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Massachusetts Estuaries Project

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

Interim Report

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For:

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DEP/SMAST Massachusetts Estuaries Project

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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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