDES permit as required by 40 CFR §122.22(b). The City shall be the sole permittee for the treatment plant and CSO discharge, as of this permit reissuance, consistent with other contract operated publicly owned treatment works (POTWs). The Towns of Raynham and Dighton shall be co-permittees for their collection systems that discharge to the Taunton WWTP.

II. DESCRIPTION OF DISCHARGE

Quantitative descriptions of the discharge in terms of significant effluent parameters based on recent discharge monitoring reports (DMRs) for June 2010 through June 2012 may be found in Fact Sheet Table 1 (attached).

III. RECEIVING WATER DESCRIPTION

The Taunton WWTP discharges to segment MA62-02 of the Taunton River, extending from the Rte 24 Bridge to the Berkley Bridge in Dighton/Berkley. The Massachusetts Surface Water Quality Standards (MA SWQS) at 314 CMR 4.06 – Table 18 classify this segment of the River as Class SB-Shellfishing (R) and CSO.

Class SB - These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfish Areas). These waters shall have consistently good aesthetic value. (314 CMR 4.05(4)(b))

Restricted shellfishing areas are designated as "(R)". These waters are subject to more stringent regulation in accordance with the rules and regulations of the Massachusetts Division of Marine Fisheries pursuant to M.G.L. c. 130, § 75. These include applicable criteria of the National Shellfishing Sanitation Program. (314 CMR 4.06(1)(d)5)

CSO - (314 CMR 4.06(1)(d)11) These waters are identified as impacted by the discharge of combined sewer overflows in the classification tables in 314 CMR 4.06(3). Overflow events may be allowed by the permitting authority without a variance or partial use designation provided that:

a. an approved facilities plan under 310 CMR 41.25 provides justification for the overflows;
b. the Masssachusetts Department of Environmental Protection (MassDEP or the Department) finds through a use attainability analysis, and EPA concurs, that achieving a greater level of CSO control is not feasible for one of the reasons specified at 314 CMR 4.03(4);
c. existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected; and
d. public notice is provided through procedures for permit issuance and facility planning under M.G.L. c. 21, §§ 26 through 53 and regulations promulgated pursuant to M.G.L.c. 30A. In addition, the Department will publish a notice in the *Environmental Monitor*. Other combined sewer overflows may be eligible for a variance granted through permit issuance procedures. When a variance is not appropriate, partial use may be designated for the segment after public notice and opportunity for a public hearing in accordance with M.G.L. c. 30A.

No variance or use attainability analysis has been submitted or approved, so CSO discharges must comply with all applicable water quality standards.

The current permit incorrectly lists the Taunton River segment at the point of discharge as Class B (freshwater). The draft permit corrects this error. Effluent limitations for fecal coliform and total copper have been made more stringent based on the SB criteria.

The Massachusetts 2010 303(d) list (Category 5 of the Year 2010 Integrated List of Waters) lists this segment of the Taunton River, Segment MA62-02, as impaired due to pathogens. The segments of the River downstream of this segment, to the mouth of the River at the Braga Bridge in Fall River, are listed as impaired for pathogens and organic enrichment/low dissolved oxygen. Mount Hope Bay, which receives the discharge of the Taunton River, is listed as impaired for fishes bioassessments, total nitrogen, dissolved oxygen, temperature, fecal coliform and chlorophyll-a.

IV. LIMITATIONS AND CONDITIONS

The effluent limitations and monitoring requirements may be found in the draft NPDES permit.

V. PERMIT BASIS: STATUTORY AND REGULATORY AUTHORITY

The Clean Water Act (the "CWA") prohibits the discharge of pollutants to waters of the United States without an NPDES permit unless such a discharge is otherwise authorized by the Act. A NPDES permit is used to implement technology-based and water quality-based effluent limitations as well as other requirements including monitoring and reporting. This draft NPDES permit was developed in accordance with statutory and regulatory authorities established pursuant to the Act. The regulations governing the NPDES program are found in 40 CFR Parts 122, 124 and 125.

Under Section 301(b)(1)(B) of the CWA, POTWs are required to achieve technology-based effluent limitations based upon secondary treatment. The secondary treatment requirements are set forth in 40 CFR Part 133 and define secondary treatment as an effluent achieving specific limitations for biochemical oxygen demand (BOD_5), total suspended solids (TSS), and pH.

Under Section 301(b)(1)(C) of the CWA, discharges are subject to effluent limitations based on water quality standards. The MA SWQS, 314 CMR 4.00, include requirements for the regulation and control of toxic constituents and also require that EPA criteria, established pursuant to Section 304(a) of the CWA, shall be used unless a site specific criteria is established. Massachusetts regulations similarly require that its permits contain limitations which are adequate to assure the attainment and maintenance of the water quality standards of the receiving waters as assigned in the MA SWQS, 314 CMR 4.00. See 314 CMR 3.11(3). Additionally, under 40 CFR. § 122.44 (d)(1)(i), "Limitations must control all pollutants or pollutant parameters which the Director determines are or may be discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any state water quality standard."

VI. EXPLANATION OF THE PERMIT'S EFFLUENT LIMITATIONS

A. TREATMENT PROCESS AND COLLECTION SYSTEM DESCRIPTION

The Taunton WWTP is engaged in the collection and treatment of municipal wastewater, including industrial wastewater from 12 non-categorical significant industrial users and 10 categorical industrial users (including a semiconductor manufacturer, battery manufacturer and metal finishers). This is a smaller number than noted in the previous draft permit as a number of industrial users have closed since the last draft permit was issued, including several metal finishers. The facility provides advanced treatment and single stage ammonia-nitrogen removal. Figure 2. The wastewater treatment processes are as follows:

At the headworks, wastewater passes through one of two mechanically cleaned bar screens or a bypass bar rack. Lime is added for pH control and flocculation. After screening, the wastewater passes through a distribution structure and then to one of three primary settling tanks. Grit is removed by pumping primary sludge to a cyclone degritter. After settling, the flow continues on through one of two parallel treatment trains. Each treatment train, or "Battery," consists of a bank of three aeration tanks and two secondary settling tanks. Battery 2 is twice the size of Battery 1 and the flow is split approximately 2/3 to 1/3, with adjustments depending on treatment performance. After settling, the recombined flow is sent to the chlorine contact chamber where it is disinfected with the flow paced addition of liquid hypochlorite and dechlorinated with bisulfate. Defoamer is added for suppression of foam at the discharge. The effluent passes through a reaeration cascade to a 36-inch pipe leading to a headwall on the bank of the Taunton River. Sludge is dewatered by centrifuge and is sent for co-disposal at the Taunton Municipal Sanitary Landfill.

The treatment process described reflects a treatment plant rehabilitation and upgrade project completed in 2004. The rehabilitation and upgrade included the construction of increased pumping capacity, conversion of the activated sludge aeration facilities from pure oxygen to air, addition of two new aeration tanks, replacement of the influent screens, and rehabilitation of the primary clarifiers.

The sewage collection system is partially combined, with over 150 miles of sewer and 20 pump stations in the municipalities of Taunton, Raynham, Dighton and Norton. Table 2 below shows the number of households served in each municipality.

Table 2. Communities served

Town	**Households served by WWTP**
Taunton	13,000
Raynham	4,120
Dighton	560
Norton	40

Some of the collection system is over 100 years old, and is subject to large amounts of inflow and infiltration. As of 2006, at least 300 manhole covers in the system had holes drilled in them so that they act as catch basins during storm events, and an additional 33 manholes had combined drainage and sanitary pipelines in the same structure (August 28, 2006 letter from Veolia Water). This results in high peak flows under wet weather conditions. The highest maximum daily flow reported by the facility since 2001 is 21.8 million gallons per day (MGD), recorded in October 2005; the facility also exceeded 20 MGD in maximum daily flow in April 2010 (20.7 MGD).

Pursuant to an Administrative Order (AO) issued by EPA (EPA AO Docket No. 08-042) in September, 2008 and a MassDEP Administrative Consent Order from April 2005, the permittee has undertaken a seven phase program to address high priority improvements required for the collection system, including manhole repairs and rehabilitation, sewer and service lateral line replacement and/or relining, and private inflow source elimination. According to the permittee's 2010 Inflow/Infiltration Report, the City has removed 4.49 MGD of inflow and infiltration from the system from 2005 to 2010. An overall reduction in flows is confirmed by the facility's DMR data: twelve month average flow ranged between 7.4 and 9.1 MGD in 2004-05 as compared to a range of 6.5 to 7.6 MGD in 2010-11. Work remains to be done, however, as indicated by continued high peak flows in wet weather (e.g April 2010 maximum daily flow of 20.7 mgd).

There is one remaining combined sewer overflow (CSO) on West Water Street, Outfall 004. Pursuant to the 2008 AO, the City is required to continue working on improving its collection system and to evaluate its ability to eliminate the CSO outfall through the collection system improvements. If the collection system improvements by themselves will not eliminate the CSO outfall, the AO requires that the City submit a plan and schedule for additional options; the target elimination date set in the AO is October 2013.

The City has also prepared a comprehensive wastewater management plan (CWMP) as required by the 2005 MassDEP order, and has submitted a Draft Environmental Impact Report (DEIR). The Secretary of the Executive Office of Environmental Affairs (EOEA) issued a Certificate on the DEIR on October 30, 2009 (EOEA No. 13897), and the City is currently completing the Final Environmental Impact Report. As described in the DEIR, the City proposes to expand its sewer system to encompass an additional 14 priority needs areas throughout the city that are currently served by on-site wastewater disposal systems, involving the expansion of the wastewater collection system, an upgrade of the WWTP for nutrient control and future flow capacity, and implementation of a plan to eliminate the CSO. The project would require the expansion of the wastewater treatment plant to a design flow of 10.2 MGD to handle the wastewater from the priority needs areas, future infill development within existing areas and projected additional inter-municipal flows.

B. DERIVATION OF EFFLUENT LIMITATIONS

1. Available Dilution

Water quality based limitations are established with the use of a calculated available dilution. Title 314 CMR 4.03(3)(a) requires that effluent dilution be calculated based on the receiving water 7Q10. The 7Q10 is the lowest observed mean river flow for 7 consecutive days, recorded over a 10 year recurrence interval. Additionally, the plant design flow is used to calculate available effluent dilution.

The plant design flow used to calculate the dilution factor for the current permit was 8.4 mgd (13.0 cfs). The City in its application requested that a design flow of 9 MGD be used, consistent with estimates made by its consultant that the current upgraded treatment plant capacity would be 9 MGD. Because this design flow has not received final state approval, and because such an increase would not be consistent with MassDEP's antidegradation regulations, we have used 8.4 MGD in our calculations. A further discussion of this decision follows in the Flow section.

The nearest USGS river gage station to the discharge is located near Bridgewater (USGS Station No. 01108000). The 7Q10 flow at the Taunton Treatment Plant has been calculated using the 7Q10 flow at the Bridgewater gage and adjusting it based on drainage area. The 7Q10 for the Taunton River at the Bridgewater gaging station is 22.9 cfs, using daily flow data from 1931 to 2002. The drainage area at the gage is 261 square miles. The drainage area at the Taunton WWTP is about (360) square miles, per the USGS Taunton River Gazetteer.

Using drainage area ratios the 7Q10 at the POTW is 22.9 x 360/261 = 31.6 cfs.

The dilution factor for the Taunton WWTP can then be calculated using the following equation.

Dilution Factor = $\frac{\text{Daily average design effluent flow + river flow (7Q10)}}{\text{Daily average design effluent flow}}$

(13.0 cfs + 31.6 cfs) / 13.0 cfs = 3.4

2. Flow

The draft permit continues the flow limit in the current permit of 8.4 mgd. Flow is to be measured continuously. The permittee shall report the annual average monthly flow using the annual rolling average method (See Permit Footnote 2). The monthly average and maximum daily flow shall also be reported.

As described earlier, the permittee has requested that the flow limit be increased to 9 MGD based in the estimate of design flow made by its consultant. EPA will not consider that request until the State has approved a design flow pursuant to its antidegradation policy. As the permittee is subject to the SRF process, the State does not anticipate approving any increase in design flow until the permittee has completed the Environmental Impact Report (EIR) for its CWMP and received an EOEA certificate. Mass DEP, *Implementation Procedures for the Antidegradation Provisions of the Massachusetts Surface Water Quality Standards*, 314 CMR 4.00 (10/21/09). The permittee has completed a draft EIR and is currently preparing a final EIR.

Additionally, any increase in authorized flow and increase in pollutant discharge can only be authorized in compliance with water quality standards, including antidegradation. As has been shown previously, the Taunton River and Mount Hope Bay are not currently attaining water quality standards. The reach of the Taunton River immediately below the Taunton WWTP discharge is impaired for pathogens, and the lower reaches of the Taunton River are impaired for pathogens and organic enrichment/low dissolved oxygen. Mount Hope Bay is impaired for fishes bioassessments, total nitrogen, dissolved oxygen, temperature, fecal coliform and chlorophyll-a.

The Taunton WWTP discharge is only one source of pollutants to a waterbody receiving numerous municipal discharges, industrial discharges, and nonpoint source discharges, which all contribute to the noted water quality violations. In the absence of a TMDL or other water quality information, EPA does not believe that an increase in any pollutant loads to this watershed can be authorized, particularly for pollutants causing the noted water quality impairments. Table 3 lists the wastewater discharges to the Taunton River and its tributaries.

Table 3. Wastewater Treatment Plants discharging to Taunton River Watershed

Discharger	River or Tributary	Flow in MGD*
SOMERSET WPCF	TAUNTON RIVER	4.2
TAUNTON WWTP	TAUNTON RIVER	8.4
OAK POINT HOMES	TAUNTON RIVER	0.185
EAST BRIDGEWATER SCHOOLS	TRIBUTARY BROOK TO TAUNTON	0.012
DIGHTON-REHOBOTH SCHOOL	SEGREGANSET RIVER	0.01
MCI-BRIDGEWATER WPCF	SAW MILL BROOK TO TAUNTON	0.55
MIDDLEBOROUGH WPCF	NEMASKET RIVER	2.16
WHEATON COLLEGE	RUMFORD RIVER	0.12
BRIDGEWATER WWTF	TOWN RIVER	1.44
BROCKTON AWTF	SALISBURY PLAIN RIVER	18.0
MANSFIELD WPCF	THREE MILE RIVER	3.14
	Total	≈ 40. MGD

*MGD-million gallons per day – design flow

As noted earlier, the 7Q10 flow of the Taunton River upstream of the Taunton WWTP is 31.6 cfs (20 MGD). Design flows for facilities upstream of Taunton total approximately 27MGD (total design flows in Table minus Taunton and Somerset). While the actual wastewater discharge volume during critical low flow periods will be lower than the design discharge volume, it is clear that this is an effluent dominated watershed.

3. Conventional Pollutants

Biochemical Oxygen Demand (BOD_5) and Carbonaceous Biochemical Oxygen Demand ($CBOD_5$) – Limits for BOD_5 and $CBOD_5$ are the same as in the current permit. POTWs are subject to the secondary treatment requirements set forth at 40 CFR Part 133. The permit alternates BOD_5 and $CBOD_5$ limits seasonally.

For November through March the standard secondary treatment requirements for BOD_5 (30 mg/l avg monthly; 45 mg/l avg weekly) apply based on the requirements set forth at 40 CFR §§ 133.102(a)(1), (2), (3), and 40 CFR § 122.45(f).

For April through October, the permit contains more stringent water quality based limitations for $CBOD_5$. The limits are an average monthly concentration of 15 mg/l, and a weekly average concentration of 15 mg/l, with accompanying mass limitations. These were established by the MassDEP as a wasteload allocation for BOD_5. These limits are more stringent than those required in 40 CFR § 133.102(a)(4).

The permit utilizes $CBOD_5$ seasonally as the measure of oxygen demand due to high nitrogenous oxygen demand in the effluent during the summer nitrifying season, as allowed under 40 CFR § 133.102(a)(4). The $CBOD_5$ test reduces the interference from nitrogenous compounds that would otherwise make accurate assessment of the organic (carbonaceous) oxygen demand impossible. The use of $CBOD_5$ instead of BOD_5 is not necessary in the colder season as the facility discontinues the nitrifying process, making the use the $CBOD_5$ tests unnecessary.

Total Suspended Solids (TSS) - Limits for TSS are the same as in the current permit. The draft permit includes average monthly and average weekly TSS limitations that are based on secondary treatment requirements set forth at 40 CFR §§ 133.102(b)(1), (2), and (3), and 40 CFR § 122.45(f) for November through March. For April through October, the TSS limits are based on the wasteload allocation. The maximum daily concentration shall continue to be reported.

The mass limitations for BOD_5, $CBOD_5$, and TSS are based on the 8.4 mgd design flow. Average monthly and average weekly TSS mass limits (lbs per day) are required under 40 CFR §122.45(f).

$CBOD_5$, BOD_5, and TSS Mass Loading Calculations:

Calculations of maximum allowable loads for average monthly BOD_5 and TSS are based on the following equation:

L = C x 8.4 x 8.34

L = Maximum allowable load in lbs/day.
C = Maximum allowable effluent concentration for reporting period in mg/l.
Reporting periods are average monthly and weekly and daily maximum.
8.4 = Design flow of facility
8.34 = Factor to convert effluent concentration in mg/l and design flow in mgd to lbs/day.

(Concentration limit) [45] X 8.34 (Constant) X 8.4 (design flow) = 3,152 lb/day
(Concentration limit) [30] X 8.34 (Constant) X 8.4 (design flow) = 2,102 lb/day
(Concentration limit) [20] X 8.34 (Constant) X 8.4 (design flow) = 1,401 lb/day
(Concentration limit) [15] X 8.34 (Constant) X 8.4 (design flow) = 1,051 lb/day

Eighty-Five Percent (85%) BOD_5 and TSS Removal - the provisions of 40 CFR §133.102(a)(3), require that the 30 day average percent removal for BOD_5 and TSS be not less than 85%.

Eighty-Five Percent (85%) $CBOD_5$ Removal - the provisions of 40 CFR §133.102(a)(4)(iii), require that the 30 day average percent removal for $CBOD_5$ be not less than 85%.

pH - The draft permit includes pH limitations required as a condition of state certification, that are protective of pH standards set forth at 314 CMR 4.05(4)(b)(3), for Class SB waters.

The biological nitrification process uses alkalinity, which tends to lower the pH of wastewater leaving the activated sludge process. Lime is added to supplement alkalinity during the nitrification season, but there are still occasional periods when the pH is depressed below 6.5 SU. The MassDEP has stated that a permitted pH range of 6.0-8.5 SU is protective of State water quality standards, and this range has been included in the draft permit. These pH limits are more stringent than those required under 40 CFR § 133.102(c). The monitoring frequency remains once (1) per day.

Bacteria – The MA SWQS include criteria for two bacterial indicators for Class SB waters. Fecal coliform bacteria are applicable in water designated for shellfishing and enterococci criteria have been established to protect recreational uses. Criteria for enterococci were first promulgated for

Massachusetts coastal waters by EPA on November 16, 2004 (see 40 CFR 131.41). Massachusetts subsequently adopted enterococci criteria for marine waters into its water quality standards that were approved by EPA on September 19, 2007. Given the location of this discharge, the draft permit includes permit limitations for both bacterial indicators.

The fecal coliform criteria for SB water designated for shellfishing require that the median or geometric mean most probable number (MPN) not exceed 88 organisms/100 ml, and that no more than 10% of the samples may exceed an MPN of 260/100 ml. The draft permit includes a monthly average (geometric mean) effluent limit of 88 MPN and a maximum daily limit of 260 MPN.

The enterococci criteria require that no single sample exceed 104 colonies per 100 ml and that geometric mean of all samples taken within the most recent six months based on a minimum of five samples shall not exceed 35 colonies per 100 ml. MassDEP views the use of the 90% upper confidence level of 276 cfu/100ml as appropriate for setting the maximum daily limit for enterococci in the draft permit. Therefore EPA has established a monthly average (geometric mean) effluent limit of 35 cfu/100ml and daily maximum effluent limit of 276 cfu/100ml for enterococci in the draft permit in order to ensure that the discharge does not cause or contribute to exceedances of the MA SWQS found at 314 CMR 4.05 (4)(a)4b.

Sampling is required three times per week. Colony forming units (CFU) are determined by membrane filter methods and MPN units are determined by most probable number methods. Both methods and units are acceptable.

Disinfection is currently required year-round as determined by the MassDEP due to the designation of the receiving water for shellfishing and the location of the Aquaria desalinization plant in Dighton, downstream of the Taunton WWTP discharge. The year round disinfection requirement shall remain in the draft permit.

4. Dissolved Oxygen (DO) and Total Residual Chlorine

Dissolved Oxygen - The instantaneous minimum effluent DO limit of 6.0 mg/l or greater is carried forward from the current permit. The limit ensures that DO levels depleted during wastewater treatment process are restored prior to discharge to the Taunton River. The limit is established to protect the DO minimum Water Quality Criteria of 5.0 mg/l for waters designated by the State as Class SB.

Total Residual Chlorine (TRC) - Chlorine compounds resulting from the disinfection process can be extremely toxic to aquatic life. The instream chlorine criteria are defined in *National Recommended Water Quality Criteria: 2002*, EPA 822R-02-047 (November 2002), as adopted by the MassDEP into the state water quality standards at 314 CMR 4.05(5)(e). The criteria establish that the total residual chlorine in the receiving water should not exceed 7.5 ug/l (chronic) and 13 ug/l (acute). The following is a water quality based calculation of chlorine limits:

Acute Chlorine Salt Water Criteria = 13 ug/l

Chronic Chlorine Salt Water Criteria = 7.5 ug/l

(acute criteria * dilution factor) = Acute (Maximum Daily)
13 ug/l x 3.4 = 44.2 ug/l = **0.044 mg/l Maximum Daily**.

(chronic criteria * dilution factor) = Chronic (Average Monthly)
7.5 ug/l x 3.4 = 25.5 ug/l = **0.026 mg/l Average Monthly**

The permittee is required to have an alarm to system to warn of a chlorination system malfunction. This is a best management practice (BMP), and is being required under authority of 40 CFR § 122.44(k)(4). The permit requires the submission of the results to EPA of any additional testing done beyond that required in the permit, if it is conducted in accordance with EPA approved methods, consistent with the provisions of 40 CFR §122.41(l)(4)(ii).

5. Total Nitrogen

In their comments on the 2007 draft permit, several commenters contended that, among other things, the permit failed to ensure compliance with applicable state water quality standards and relevant provisions of the CWA because it lacked an effluent limitation for total nitrogen (TN).

Upon review, EPA concluded that the comments raise substantial new questions regarding the need to establish an effluent limit for total nitrogen under CWA Section 301(b)(1)(C), which requires, among other things, the imposition of effluent limitations to ensure that the discharge will not cause or contribute to a violation of state water quality standards, including narrative criteria for water quality. Based on an analysis of these comments and other relevant information, EPA decided to issue a new draft permit pursuant to 40 C.F.R. § 124.14(b)(1), containing a new effluent limit for nitrogen. The permit limit is 3.0 mg/l total nitrogen as a seasonal average, and a mass limit of 210 lbs/day based on the concentration limit and the design flow of the treatment facility, in effect for the months of May through October. In addition to this seasonally-applied numeric limit, the permit requires the permittee to optimize the treatment facility operations for the removal of total nitrogen during the months of November through April using all available treatment equipment at the facility. The basis for this determination is set forth below.

a. Ecological Setting: the Taunton River Estuary, Mount Hope Bay and Estuarine Systems Generally

The saltwater portions of the Taunton River (the “Taunton River Estuary”) and Mount Hope Bay are part of the greater Narragansett Bay Estuary system, which covers approximately 147 square miles within Massachusetts and Rhode Island (RI). The Narragansett Bay Estuary is one of only 28 “estuaries of national significance” under the National Estuary Program (NEP), which was established in 1987 by amendments to the CWA to identify, restore and protect estuaries along the coasts of the United States.

Mt. Hope Bay (the Bay) is situated in the northeast corner of Narragansett Bay, lying within both

Rhode Island to the south and west and Massachusetts to the north and east. The Bay connects to the East Passage of Narragansett Bay to the southwest, via a deep, narrow channel where the Mt. Hope Bridge crosses over from Aquidneck Island to Bristol Point, and to Rhode Island Sound to the South via the Sakonnet River (actually an embayment) between Tiverton, RI and Aquidneck Island. The Bay covers an area of 13.6 square miles, and has a volume of 53.3 billion gallons at mean low water (MLW). http://www.smast.umassd.edu/MHBNL/report2003.php
The Bay has a tidal range averaging approximately 4.5 feet.

The Taunton River is the largest freshwater source to Mount Hope Bay. It discharges into the Bay from the north at Fall River. The Taunton River Estuary consists of the saltwater portions of the Taunton River, extending from the Braga Bridge at the confluence with Mount Hope Bay upstream to the Route 24 bridge (Taunton/Raynham), approximately four miles upstream of the Taunton WWTP discharge. (MassDEP, 2001). It is the longest river unobstructed by dams in New England, with tidal influence extending upriver approximately 20 miles. (Horsley Witten, 2007).

Estuaries are extremely significant aquatic resources. An estuary is a partially enclosed coastal body of water located between freshwater ecosystems (lakes, rivers, and streams; freshwater and coastal wetlands; and groundwater systems) and coastal shelf systems where freshwater from the land measurably dilutes saltwater from the ocean. This mixture of water types creates a unique transitional environment that is critical for the survival of many species of fish, birds, and other wildlife. Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably sized areas of forest, grassland, or agricultural land (EPA, 2001).

Maintaining water quality within an estuary is important for many reasons. Estuaries provide a variety of habitats such as shallow open waters, freshwater and saltwater marshes, sandy beaches, mud and sand flats, rocky shores, oyster reefs, tidal pools, and seagrass beds. Tens of thousands of birds, mammals, fish, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce. Many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn.

Moreover, estuaries also provide a number of recreational values such as swimming, boating, fishing, and bird watching. In addition, estuaries have an important commercial value since they serve as nursery grounds for two thirds of the nation's commercial fish and shellfish, and support tourism drawing on the natural resources that estuaries supply. (EPA, 1998). Consequently, EPA believes sound environmental policy reasons favor a pollution control approach that is both protective and undertaken expeditiously to prevent degradation of these critical natural resources. Because estuaries are the intermediary between oceans and land, both of these geographic features influence their physical, chemical, and biological properties. In the course of flowing downstream through a watershed to an estuary, tributaries pick up materials that wash off the land or are discharged directly into the water by land-based activities.

Eventually, the materials that accumulate in the tributaries are delivered to estuaries. The types of materials that eventually enter an estuary largely depend on how the land is used. Undisturbed land, for example, will discharge considerably fewer pollutants than an urban center or areas with large amounts of impervious cover. Accordingly, an estuary's overall health can be heavily impacted by surrounding land uses.

Unlike free-flowing rivers, which tend to flush out sediments and pollutants relatively quickly, an estuary will often have a lengthy retention period as up-estuary saltwater movement interacts with down-estuary freshwater flow (EPA, 2001). Estuaries are particle-rich relative to coastal systems and have physical mechanisms that tend to retain particles. These suspended particles mediate a number of activities (e.g., absorbing and scattering light, or absorbing hydroscopic materials such as phosphate and toxic contaminants). New particles enter with river flow and may be resuspended from the bottom by tidal currents and wind-wave activity. Many estuaries are naturally nutrient-rich because of inputs from the land surface and geochemical and biological processes that act as "filters" to retain nutrients within estuaries (EPA, 2001). Consequently, waterborne pollutants, along with contaminated sediment, may remain in the estuary for a long time, magnifying their potential to adversely affect the estuary's plants and animals.

b. Effects of Nutrients on Estuarine Water Quality

The basic cause of nutrient problems in estuaries and nearshore coastal waters is the enrichment of freshwater with nitrogen (N) and phosphorus (P) on its way to the sea and by direct inputs within tidal systems (EPA, 2001). EPA defines nutrient overenrichment as the anthropogenic addition of nutrients, in addition to any natural processes, causing adverse effects or impairments to beneficial uses of a waterbody. (EPA, 2001).

Eutrophication is an aspect of nutrient overenrichment and is defined as an increase in the rate of supply of organic matter to a waterbody (EPA, 2001). Increased nutrient inputs promote a progression of symptoms beginning with excessive growth of phytoplankton and macroalgae to the point where grazers cannot control growth (NOAA, 2007). Phytoplankton is microscopic algae growing in the water column and is measured by chlorophyll-a. Macroalgae are large algae, commonly referred to as "seaweed." The primary symptoms of nutrient overenrichment include an increase in the rate of organic matter supply, changes in algal dominance, and loss of water clarity and are followed by one or more secondary symptoms such as loss of submerged aquatic vegetation, nuisance/toxic algal blooms and low dissolved oxygen. (EPA, 2001). In U.S. coastal waters, nutrient overenrichment is a common thread that ties together a diverse suite of coastal problems such as red tides, fish kills, some marine mammal deaths, outbreaks of shellfish poisonings, loss of seagrass and bottom shellfish habitats, coral reef destruction, and hypoxia and anoxia now experienced as the Gulf of Mexico's "dead zone." (EPA, 2001). Figure 1 shows the progression of nutrient impacts on a waterbody.

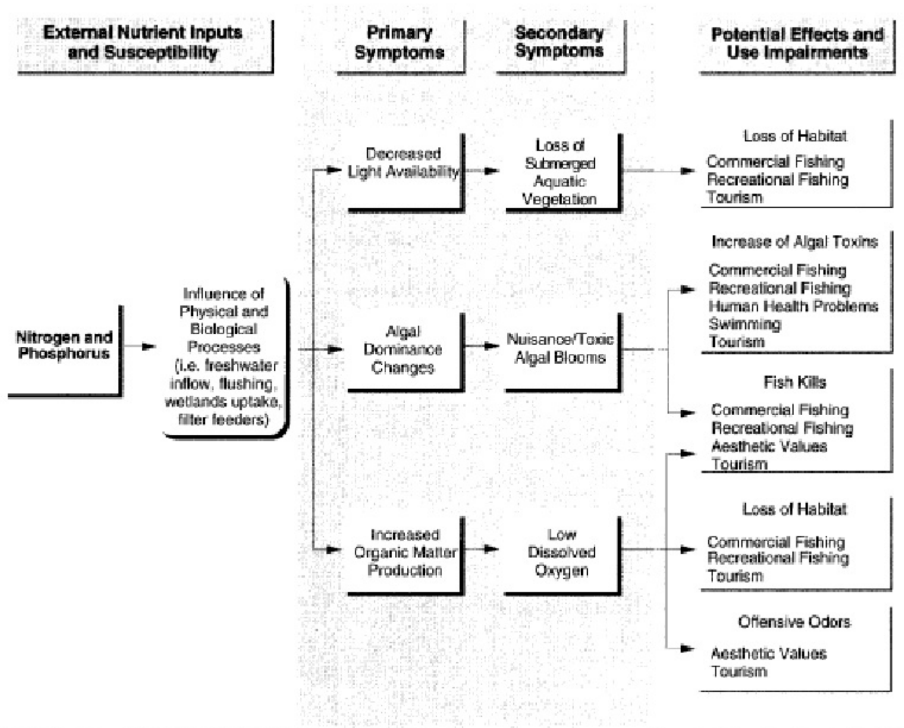

Figure 1
Source: EPA, 2001

Estuarine nutrient dynamics are complex and are influenced by flushing time, freshwater inflow and stratification, among other factors. The deleterious physical, chemical, and biological responses in surface water resulting from excessive plant growth impair designated uses in both receiving and downstream waterbodies. Excessive plant growth can result in a loss of diversity and other changes in the aquatic plant, invertebrate, and fish community structure and habitat.

Nutrient-driven impacts on aquatic life and habitat are felt throughout the eutrophic cycle of plant growth and decomposition. Nutrient-laden plant detritus can settle to the bottom of a water body. In addition to physically altering the benthic environment and aquatic habitat, organic materials (*i.e.*, nutrients) in the sediments can become available for future uptake by aquatic plant growth, further perpetuating and potentially intensifying the eutrophic cycle.

Excessive aquatic plant growth, in addition, degrades aesthetic and recreational uses. Unsightly algal growth is unappealing to swimmers and other stream users and reduces water clarity. Decomposing plant matter also produces unpleasant sights and strong odors. Heavy growths of algae on rocks can make streambeds slippery and difficult or dangerous to walk on. Algae and macrophytes can interfere with angling by fouling fishing lures and equipment. Boat propellers and oars may also get tangled by aquatic vegetation.

When nutrients exceed the assimilative capacity of a water body, the ensuing eutrophic cycle can negatively impact in-stream dissolved oxygen levels. Through respiration, and the decomposition of dead plant matter, excessive algae and plant growth can reduce instream dissolved oxygen concentrations to levels that could negatively impact aquatic life. During the day, primary producers (*e.g.*, algae, plants) provide oxygen to the water as a by-product of photosynthesis. At night, however, when photosynthesis ceases but respiration continues, dissolved oxygen concentrations decline. Furthermore, as primary producers die, they are decomposed by bacteria that consume oxygen, and large populations of decomposers can consume large amounts of dissolved oxygen. Many aquatic insects, fish, and other organisms become stressed and may even die when dissolved oxygen levels drop below a particular threshold level.

Nutrient overenrichment of estuaries and nearshore coastal waters from human-based causes is now recognized as a national problem on the basis of CWA Section 305(b) reports from coastal States (EPA, 2001). Most of the nation's estuarine and coastal waters are moderately to severely polluted by excessive nutrients, especially nitrogen and phosphorus (NOAA, 2007; NOAA, 1999, EPA, 2006; EPA, 2004, EPA; and EPA, 2001).

c. Water Quality Standards Applicable to the Taunton River Estuary and Mount Hope Bay

Under the Massachusetts Surface Water Quality Standards, 314 CMR 4.00 (MA SWQS), surface waters are divided into water "use" classifications, including Class SA and SB for marine and coastal waters. The Taunton River Estuary and the eastern portion of Mount Hope Bay are classified as SB waters, with designations for Shellfishing (R) and CSO. Class SB waters are designated as a "habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In certain waters, habitat for fish, other aquatic life and wildlife may include, but is not limited to, seagrass. Where designated in the tables to 314 CMR 4.00 for shellfishing, these waters shall be suitable for shellfish harvesting with depuration (Restricted and Conditionally Restricted Shellfish Areas)." 314 CMR 4.05(4)(b). Waters in this classification "shall have consistently good aesthetic value." *Id.*

Class SB waters are subject to class-specific narrative and/or numeric water quality criteria. 314 CMR 4.05(4)(b)1 to 8. Dissolved oxygen concentrations in Class SB waters "[s]hall not be less than 5.0 mg/l. Seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained. Where natural background conditions are lower, DO shall not be less than natural background."

The western portion of Mount Hope Bay is designated as a Class SA – Shellfishing water. These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas, they shall be suitable for shellfish harvesting without depuration (Open Shellfish Areas). These waters shall have excellent aesthetic value. With respect to DO, the criteria for class SA waters is "not less than 6.0 mg/L unless background conditions are lower; natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge."

Both Class SA and Class SB waters are also subject to additional minimum standards applicable to all surface waters, as set forth at 314 CMR 4.05(5). With respect to nutrients, the MA SWQS provide:

> Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated

> uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established by the Department pursuant to 314 CMR 4.00. Any existing point source discharge containing nutrients in concentrations that would cause or contribute to cultural eutrophication, including the excessive growth of aquatic plants or algae, in any surface water shall be provided with the most appropriate treatment as determined by the Department, including, where necessary, highest and best practical treatment (HBPT) for POTWs and Best Available Technology (BAT) for non POTWs, to remove such nutrients to ensure protection of existing and designated uses.

314 CMR 4.05(5)(a). In addition, the MA SWQS require:

> Aesthetics – All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances; produce objectionable odor, color, taste, or turbidity; or produce undesirable or nuisance species of aquatic life. 314 CMR 4.05(5)(a)

Massachusetts has not adopted numeric criteria for total nitrogen or other nutrients. MassDEP has, however, used a number of indicators in interpreting its narrative nutrient standard. The DEP/SMAST Massachusetts Estuaries Project report, *Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators - Interim Report* (Howes et al., 2003) (Critical Indicators Report), was developed to provide "a translator between the current narrative standard and nitrogen thresholds (as they relate to the ecological health of each embayment) which can be further refined based on the specific physical, chemical and biological characteristics of each embayment. This report is intended to provide a detailed discussion of the issue and types of indicators that can be used, as well as propose an acceptable range of nitrogen thresholds that will be used to interpret the current narrative standard." http://www.oceanscience.net/estuaries/pdf/nitroest.pdf. This interpretive guidance has been used in a number of TMDLs for estuarine waters in southeastern Massachusetts.

The Critical Indicators Report finds that the indicators of primary concern to be:

- plant presence and diversity (eelgrass, macroalgae, etc.)
- animal species presence and diversity (finfish, shellfish, infauna)
- nutrient concentrations (nitrogen species)
- chlorophyll-a concentration
- dissolved oxygen levels in the embayment water column

(Howes et al., 2003 at 11). With respect to total nitrogen, it concluded:

> It is not possible at this time to put quantitative nitrogen levels on each Water Quality Class. In fact, initial results of the Massachusetts Estuaries Project (Chatham Embayment Report 2003) indicate that the total nitrogen level associated with a particular ecological response can vary by over 1.4 fold (e.g. Stage Harbor versus Bassing Harbor in Chatham MA). Although between embayments nitrogen criteria may be different, it does appear that within a single embayment a consistent quantitative nitrogen criterion can be developed.

However, the Critical Indicators Report provides guidance for indicators, including total nitrogen, for various water quality classes. The nitrogen indicator ranges are based on long-term (>3 yr) average mid-ebb tide concentrations of total nitrogen (mg/L) in the water column. For "Excellent to Good" nitrogen related water quality conditions, equivalent to SA classification, the Report guidance is as follows: "Eelgrass beds are present, macroalgae is generally non-existent but in some cases may be present, benthic animal diversity and shellfish productivity are high, oxygen levels are generally not less than 6.0 mg/l with occasional depletions being rare (if at all), chlorophyll-a levels are in the 3 to 5 µg/L range. . . . For the case study, total nitrogen levels of 0.30-0.39 mg N/L were used to designate "excellent to good" quality areas." Id at 21-22.

For SB waters, the Critical Indicators Report provides the following guidance for indicators of unimpaired conditions, to be refined based on data from the specific embayments: "benthic animal diversity and shellfish productivity are high, oxygen levels are generally not less than 5.0 mg/l with depletions to <4 mg/L being infrequent, chlorophyll-a levels are in the 3 to 5 µg/L range and nitrogen levels are in the 0.39 - 0.50 range. . . . eelgrass is not present . . . and macroalgae is not present or present in limited amounts even though a good healthy aquatic community still exists." Id. at 22.

"Moderate Impairment" is indicated by "Shellfisheries may shift to more resistant species. Oxygen levels generally do not fall below 4 mg/L, although phytoplankton blooms raise chlorophyll a levels to around 10 µg/L. Eelgrass is not sustainable and macro-algae accumulations occur in some regions of the embayment. In the Case Study, embayment regions supporting total nitrogen levels >0.5 mg N/L were clearly impaired." Significant Impairment is indicated by total nitrogen concentrations of 0.6/0.7 mg/l and above. In "severely degraded" conditions, "algal blooms are typical with chlorophyll-a levels generally >20 µg/L, oxygen depletions to hypoxic levels are common, there are periodic fish kills, and macro-algal accumulations occur with both ecological and aesthetic impacts."

In addition to the Massachusetts water quality standards, RI water quality standards applicable to the Rhode Island portion of Mount Hope Bay must also be satisfied. As in Massachusetts, the Rhode Island portions of Mount Hope Bay are designated SB waters in the eastern portion and SA waters in the western portion of the Bay. Rhode Island, like Massachusetts, has specific numeric criteria for dissolved oxygen in SA and SB waters[1], and narrative criteria for nutrients[2]

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[1] Rule 8.D.3. Table 3. For waters with a seasonal pynocline, no less than 4.8 mg/l above the seasonal pynocline; below the seasonal pynocline DO concentrations above 4.8 mg/l shall be considered protective of Aquatic Life Uses. When instantaneous DO values fall below 4.8 mg/l, the waters shall not be (1) Less than 2.9 mg/l for more than 24 consecutive hours during the recruitment season; nor (2) Less than 1.4 mg/l for more than 1 hour more than twice during the recruitment season; nor (3) Shall they exceed the allowable cumulative DO exposure (Table 3.A).

For waters without a seasonal pycnocline, DO concentrations above 4.8 mg/l shall be considered protective of Aquatic Life Uses. When instantaneous DO values fall below 4.8 mg/l, the waters shall not be: (1) Less than 3.0 mg/l for more than 24 consecutive hours during the recruitment season; nor (2) Less than 1.4 mg/l for more than 1 hour more than twice during the recruitment season; nor (3) Shall they exceed the allowable cumulative DO exposure presented (Table 3.A. and Table 3.B).

and aesthetics.[3] The Rhode Island portions of Mount Hope Bay, like the Massachusetts portions are listed for impairments due to total nitrogen, dissolved oxygen (as well as fishes bioassessments and temperature impairments linked to the Brayton Point power plant). As discussed below, permit limits designed to meet water quality standards in the Taunton River Estuary and the Massachusetts portions of Mount Hope Bay are expected to achieve water quality standards in Rhode Island.

d. Receiving Water Quality Violations

The Taunton River Estuary and Mount Hope Bay have reached their assimilative capacity for nitrogen and are suffering from the adverse water quality impacts of nutrient overenrichment, including cultural eutrophication. They are, consequently, failing to attain the water quality standards described above. The impacts of excessive nutrients are evident throughout the Taunton River Estuary and Mount Hope Bay.

Section 303(d) of the CWA requires states to identify those waterbodies that are not expected to meet surface water quality standards after implementation of technology-based controls. The State of Massachusetts has identified Mount Hope Bay and the lower reach[es] of the Taunton River Estuary for impairments due to organic enrichment/low DO, with Total Nitrogen specifically identified as a cause of impairments in Mount Hope Bay.

A three-year water quality monitoring study was conducted by the School for Marine Science and Technology at UMass-Dartmouth (SMAST) and involved monthly sampling at 22 sites across Mount Hope Bay and the Taunton River Estuary from 2004 to 2006 (see Figure 4). This study showed that average chlorophyll-a over the three year period was above 10 ug/l at all monitoring stations across the Taunton River Estuary and Mount Hope Bay. The 20th percentile DO concentrations for the three year period were below the 5.0 mg/l water quality standard at four of the six sites in the Taunton River Estuary (MHB 1, 2 and 18-21). Table 4, reproduced from SMAST, *Summary of Water Quality Monitoring Program for the Mount Hope Bay Embayment System (2004 – 2006)* at 24 (August 16, 2007).

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2 Rule 8.D.1(d). Nutrients - Nutrients shall not exceed the limitations specified in rule 8.D.(2) (freshwaters) and 8.D.(3) (seawaters) and/or more stringent site-specific limits necessary to prevent or minimize accelerated or cultural eutrophication.

Rule 8.D.3. None in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication. Shall not exceed site-specific limits if deemed necessary by the Director to prevent or minimize accelerated or cultural eutrophication. Total phosphorus, nitrates and ammonia may be assigned site-specific permit limits based on reasonable Best Available Technologies. Where waters have low tidal flushing rates, applicable treatment to prevent or minimize accelerated or cultural eutrophication may be required for regulated nonpoint source activities.

3 Rule 8.D.1(b)(iv). Aesthetics - all waters shall be free from pollutants in concentrations or combinations that: iv. Result in the dominance of species of fish and wildlife to such a degree as to create a nuisance or interfere with the existing or designated uses.

Table 4. Mount Hope Bay Monitoring Program results as reported in SMAST, 2007.

Summary of average levels of primary nutrient related water quality parameters measured in the summers of 2004, 2005 and 2006 in Mount Hope Bay by SMAST Coastal Systems staff.

Station	Total Depth (m)	20% Low* D.O. (mg/L)	Sal (ppt)	PO4 (mg/L)	NH4 (mg/L)	NOX (mg/L)	DIN (mg/L)	DON (mg/L)	PON (mg/L)	TN (mg/L)	DIN/DIP Molar Ratio	Total Chl a (ug/L)
MHB1	10.0	5.02	23.3	0.054	0.052	0.095	0.147	0.299	0.155	0.601	6	11.75
MHB2	8.9	4.94	26.1	0.052	0.047	0.043	0.090	0.312	0.170	0.572	4	13.50
MHB3	5.2	5.49	26.0	0.051	0.037	0.035	0.072	0.282	0.163	0.517	3	14.32
MHB4	3.5	5.61	25.7	0.052	0.026	0.017	0.043	0.308	0.173	0.525	3	14.71
MHB5	5.6	5.20	26.2	0.050	0.029	0.020	0.050	0.294	0.169	0.512	2	14.53
MHB6	3.9	5.09	24.1	0.061	0.049	0.030	0.079	0.359	0.168	0.606	3	12.87
MHB7	4.5	5.94	25.5	0.049	0.023	0.016	0.039	0.308	0.189	0.536	2	17.46
MHB8	5.1	4.93	25.8	0.046	0.022	0.019	0.041	0.280	0.165	0.486	2	15.84
MHB9	ND	ND	19.7	0.062	0.049	0.040	0.089	0.453	0.263	0.805	3	14.02
MHB10	3.2	5.86	25.7	0.048	0.017	0.012	0.027	0.314	0.167	0.508	1	14.11
MHB11	4.9	5.02	26.2	0.043	0.017	0.012	0.029	0.268	0.175	0.472	1	16.23
MHB12	5.0	5.36	26.4	0.049	0.020	0.021	0.040	0.284	0.168	0.493	2	16.12
MHB13	5.9	6.00	26.8	0.045	0.020	0.013	0.033	0.282	0.158	0.473	2	15.40
MHB14	6.5	5.34	27.0	0.044	0.024	0.009	0.033	0.289	0.197	0.519	2	16.78
MHB15	12.9	6.46	27.9	0.035	0.021	0.009	0.029	0.273	0.143	0.445	2	12.68
MHB16	11.2	6.33	27.7	0.043	0.028	0.012	0.039	0.265	0.157	0.461	2	13.02
MHB17	ND	ND	24.6	0.064	0.057	0.026	0.083	0.404	0.181	0.669	3	11.81
MHB18	6.7	4.96	22.3	0.062	0.061	0.136	0.197	0.300	0.156	0.652	7	11.44
MHB19	4.0	4.93	18.7	0.058	0.074	0.201	0.275	0.342	0.178	0.799	10	12.27
MHB20	1.8	5.09	17.5	0.054	0.063	0.144	0.207	0.372	0.192	0.771	8	13.59
MHB21	2.6	4.60	14.2	0.061	0.066	0.350	0.415	0.420	0.219	1.058	15	13.34
MHBMOOR	6.3	5.85	26.8	0.045	0.025	0.013	0.038	0.284	0.181	0.503	2	15.57

* Average of the lowest 20% of recorded values

Figure 4. Mount Hope Bay Monitoring Program estuarine stations.

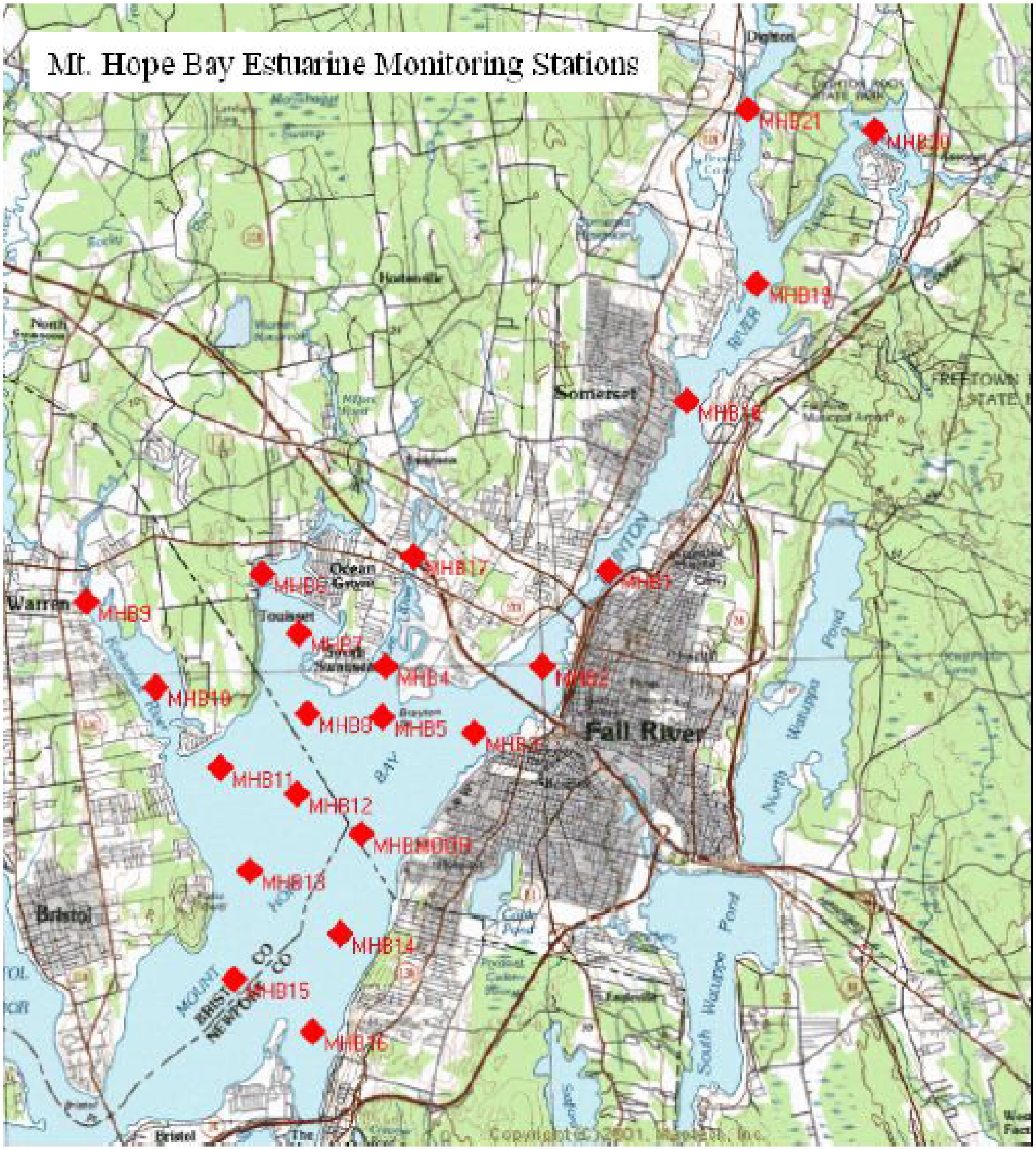


Table 5 below shows the results of the SMAST monitoring for each of the three years of the monitoring program, with the Taunton River stations highlighted. Minimum measured DO concentrations in each year were below 5.0 mg/l at all the Taunton River stations in 2004 and 2006, and a majority of those stations in 2005. In Mount Hope Bay proper, minimum DO concentrations below 5.0 mg/l were encountered at all but one of the Mount Hope Bay stations at least once during the three year period, and at five of the ten stations in both 2004 and 2005. This is compelling evidence of pervasive low DO conditions throughout the Taunton River

Estuary and Mount Hope Bay, given that the sampling was intermittent (and therefore unlikely to capture isolated low DO events) and was not timed to reflect the lowest DO conditions in the waterbody (just before dawn, when oxygen depletion due to respiration is greatest).

Elevated chlorophyll-a concentrations are similarly pervasive based on the SMAST monitoring data. Mean chlorophyll-a concentrations are above the Critical Indicators Report guidelines for unimpaired waters (3-5 ug/l) at every station monitored, in all three of the monitoring seasons. See Table 5. Maximum chlorophyll-a concentrations are routinely above 20 ug/l, a commonly used threshold for determining algal blooms. Again, given the likelihood of intermittent sampling missing the worst conditions in terms of algal blooms, this is compelling evidence of pervasive eutrophic conditions throughout the Taunton River Estuary and Mount Hope Bay.

Total nitrogen concentrations are elevated throughout the system, with a three year average TN concentration above 0.5 mg/l at sixteen of the 22 sites and above 0.45 mg/l at 21 of 22 sites. SMAST, 2007. Total Nitrogen concentrations are generally highest in the tidal rivers, including the Taunton River (e.g. Station 19, TN range 0.66 to 0.99 mg/l). Molar N/P ratios are consistent with nitrogen limitation (≤ 10 at all stations other than MHB21, the uppermost Taunton River station).

Table 5. SMAST Monitoring Data Summarized by Year. Taunton River stations highlighted.

			2004				2005				2006			
Station	Location	State	DO min (mg/l)	Chl-a max (ug/l)	Chl-a mean (ug/l)	TN mean (mg/l)	DO min (mg/l)	Chl-a max (ug/l)	Chl-a mean (ug/l)	TN mean (mg/l)	DO min (mg/l)	Chl-a max (ug/l)	Chl-a mean (ug/l)	TN mean (mg/l)
1	Taunton River	MA	4.8	24.2	7.8	0.53	5.1	49.2	10.9	0.56	4.1	26.6	10.3	0.74
2	Taunton River	MA	4.7	33.2	9.6	0.53	5.0	16.6	8.2	0.51	3.0	48.6	14.2	0.68
3	MHB proper (61-06)	MA	5.1	65.1	11.9	0.51	5.2	20.0	10.2	0.45	4.8	41.5	16.8	0.60
4	Lee River	MA	4.7	19.5	10.5	0.51	5.1	16.0	10.8	0.48	6.1	28.6	16.3	0.59
5	MHB proper (61-07)	MA	4.7	22.4	10.5	0.48	4.6	22.6	11.7	0.49	5.1	29.7	14.3	0.57
6	Cole River	MA	4.9	26.4	11.1	0.52	4.7	16.0	11.0	0.56	5.3	18.6	8.5	0.74
7	MHB proper (61-07)	MA	3.4	37.2	14.2	0.47	5.3	22.3	13.3	0.54	7.1	24.9	16.2	0.60
8	MHB proper (61-07)	MA	3.8	38.8	12.7	0.46	2.6	27.5	11.8	0.45	5.6	32.7	14.1	0.55
9	Kickamut River	RI	No data	19.1	11.9	0.70	No Data	17.7	9.7	0.73	No data	33.1	13.1	1.03
10	Kickamut River	RI	6.0	12.5	8.5	0.48	5.4	29.9	13.6	0.49	5.4	28.9	14.6	0.57
11	MHB-proper	RI	3.2	26.3	10.4	0.44	4.5	33.2	14.3	0.45	5.5	35.6	17.1	0.53
12	MHB-proper	RI	4.0	29.2	10.8	0.45	4.0	29.6	14.4	0.50	5.4	36.4	14.1	0.52
13	MHB-proper	RI	6.5	25.8	11.2	0.42	4.1	27.9	13.4	0.46	6.2	26.5	13.7	0.53
14	MHB-proper	RI	6.0	36.8	14.2	0.58	6.1	32.4	12.1	0.41	2.1	80.6	19.4	0.57
15	MHB-proper	RI	6.9	23.1	9.8	0.45	6.3	23.6	8.8	0.42	4.3	42.4	14.5	0.46
16	MHB-proper	RI	6.2	25.5	10.5	0.45	6.0	33.3	10.3	0.44	5.3	30.4	14.1	0.50
17	Lee River	MA	No data	9.2	4.7	0.65	No Data	17.3	7.9	0.61	No data	27.2	13.8	0.76
18	Taunton River	MA	4.7	16.1	7.5	0.61	4.4	38.0	9.0	0.60	4.3	12.9	7.2	0.80
19	Taunton River	MA	4.4	27.0	10.8	0.72	4.7	33.2	10.5	0.73	4.6	15.0	5.5	0.99
20	Assonet River	MA	5.1	15.7	9.1	0.72	5.6	27.1	12.2	0.63	4.8	16.9	7.6	0.94
21	Taunton River	MA	3.8	23.1	10.5	0.98	4.1	19.8	10.5	1.04	4.8	14.3	5.9	1.24
MOOR	MHB proper (61-06)	MA	6.3	21.4	11.4	0.51	5.4	19.9	11.5	0.45	2.7	35.4	16.5	0.55

Based on these data, the SMAST report concluded that a Massachusetts Estuaries Project ("MEP") analysis of nitrogen loading was warranted for the Mount Hope Bay/Taunton River complex, stating:

> Given the high population within the watershed and resultant N loading to this down gradient estuary and the observed high chlorophyll levels and oxygen depletions, it is not surprising that nitrogen levels are moderately to highly enriched over offshore waters. The Taunton River estuarine reach, as the focus of upper watershed N loading, showed very high total nitrogen levels (TN) in its upper reach (1.058 mg N L^{-1}) and maintained high levels throughout most of its reach (>0.6 mg N L^{-1}). The main basin of Mt. Hope Bay supported lower TN levels primarily as a result of mixing with incoming waters (generally 0.5-0.6 mg N L^{-1}). This is consistent with the observed oxygen depletions and infauna animal communities. The highest (Moderate) water quality was found at the stations in the main basin and lower reaches of Mt Hope Bay out to the channels to lower Narragansett Bay and the Sakonet River (Figure 6).
> . . .
> In general, the Taunton River Estuary, with its large watershed N load and high TN levels, is showing poor water quality due to its high chlorophyll and oxygen depletions. The main basin of Mt. Hope Bay, with its greater flushing and access to higher quality waters of the lower Bay, is showing less impairment with moderate water quality. Finally, the lower basin of Mt. Hope Bay, nearest the tidal "inlet", is generally showing moderate water quality. . . . [T]hese data indicate that the MEP analysis of this system should focus on restoration of the main basin of Mt. Hope Bay and the Taunton River estuarine reach, and that it is likely that restoration of the Taunton River Estuary will have a significant positive effect on the habitat quality of the main basin of Mt. Hope Bay.

To date, the MEP analysis, along with the TMDL that would result from the analysis, has not been completed.[4]

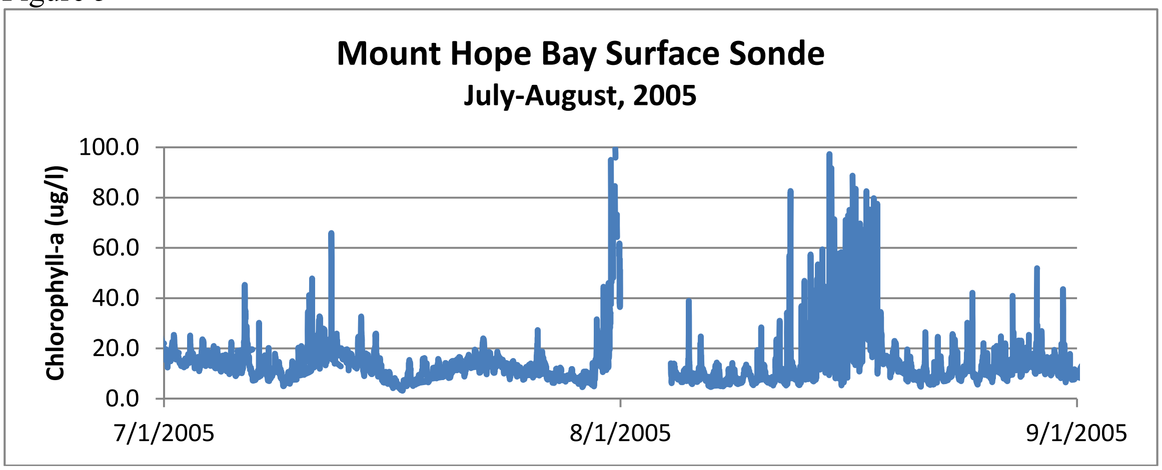
Additional evidence of conditions in Mount Hope Bay is provided from the Narragansett Bay Water Quality Network, fixed monitoring station in the Bay, equipped with two datasondes that measured temperature, salinity, dissolved oxygen and depth at approximately 1 meter from the bottom and 0.5 meters below the surface, and chlorophyll fluorescence at the near surface sonde. (http://www.narrbay.org/d_projects/buoy/buoydata.htm). The datasondes have been deployed in the Rhode Island portion of Mount Hope Bay near SMAST site MHB13, from May or June through October, since 2005. Analysis of the DO data from the deep sonde at this site in 2005 and 2006 showed multiple events (three in 2005; seven in 2006) of DO depletion below the 4.8 mg/l RI water quality threshold, with individual events lasting between two and twelve days. Codiga et al, "Narragansett Bay Hypoxic Even Characteristics Based on Fixed-Site Monitoring

[4] EPA is required to issue the permit with limits and conditions necessary to ensure compliance with State water quality standards at the time of permit reissuance. Neither the CWA nor EPA regulations require that a TMDL be completed before a water quality-based limit may be included in a permit. Rather, water quality-based effluent limitations in NPDES permits must be "consistent with the assumptions and requirements of any *available* [emphasis added] wasteload allocation." 40 C.F.R. § 122.44(d)(1)(vii)(B). Thus, an approved TMDL is not a precondition to the issuance of an NPDES permit for discharges to an impaired waterway.

Network Time Series: Intermittency, Geographic Distribution, Spatial Synchronicity, and Interannual Variability," *Estuaries and Coasts* 32:621-641 (2009). Two of the 2006 events were characterized as "hypoxic", with DO concentrations less than 2.9 mg/l persisting for over two days. Id.

The sonde data also confirms the occurrence of algal blooms and generally elevated chlorophyll-a concentrations in Mount Hope Bay. The 2005 sonde data, Figure 5, shows multiple events with chlorophyll-a concentrations well above 20 ug/l, and above the maximum concentrations captured with the intermittent SMAST sampling.

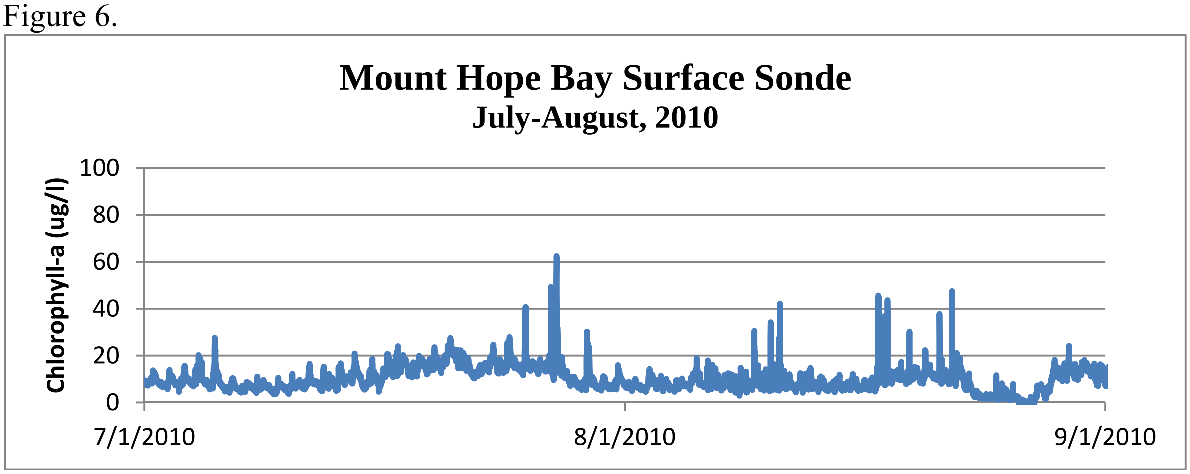
Figure 5



Charts by EPA. Source data: Narragansett Bay Fixed-Site Monitoring Network (NBFSMN), 2005. 2005 Datasets. Rhode Island Department of Environmental Management, Office of Water Resources. Data available at www.dem.ri.gov/bart

The sonde monitoring also confirms that these water quality violations continue to the present. The most recent published data (for 2010) show elevated chlorophyll-a concentrations and persistent DO concentrations below 5 mg/l. Figure 6.

Figure 6.



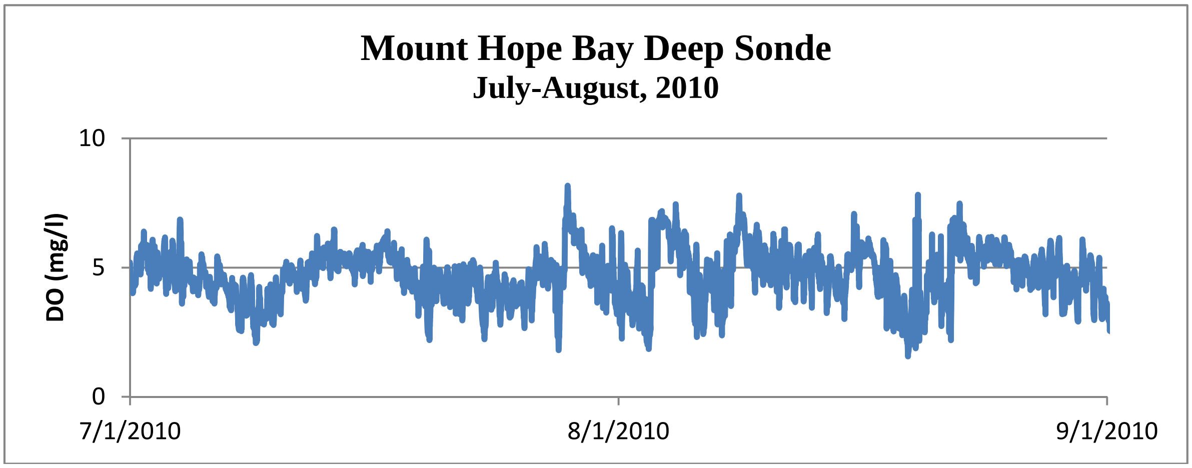


Chart by EPA. Source data: Narragansett Bay Fixed-Site Monitoring Network (NBFSMN), 2010. 2010 Datasets. Rhode Island Department of Environmental Management, Office of Water Resources. Data available at www.dem.ri.gov/bart

Based on these data, EPA has concluded that cultural eutrophication due to nitrogen overenrichment in the Taunton River Estuary and Mount Hope Bay has reached the level of a violation of both Massachusetts and Rhode Island water quality standards for nutrients and aesthetics, and has also resulted in violations of the numeric DO standards in these waters.

e. Reasonable Potential Analysis

Pursuant to 40 CFR § 122.44(d)(1), NPDES permits must contain any requirements in addition to technology-based limits necessary to achieve water quality standards established under Section 303 of the CWA, including state narrative criteria for water quality. In addition, limitations "must control any pollutant or pollutant parameter (conventional, non-conventional, or toxic) that the Director has determined are or may be discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any water quality standard, including State narrative criteria for water quality" (40 CFR § 122.44(d)(1)(i)). An excursion occurs if the actual or projected instream data exceeds any numeric or narrative water quality criterion.

To determine the extent of the facility's contribution to the violation of the MA SWQS, EPA performed an analysis of nitrogen loading to the Taunton River Estuary using data from the SMAST monitoring program, which included monitoring on the Taunton River and major tributaries to the Taunton River Estuary, in additional to the estuarine stations. The analysis focuses on the Taunton River Estuary because that area shows the greatest eutrophication impacts and greatest nitrogen concentrations. Using the 2004-2005 to representative a "typical year" based on precipitation data,[5] EPA used the USGS LOADEST program to calculate a

[5] Rainfall during the summers of 2004 and 2005 totalled 17.82 and 11.03 inches respectively (http://weather-warehouse.com/WeatherHistory/PastWeatherData_TauntonMuniArpt_EastTaunton_MA_September.html), compared to a long term average of 15.24 inches (http://www.weather.com/weather/wxclimatology/monthly/graph/02780). The third monitoring year, 2006, was excluded because extremely high rainfall in May and June (over 9 inches per month, or more than twice the long term average) has potential to disturb the "steady-state" assumption that underlies EPA's load analysis.

seasonal average (June to September) nitrogen load for the Taunton River and each tributary using measured nitrogen concentrations and flow for several discrete events. A description of the LOADEST analysis is provided in Attachment A.

EPA also calculated the point source loads to the Taunton River Estuary derived from wastewater treatment plants based on DMR data from each facility from June through September 2004. These include direct discharges to the Taunton River Estuary (Taunton and Somerset WWTPs), and discharges to the tributaries from other POTWs, which are a component of the tributary loads calculated above. For POTWs discharging to tributaries to the Taunton River, an attenuation factor was applied to account for instream uptake of nitrogen. A description of the attenuation calculation is provided in Attachment B. Attenuation was determined to range from four to eighteen percent for the major (> 1 mgd) facilities located on tributaries (eleven percent for Brockton, the largest discharger), with higher attenuation for some of the smaller facilities on smaller tributaries. Table 6 shows the point sources, the receiving stream, their nitrogen discharges and the delivered load to the estuary.

Table 6.

WWTF	Design Flow (MGD)	Receiving stream	Average 2004-05 Summer TN discharged (lb/d)	Average 2004-05 Summer TN delivered to Estuary (lb/d)
Direct discharges to Estuary				
Taunton	8.4	Taunton River Estuary	610	610
Somerset	4.2	Taunton River Estuary	349.5	349.5
			Total direct point source load:	959
Upstream discharges				
MCI Bridgewater	0.55	Taunton River	37	33
Brockton	18	Salisbury Plain River	1303	1160
Bridgewater	1.44	Town River	137.5	132
Dighton-Rehoboth Schools	0.01	Segregansett River	1	1
Mansfield	3.14	Three Mile River	375.5	312
Middleboro	2.16	Nemasket River	207.5	191
Wheaton College	0.12	Three Mile River	6	3
Oak Point	0.18	Bartlett Brook	9	8
East Bridgewater High School	0.01	Matfield River	1.5	1
			Total upstream point source load:	1841

Finally, EPA calculated total loads to the estuary and allocated those loads between point sources and nonpoint sources. For upstream loads, nonpoint sources were calculated by subtracting the delivered point source loads from the LOADEST total load. Nonpoint source loads from the watershed area downstream of the SMAST monitoring sites, not accounted for in the LOADEST analysis, were calculated using an areal loading factor derived from the LOADEST loading figures. Direct atmospheric deposition to the Taunton River Estuary was not included in the model as it is a relatively small contribution given the relatively small area of the estuary.[6] The average summer load to the estuary in 2004 to 2005 is 4,228 lbs/day.

Figure 7 and Table 7 show the total watershed nitrogen loads to the Taunton River Estuary. Wastewater treatment plant loads make up 66% of the total nitrogen load, with the Taunton WWTP alone constituting 14% of the total load. Nonpoint sources make up the remaining 34%.

Figure 7

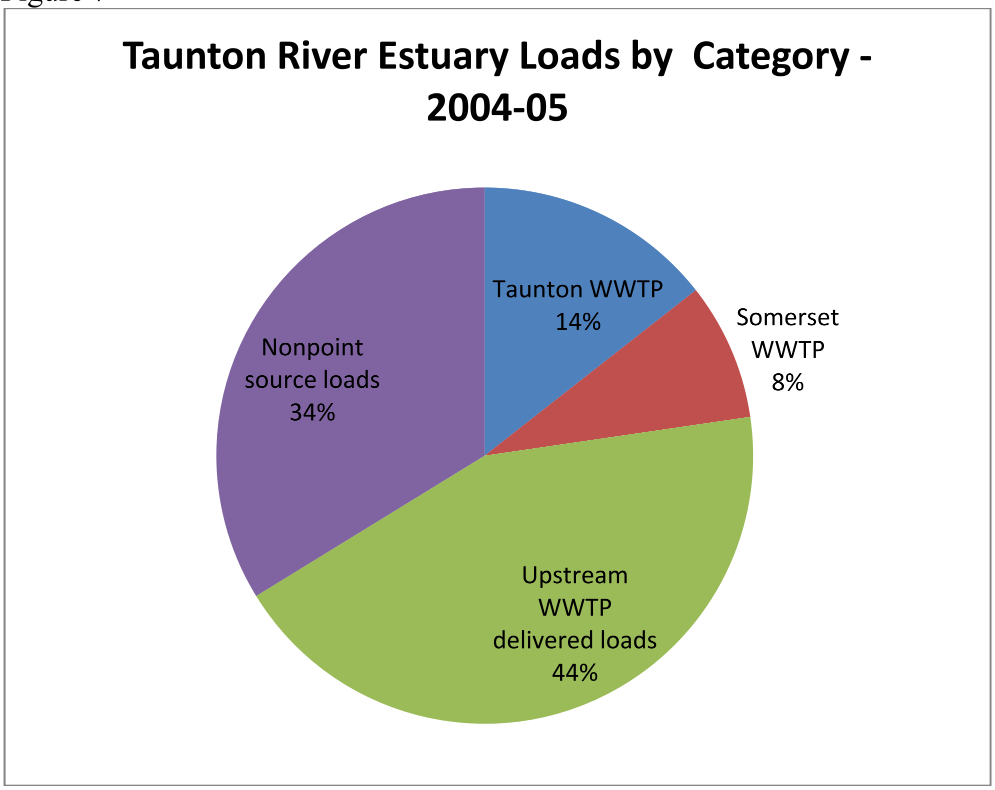


Table 7.

Total loads	Avg 2004-05 Summer Load (lb/d)
Taunton WWTP	610
Somerset WWTP	350
Upstream WWTP delivered loads	1841
Nonpoint source loads	1428
Total	4228

[6] Atmospheric deposition to the watershed is included in the nonpoint source loading figures.

On this basis, EPA concludes that the Taunton WWTP's nitrogen discharges "cause, have a reasonable potential to cause, or contribute" to nitrogen-related water quality violations in the Taunton River Estuary. Therefore, an effluent limit must be included in the permit.

f. Effluent limitation calculation

EPA's calculation of an effluent limitation for nitrogen consists of two parts. First, EPA determines a threshold nitrogen concentration in the water body that is consistent with unimpaired conditions. Second, EPA determines the allowable load from watershed sources generally, and this facility specifically, that will result in receiving water concentrations at or below the allowable threshold.

i. Threshold nitrogen concentration

To determine an appropriate threshold concentration, EPA applied the procedure developed by the Massachusetts Estuaries Project of identifying a target nitrogen concentration threshold based on a location within the estuary where water quality standards are not violated, in order to identify a nitrogen concentration consistent with unimpaired conditions. This approach is consistent with EPA guidance regarding the use of reference conditions for the purposes of developing nutrient water quality criteria. The Taunton River Estuary is classified as an SB water and is not a location where eelgrass has historically been found.[7] Therefore the primary water quality parameter considered in determining a sentinel location is DO. EPA notes that total nitrogen concentrations previously found to be protective of DO in other southeastern Massachusetts estuaries have ranged between 0.35 and 0.55 mg/l.[8]

Data from the SMAST monitoring program indicates widespread DO violations at a range of TN concentrations. Table 5 of the SMAST report (Table 4 above) provides the three year period 20% low DO concentration, which was below the 5 mg/l water quality standard at four stations, with long term average TN concentrations ranging from 0.486 to 1.058 mg/l. However, EPA does not consider a three year, 20% low DO to be a sufficiently sensitive indicator of water quality violations because the water quality criteria are based on a minimum DO concentration of 5 mg/l.

Closer examination of the SMAST monitoring data indicates multiple stations with minmum DO violations during the year with corresponding TN mean concentrations below 0.48 mg/l Indeed, minimum DO concentrations of less than 5.0 mg/l were encountered at all but one site (MHB16) during the three year monitoring program. See Table 5.

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[7] Known historic eelgrass locations within Mount Hope Bay are located on the western portion of the Bay, including the mouths of the Kickamuit, Cole and Lee Rivers, and in the Sakkonet River. See Restoration Sites and Historical Eelgrass Distribution in Narragansett Bay, Rhode Island (2001), http://www.edc.uri.edu/restoration/images/maps/historiceelgrass.pdf . Water quality based TN thresholds would be lower in those areas to protect eelgrass habitat. The DO-based thresholds used for development of permit limits will also protect eelgrass in those locations due to much greater dilution of the Taunton River discharges in those areas of the Bay.

[8] See, e.g. MassDEP, *FINAL West Falmouth Harbor Embayment System Total Maximum Daily Loads For Total Nitrogen* (2007) (Harbor Head threshold 0.35 – SA water); MassDEP, *Oyster Pond Embayment System Total Maximum Daily Loads For Total Nitrogen* (2008) (threshold 0.55).

In addition, DO concentrations from the fixed site monitoring station indicate extensive periods with DO below 5.0 mg/l in 2005 and 2006 (the datasonde was not operating in 2004). EPA considers fixed site monitoring to be superior to intermittent sampling data with respect to DO concentrations because the continuous monitoring includes critical conditions and time periods (e.g. early morning DO minimums) that are generally missed in intermittent sampling. The SMAST monitoring station that is closest to the fixed site station is MHB13. The average TN concentration at MHB13 between 2004 and 2006 was 0.473 mg/l, indicating that the threshold concentration must be lower than that value.

On the basis of these data, EPA determined that station MHB16 was appropriate as a sentinel site where dissolved oxygen standards were met, and that a total nitrogen concentration of **0.45** mg/l (the average of 2004-05 concentrations) represents the threshold protective of the dissolved oxygen water quality standard of 5.0 mg/l. Higher TN concentrations are associated with multiple DO violations, based on the available monitoring data. EPA notes that this value is within the range of target nitrogen thresholds previously determined in southeastern Massachusetts embayments, and is also consistent with TN concentration thresholds to protect dissolved oxygen standards identified in other estuaries. See NHDES, 2009.

ii. Allowable TN load

EPA next determined an allowable total nitrogen load from the watershed that would result in TN concentrations at or below the 0.45 mg/l TN threshold. To do so, EPA applied a steady state ocean water dilution model based on salinity, from Fischer et al. (1979). A similar approach was used by the New Hampshire Department of Environmental Services (NHDES) to develop loading scenarios for the Great Bay Estuary (NHDES, 2009). The basic premise is that steady state concentrations of nitrogen in an estuary will be equal to the nitrogen load divided by the total water flushing rate from freshwater and ocean water. Estuaries are complicated systems with variability due to tides, weather, and stream flows. However, by making the steady state assumption, it is not necessary to model all of these factors. The steady state assumption can be valid for calculations based on long term average conditions, which approximate steady state conditions.

Salinity data is used to determine the proportion of fresh and ocean water in the estuary. Freshwater input is calculated from streamflow measurements at USGS gages in the watershed. Then, ocean water inputs are estimated using salinity measurements and the freshwater inputs. The total flushing rate is then used with the target nitrogen threshold to determine the total allowable load to the estuary. For this calculation, salinity at Station MHB19 during 2004-05[9] was used to represent the sentinel location for meeting the target threshold, because it is the uppermost station that appears clearly nitrogen limited based on the Mount Hope Bay Monitoring Program data.

Freshwater Flow: Average freshwater flow input to the estuary in the summers of 2004 and 2005 is shown in Table 8. Freshwater flows at the mouths of the river is determined based on the USGS streamgage data using a drainage area ratio calculation as follows:

[9] As discussed above, 2004-05 represent a typical year.

Flow at mouth = Flow at USGS gage * Drainage area at mouth/Drainage area at gage

Table 8

	1 Taunton River (Bridge-water) *USGS Gage*	2 Taunton River (area to mouth of estuary minus tributaries) *Drainage Area calculation*	3 Three Mile River (North Dighton) *USGS Gage*	4 Three Mile River (mouth) *Drainage Area calculation*	5 Segre-ganset River (Dighton) *USGS Gage*	6 Segre ganset River (mouth) *Drainage Area calculation*	7 Assonet River (dam) *based on Segregansett*	8 Quequechan River (mouth) *based on Segregansett*	Total Fresh-water Flow (Sum of Columns 2+ 4+6+ 7+8
Drainage Area	261 sq. miles	410 sq. Miles	84 sq. miles	85 sq. miles	10.6 sq. miles	14.9 sq. miles	21.9 sq. miles	30.5 sq. miles	
2004	195 cfs	306 cfs	54 cfs	55 cfs	4.4 cfs	6.1 cfs	9.0 cfs	12.6 cfs	**389 cfs**
2005	217 cfs	341 cfs	55 cfs	56 cfs	4.6 cfs	6.4 cfs	9.4 cfs	13.1 cfs	**427 cfs**

Salinity: A mass balance equation is applied as follows:

Average salinity at ocean boundary (Rhode Island Sound) = 30 ppt (Kincaid and Pockalny, 2003)
Average salinity at MHB19 in Taunton River Estuary for 2004-05 = 22.35 ppt

Average freshwater flow 2004-05 (Table 8) = 408 cfs

(30 ppt * X cfs + 0 ppt * 408 cfs)/(408 cfs + X) = 22.35 ppt

X = 1,192 cfs ocean water

Nitrogen Target: The nitrogen target load in lbs per day is calculated by combining all water inputs and multiplying by the threshold concentration and the appropriate conversion factors.

(408 cfs + 1,192 cfs)*(0.646)*(8.34)*(0.45 mg/l) = 3,879 lbs/day

The nitrogen concentration at the seaward boundary is 0.28 mg/l (from Oviattet al., Annual Primary Production in Narragansett Bay with no Bay-Wide Winter-Spring*** (2001)). The ocean load can then be calculated:

Ocean load = 1,192 cfs * (0.646)*(8.34)*(0.28 mg/l) = 1,798 lbs/day

Based on the overall flow of the estuary (average of summers 2004 and 2005), the allowable TN load to the Taunton River Estuary, including both ocean and watershed loads, is 3,879 lbs/day.[10]

[10] To provide a check on this calculation, EPA calculated the predicted TN concentration in the estuary using calculated loads from 2004-05 using the same mass balance equation. Using the calculated watershed load of 4,228 lbs/day and an ocean load of 1,798 lbs/day as calculated above, the predicted concentration in the estuary is 0.70

The load from the ocean is 1,798 lbs/day, leaving an allowable load of **2,081** lbs/day from watershed sources. As noted above, actual loads in 2004-05 averaged 4,228 lbs/day. This means a reduction in watershed loads of 2,147 lbs/day, or approximately 51%, is required in order to meet water quality standards in the Taunton River Estuary.[11]

Clearly, the required load reduction is greater than the total load currently discharged from the Taunton WWTP and cannot be achieved only through permit limits on this facility. Furthermore, the reduction should be fairly allocated among all discharges to the estuary. EPA notes that all the wastewater treatment plants contributing to the Taunton River are due for permit reissuance, and it is EPA's intent to include nitrogen limits in those permits as appropriate, consistent with this analysis. In doing so, EPA considers not only the facility's current discharges, but their potential discharges under their approved design flows. As this analysis considers summer flows only, an estimated summer flow is calculated at 90% of design flow, consistent with the analysis done by RIDEM for Narragansett Bay facilities. (RIDEM, 2004) See Table 9. This accounts for the fact that a facility discharging at an annual average flow equal to its design flow will average less than design flow during the drier summer months.

For purposes of allocating the required load reduction, EPA first notes that nonpoint sources are unlikely to be reduced by 51% (the overall reduction required in the estuary), and that therefore a higher proportion of the reduction will be allocated to wastewater point sources in the estuary. This is consistent with approaches in approved TMDLs in Massachusetts and elsewhere. EPA considers a 20% nonpoint source (NPS) reduction to be a reasonably aggressive target for nonpoint source reduction in this watershed based on the prevalence of regulated MS4 stormwater discharges, trends in agricultural uses and population, and potential reductions in atmospheric deposition through air quality programs. EPA notes that should nonpoint source reductions fail to be achieved, permit limits for WWTPs in the watershed shall be revisited to ensure that water quality standards are met.

Using the baseline NPS load of 1,428 lbs/day from 2004-05, as shown in Table 7, a 20% reduction would result in a NPS load of 1,142 lbs/day. This leaves an available load for wastewater discharges of 939 lbs/day. Of the eleven facilities discharging to the watershed, five are minor discharges (< 1 MGD) with a combined load of less than 50 lbs/day. These facilities are considered de minimis contributors for the purposes of this analysis and are not analyzed further here.

To determine an equitable load allocation, EPA first determined the permit limit that would be required to meet the allowable load if a uniform limit were applied to all facilities. While permit limits are generally set to be more stringent on larger dischargers/direct discharges to impaired waters, calculating a uniform limit allows EPA to determine the range of options for permit limits. As shown in Table 9 below, a uniform permit limit on all discharges > 1 MGD in the Taunton would have to be between 3.4 and 3.5 mg/l for the allowable loading threshold to be met. For the largest discharges such at Taunton, therefore, a 3.4 mg/l limit represents the upper bound of possible permit limits to meet the water quality requirement. For a lower bound on

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mg/l. The monitoring data indicates that the average TN concentration was 0.73 mg/l, within 5% of the predicted value.

[11] Ocean loads are not considered controllable.

potential permit limits, EPA notes that the currently accepted limit of technology (LOT) for nitrogen removal is a seasonal average of 3.0 mg/l.

Table 9.

WWTF	Design Flow (MGD)	Percent delivered to estuary	Limit assumption: 3.3	Limit assumption: 3.4	Limit assumption: 3.5
Taunton	8.4	100%	208	214	221
Somerset	4.2	100%	104	107	110
Brockton	18	89%	397	409	421
Bridgewater	1.44	96%	34	35	36
Mansfield	3.14	83%	65	67	69
Middleboro	2.16	92%	49	51	52
Smaller facilities (at current loads)			46	46	46
Total			903	929	955

Given the determination that the maximum possible limit is less than 4 mg/l, and that upgrades to meet the most stringent permit limits are more cost-effective at facilities with the highest flows and highest proportion of the load delivered to the estuary, EPA concludes that a LOT permit limit of 3.0 mg/l (seasonal average) is required for the Taunton WWTP. The Taunton WWTP is the second largest discharger to the Taunton River watershed, is responsible for approximately 14% of watershed loads, and discharges directly to the upper portion of the Taunton River estuary, with no potential for uptake or attenuation of its nitrogen discharges.

EPA notes that this will mean the potential for somewhat higher, although still stringent, nitrogen limits at some of the smaller dischargers in the Taunton River watershed. Table 10 shows an example permitting scenario that would meet the allowable loading threshold. In this particular example permit limits for the Brockton AWRF (the largest discharger) and Somerset WWTP (the third largest discharge and a direct discharger to the estuary) are also set at 3.0 mg/l; and the remaining three facilities (Bridgewater, Mansfield and Middleboro) are set at 5.5 mg/l. Final determinations as to the permit limits on these facilities will be made in each individual permit issuance.

Table 10.

WWTF	Design Flow (MGD)	Percent delivered to estuary	Potential permit limit	Load discharged (lbs/d) at 90% design flow	Load delivered to Estuary
Taunton	8.4	100%	3	189	189
Somerset	4.2	100%	3	95	95
Brockton	18	89%	3	405	361
Bridgewater	1.44	96%	5.5	59	57
Mansfield	3.14	83%	5.5	130	108
Middleboro	2.16	92%	5.5	89	82
Smaller facilities (at current loads)					46
Total					938