Development of Nutrient Criteria For Maine's Coastal Waters

Submitted Pursuant to Resolve 2007, chapter 49

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Executive Summary – Key Findings

- This report was required by Resolve 2007, chapter 49 enacted by the 123rd Maine Legislature. This resolve directed the Maine Department of Environmental Protection (DEP) to develop a conceptual plan to establish nutrient criteria for all coastal areas of Maine, with an initial focus on the waters of Casco Bay.

- Existing ambient nutrient data are insufficient to make a determination of both coastal water quality or to ascribe relevant nutrient criteria at this time. Review of initial data indicates that nutrient concentrations in coastal Maine waters and Casco Bay waters are generally below values expected to elicit a negative environmental response.

- There is an essential need for the collection of data for Maine coastal waters outside of Casco Bay. Associated water quality data, such as chlorophyll and oxygen measurements, are needed to strengthen the relationship of this data to nutrient concentrations.

- Methods to assess other effects (e.g. green algae production, loss of submerged aquatic vegetation) need to be developed and implemented as an additional means to assess nutrient effects.

- An additional two to four years of both ambient water quality and wastewater effluent data may be required, depending on the availability of monitoring resources, to determine a final approach to criteria development and expected costs of implementation. The most expeditious means to develop marine nutrient criteria is through a data-distribution approach. Final draft criteria could be developed by 2012 assuming there is sufficient additional data and staff available in the next few years.

- Additional work is needed to assess the terrestrial nonpoint source load to Casco Bay as well as develop mitigation strategies. This could be accomplished using existing computer models and land use data. Implementation of marine nutrient criteria should be done with an understanding of the relative contribution that point and nonpoint sources have, and how controls placed on each relate to criteria attainment.

- An assessment of the ability to remove nitrogen from the seven largest waste treatment facilities that discharge to Casco Bay should be undertaken to more precisely understand facility-specific, as well as any incidental environmental, costs associated with nitrogen removal. Those costs may be extrapolated to other facilities along the coast if it is determined that nitrogen removal will be required.

- The DEP does not presently have sufficient staff and monitoring resources to conduct much of the needed data acquisition and research required to construct a draft rule. Reliance must therefore be made on the U.S. Environmental Protection Agency (EPA) and interested groups to provide data and resources needed to complete the development of nutrient criteria.

Introduction

This report is submitted as required by Resolve 2007, chapter 49 enacted by the 123rd Maine Legislature, Resolve, Regarding Measures to Ensure the Continued Health and Commercial Viability of Maine's Seacoast by Establishing Nutrient Criteria for Coastal Waters, and is presented to the legislature's Joint Standing Committee on Natural Resources. The full text of the enacted resolve is attached as Appendix A to this report.

The resolve directed the Department of Environmental Protection (DEP or Department) to provide:

1. A conceptual plan to establish nutrient criteria for all coastal waters of Maine;
2. An inventory of significant point and nonpoint sources of nutrients to Casco Bay;
3. Available technologies and projected costs of nutrient removal from wastewater; and
4. A workplan and timeline leading to adoption of nutrient criteria for coastal waters.

In assembling this report, the DEP focused largely on the waters of Casco Bay, however the development of nutrient criteria considered the entire coast of Maine -- both requirements of the resolve. The DEP consulted with the Department of Marine Resources (DMR), the U.S. Environmental Protection Agency (EPA), municipal and industrial wastewater facilities in the Casco Bay watershed, and interested organizations, in particular the Friends of Casco Bay and the Casco Bay Estuary Partnership. The consultations included a stakeholder meeting conducted in November 2007. A second meeting was held April 28 to review a report prepared for the EPA and DEP by Battelle that presented a conceptual approach for criteria development and to review a draft of this report. Additional comments were also received after the April 28 meeting. Appendix B provides a list of participating stakeholders and their contact information.

The DEP has been engaged in developing nutrient criteria for fresh waters over the past several years as a requirement in the EPA-DEP Performance Partnership Agreement. The EPA has also been encouraging coastal states to begin the development of nutrient criteria for coastal waters, but to date criteria have only been established for a few selected coastal areas in the nation. The EPA has been actively working with Maine and other coastal states in recent years to conduct monitoring and assemble data in anticipation of needed criteria development.

There are also some terms that are used throughout this paper which should be defined at the start.

- ***Aerobic*** refers to a system that has available molecular oxygen. Most wastewater treatment facilities operate as aerobic systems using mechanical devices to provide oxygen for the microbes that remove the organic wastes from the water.
- ***Anoxic*** refers to a system where there is little or no molecular oxygen but where there is available oxygen bound to other chemicals such as phosphorous, nitrogen or sulfur.
- ***Anaerobic*** refers to a system where there is neither molecular nor bound oxygen available.
- ***Facultative*** bacteria will use molecular oxygen to support their life cycle when it is available. If free oxygen is unavailable, these bacteria well take oxygen from other molecules, like nitrate, to live.

- ***Total Nitrogen*** (TN) refers to all forms of nitrogen, except elemental (gaseous) nitrogen, in the water. Total nitrogen includes unoxidized and oxidized forms of nitrogen.
- ***Total Phosphorous*** refers to all forms of phosphorous in the water.

1. Conceptual Plan

In cooperation with EPA Region I, a study was conducted by Battelle (2008) that collected and assessed readily available marine nutrient data, reviewed other jurisdictions where nutrient criteria have been developed, and presented a conceptual plan of how Maine might proceed in developing nutrient criteria. A copy of this study is attached as Appendix C. This study is quite helpful in recommending preferable courses of action and in defining additional information and data needs.

General interest from the stakeholder meetings and additional correspondence suggests that the Department consider two approaches. Given its potential to accurately correlate nutrient concentrations with ecological impacts, a preferable approach is to design the criteria based on *effects-based* measures (also referred to as a *weight-of-evidence approach* in the Battelle report). This is similar to the design that the Department is using for freshwater nutrient criteria. Nutrients are unique in that, unlike toxics criteria (for example), nutrient effects do not act in a linear manner. An increase or decrease in nutrient concentration does not always elicit a consistent environmental response because there are often considerable interactions with many other environmental variables. Likewise, nutrients can often display subsidy-stress effects, where some elements of an ecosystem can benefit while others do not depending on the change in nutrient conditions. The preferred means to assess nutrients should be to measure the nutrient effect rather than simply measuring an in-water concentration. The Department prefers to proceed along an effects-based criteria design, but only as a long term strategy.

At this time, however, the DEP does not have sufficient effects-based data, or even sufficient standardized methods to gather such data. It will take a considerable amount of time and resources to build such an effects-based database and to develop the relationship that such effects have with nutrients. The DEP needs to build a consensus of which environmental effects are relevant to nutrient management and how these apply to the designated uses specified in our existing marine water classification system. This would be similar to what the Department has already done in its freshwater jurisdiction by proposing dissolved oxygen, pH, chlorophyll, algae, and macroinvertebrate responses based on waterbody classification criteria in relation to ambient nutrient concentrations.

Since the DEP lacks a comprehensive database on nutrient effects for marine waters, the Department recommends that it proceed to implement nutrient criteria using a *data-distribution* approach. The Battelle report provides analysis of a variety of datasets that suggest that interim concentration criteria might be adopted that could guide the state in marine nutrient management decisions. Water quality along the Maine coast is generally very good, including Casco Bay, with only some localized or temporal problems. For example, Dettman and Kurtz (2006) suggest that concentrations in the range of 35-50 micromoles (µM) (~0.5-0.7 mg/l) for total nitrogen (TN) may be a threshold range where initial impacts can be detected. Review of available data used in the Battelle study indicates that the mean TN values for most sites along the Maine coast fall below this threshold range. Values in this range might be helpful as interim criteria since it appears that they may be readily attainable with current practices, but could provide useful planning limits in the face of expected growth and changing water quality.

A number of issues will need to be resolved before either criteria development strategy (effects-based or data-distribution) can be adopted:

- **Waterbody type** – response to nutrient concentrations can vary widely depending on the marine waterbody type. Waterbody type is not the same as the marine water classification designation of SA, SB, or SC (see 38 MRSA §465-B). In Maine, there are considerable ecological differences between eastern coastal waters and western coastal waters. Additionally, the effects of mixing with offshore waters versus riverine inputs, salinity differences, temperature differences in different coastal areas, proximity to shore, depth, and tidal flux can all significantly affect nutrient response. Variability of grazing and harvesting can further complicate nutrient response. Criteria development needs to take such characteristics into account, possibly specifying different criteria for different geographical areas or waterbody types.
- **Water Classification** – Maine has three marine waterbody classes each with somewhat different designated uses and different water quality criteria, such as dissolved oxygen. Separate criteria may need to be developed depending on differential effects that nutrients may have on designated uses.
- **Season** – Nutrient response varies by season. Criteria, and the monitoring necessary to assess the criteria, need to focus on appropriate seasonal periods relevant to designated uses that the criteria are intended to protect. The Department needs to further assess seasonal treatment practices for wastewater.
- **Nutrient parameters** – A wide variety of nutrient measurements are available. Nitrogen (N) appears to be the nutrient of greatest concern that causes eutrophication (excessive plant growth) in coastal waters, but even nitrogen can be measured and analyzed in a wide variety of ways. While monitoring needs to continue addressing the reactive forms of nitrogen that contribute to eutrophication (TN, total inorganic N, total organic N, total Kjeldahl nitrogen (TKN), nitrate-nitrite, and ammonia), interim criteria should be designed for a single measure, like TN.
- **Data sufficiency** – Nutrient concentrations can be highly variable, spatially and temporally, and trophic response correlates to general rather than sample-specific concentration results. Concentration-based criteria need some dimensions, spatially and temporally, for application.
- **Effects-based parameters** – To proceed any further with an effects-based approach, the Department needs to identify important response variables, develop standardized methods to measure these variables, and build a sufficient database to test the response relative to nutrient measures.
- **Data acquisition** – Much of the Battelle report relies on averaging data within each year or just a single datapoint for a site that year. While nutrients tend to affect response over some duration of exposure, a yearly average may not be appropriate and could dilute important nutrient-response relationships, just as a single-sample event can also provide an incorrect assessment of condition. Additional data need to be obtained

so that better within-year and between-year analysis can occur. Likewise, response variables also need to be assessed in an appropriate measure of time and space.

2. Inventory of Nutrient Sources to Casco Bay

Point Sources

A list of all licensed point sources that discharge directly into Casco Bay was reviewed to determine the potential for significant nitrogen contribution based on the size and type of discharge. Based on literature values for nitrogen content and staff knowledge of the characteristics of the discharges, the list was limited to the facilities in Table 1. The list is comprised of:

- All six publicly owned treatment works (POTWs) greater than 750,000 gallons per day.
- The combined sewer overflows from the City of Portland and the Portland Water District East End Facility.
- The SAPPI paper mill in Westbrook.

While there are other point sources that may discharge nitrogen to Casco Bay (such as smaller POTWs and other licensed dischargers including overboard discharges) they are not considered significant based on their size and/or characteristics of their effluent.

The nitrogen loadings included in the table are estimates based on average flow data from the last five years and literature values for nitrogen content of similar effluents. Little or no actual nitrogen effluent data for these facilities currently exists. The Department will work with the listed dischargers in 2008 to collect representative data from their facilities in order to better assess actual point source nitrogen loadings.

Additionally, the Department licenses 186 small overboard discharges (OBDs) that total just over 0.5 million gallons per day (MGD) of permitted waste flow in the Casco Bay watershed. Many of these are seasonal and most discharge directly to marine waters. The Department does not intend to monitor these discharges for nutrients as the discharge volume is very small relative to the overall discharge volume into Casco Bay.

In addressing point sources of nutrients to Maine coastal waters, consideration needs to given to time and distance of travel from any upstream freshwater discharge source until it reaches estuarine waters. Uptake and transformation of nitrogen in freshwater may substantially reduce any effect of inland sources to marine waters. This may be a complicated modeling problem but the outcome could have a significant effect on any loading model for marine waters and substantially affect how a facility might be regulated.

Table 1: Licensed Point Sources that Discharge Directly into Casco Bay and Nitrogen Loading[1]

Facility	Facility Type	Design Flow[2] in Million Gallons Per Day (MGD)	Average Flow[3] in Million Gallons Per Day (MGD)	Estimated Total Nitrogen[4] Loading Based on Design Flow (lbs/day)	Estimated Total Nitrogen Loading Based on Average Flow (lbs/day)
Portland Water District (Portland)	POTW[5]	19.80	18.20	3,303	3,036
South Portland Water Pollution Control Facility	POTW	9.30	7.27	1,551	1,213
Portland Water District (Westbrook)	POTW	4.54	2.93	757	489
SAPPI Westbrook	Paper Mill	15.00	6.40	1,063	454
Falmouth Water Pollution Control Facility	POTW	1.56	0.81	260	135
Town of Yarmouth	POTW	1.31	0.79	219	132
Freeport Sewer District	POTW	0.75	0.39	125	65
TOTAL				**7,278**	**5,523**
Facility	**Facility Type**		**Average CSO Summertime Flow (million gallons)**	**Estimated TKN[7] loading (lbs. per summer)**	**Estimated TKN loading (lbs. per summer day)[8]**
City of Portland (33 CSOs[6])	CSO		332	13,844	**114**

[1] Nitrogen loadings in this table are estimates based on literature values for nitrogen content of similar effluents and average flow data over the last five years. Little or no actual nitrogen effluent data for these facilities currently exists. The Department plans on working with the listed dischargers in 2008 to collect representative data from these facilities in order to better assess actual nitrogen loadings. Loadings are calculated on the following estimates: POTWs TN = 20 mg/L, paper mill TN = 8.5 mg/L, CSO TKN = 5 mg/L

[2] The design flow of the facility is typically used as the maximum amount of flow the facility is allowed to discharge under its waste discharge license. Therefore these values represent the maximum amount the facility is likely to discharge.

[3] Average flow based on average of last five years.

[4] Total Nitrogen (TN) = ammonia (NH_4) + organic nitrogen + nitrate (NO_3) + nitrite (NO_2)

[5] POTW = Publicly Owned Treatment Works

[6] Includes CSO's from Portland Water District East End Facility. CSO = Combined Sewer Overflow. CSOs occur during storm events when a mixture of untreated stormwater and wastewater overflows a combined sewer collection system.

[7] TKN = Total Kjeldahl Nitrogen. (NH_4 + organic nitrogen) TN data was not available for CSOs therefore the numbers for CSOs and other point source discharges reported as TN are not directly comparable.

[8] CSOs occur sporadically throughout the year in relation to rain events and snow melt. Only summertime flow data (average of last five summers) was used here as summertime is when nitrogen impacts are most likely to occur. This estimated loading of lbs. per summer day is calculated by dividing the estimated TKN loading per summer by 121 days in June-Sept. It is shown only to give a daily loading relative to the daily loadings from other point sources. In reality, CSOs do not occur daily.

Nonpoint sources

Nonpoint source pollution (NPS) is the diffuse source of pollution that cannot be attributed to a clearly identifiable physical location or a defined discharge channel. This includes the nutrients that run off the ground from any land use type - croplands, feedlots, lawns, parking lots, streets, forests, etc. - and enter waterways. It also includes nutrients that enter through air pollution, or through the groundwater, as from septic systems.

Nitrogen occurs naturally in soil, animal waste, plant material, and the atmosphere (some plants, including some algae, can also fix elemental nitrogen as a source). In addition to these natural sources, sewage treatment plants, industries, vehicle exhaust, acid rain, and runoff from agricultural, residential and urban areas contribute nitrogen to coastal waters, including Casco Bay and its tributaries. Many forms of nitrogen are highly soluble, therefore it readily moves as the water moves including through groundwater.

Driscoll et al. (2003) identifies 3 primary sources of reactive nitrogen in the Northeast: nitrogen from foods consumed by humans (including domestic animal feed), atmospheric deposition of nitrogen, and nitrogen fertilizer. For Casco Bay, the report estimates reactive nitrogen input at about 17 kilograms per hectare per year (kg/ha/yr). Of the ten watersheds studied by Driscoll, this was the lowest. The relative contribution of each source is related to population density (nitrogen from food), land use (nitrogen fertilizer), vehicle emissions and electric utilities (atmospheric). The highest relative sources for Casco Bay are nitrogen from food and atmospheric deposition. Nitrogen from food would get to the bay either via wastewater treatment facilities (point source), or septic systems or other means such as animal waste (nonpoint sources).

Controllable nonpoint sources of nitrogen can be sorted into 2 types:

1. Nonpoint sources, or runoff from land use activities, including direct stormwater discharges from developed areas, indirect overland runoff, and groundwater transport from all land use types. Certain stormwater discharges are presently regulated through general permits, but these permits do not directly address nutrient levels or treatment requirements.
2. Atmospheric deposition directly to water surfaces, and to the land which eventually drains into Casco Bay.

A third source type, offshore sources (from tidal exchange and other currents, upwellings, ocean storms, etc. which move and mix offshore and nearshore nutrients together), cannot be controlled. However, offshore sources can often be the dominant source of nutrients and generally play a beneficial role in maintaining the productivity of our marine waters.

Land Use Activities

Nitrogen in surface water runoff and streams comes from atmospheric deposition, agriculture, and urban (developed) land areas. Nonpoint sources of nitrogen are widely distributed over the watershed landscape. Primary nitrogen inputs from agriculture are fertilizers, manure from animal production, and soil disturbance. There are many nitrogen sources from urban or residential activities such as fertilizers, chemical spillage, soil disturbance, septic systems, etc. While the Department's stormwater general permits do not directly address nutrient removal, the required best management practices (BMPs) can effectively reduce nutrient loads (e.g. phosphorus uptake and denitrification associated with wet ponds). Stormwater discharges from new developments are regulated by the Stormwater Management Law (DEP rules, chapter 500) which requires that a permit be obtained from the DEP prior to the construction of any new project exceeding one acre or more of disturbed area, that stormwater quantity and quality be addressed at the source, and that design plans be reviewed by the DEP. Among other requirements in the law, the treatment of pollutants must be provided by BMPs specifically designed to remove fine particulates, dissolved pollutants and hydrocarbons from no less than 95% of the impervious area, 80% of the developed area and 75% from the surface of new roads.

Nitrogen is transported to rivers in surface runoff and groundwater discharge. A considerable portion of nitrogen is retained by soil, taken up by plants, or lost to the atmosphere, and does not enter surface waters. Also, nitrogen entering freshwaters distant from marine waters may be used or transformed to elemental nitrogen and never reach marine waters.

There is only very limited and generalized information regarding nitrogen loading (weight/area/year) by land use types. The relative nitrogen loads by land use type can be assessed by applying a watershed model developed by the U.S. Geological Survey (USGS). USGS, in cooperation with the U.S. Environmental Protection Agency (EPA) and the New England Interstate Water Pollution Control Commission (NEIWPCC), has prepared water-quality models to assist in regional total maximum daily load (TMDL) studies and nutrient criteria development efforts in New England. Spatially Referenced Regressions on Watershed Attributes (SPARROW) are spatially detailed, statistical models in a geographic information systems (GIS) framework that use regression equations to relate total phosphorus and total nitrogen stream loads to contaminant sources and watershed characteristics. These statistical relations are then used to predict nutrient loads in unmonitored streams.

Applications of SPARROW for evaluating nutrient loading in New England waters include estimates of the spatial distributions of total nitrogen and phosphorus yields, sources of the nutrients, and the potential for delivery of those yields to receiving waters. This information can be used to (1) predict ranges in nutrient levels in surface waters, (2) identify the environmental variables that are statistically significant predictors of nutrient levels in streams, (3) evaluate monitoring efforts for better determination of nutrient loads, and (4) evaluate management options for reducing nutrient loads to achieve water-quality goals.

Atmospheric Deposition of Nitrogen.

Nitrogen is added to marine waters directly when it rains or snows and by dry deposition. Nitrogen is an airborne pollutant emitted from many sources such as car exhaust pipes, building smokestacks, power plants, animal agriculture, etc. Nitrogen in the atmosphere is present primarily in three forms: oxidized inorganic nitrogen, ammonium compounds, and organic nitrogen compounds. A report prepared for the Casco Bay Estuary Project (CBEP), *Deposition of Air Pollutants to Casco Bay*, Sonoma Technology, Inc., 2003, estimated the atmospheric deposition of nitrogen to Casco Bay as follows:

- Atmospheric deposition (dry plus wet deposition) of inorganic nitrogen is a significant source of pollution to Casco Bay.
- Wet deposition directly to the bay surface area accounts for 200 to 246 tonnes/yr. Dry deposition totals 146 to 182 tonnes/yr. Total (dry + wet) deposition could account for as much as 30 to 40% of the overall inorganic nitrogen load to Casco Bay (point and nonpoint source).
- Additional (wet + dry) deposition to the Casco Bay watershed that reaches the bay increases the atmospheric deposition factor by an unknown amount.

The report used a surface area of 229 square miles for Casco Bay and 985 square miles for the watershed. In the CBEP study, the role and effect of organic nitrogen compounds was not assessed due to insufficient information about these compounds. Measurements of wet organic nitrogen over the mid-Atlantic coastal states indicated that organic nitrogen averages at least 20% of the total dissolved nitrogen in precipitation, however it is not known whether this is also true for Maine.

3. Technological Approaches and Projected Costs for Nutrient Reduction of Wastewater

Most of the wastewater treatment facilities in the state are not currently designed or operated to reduce nitrogen. While some nitrogen reduction may be achieved in the typical treatment processes currently used, it is incidental to the primary focus of reducing biochemical oxygen demand and total suspended solids. In order to achieve purposeful nitrogen reductions in wastewater, changes to wastewater facility infrastructure and operations would be necessary. The most common methods of nitrogen reduction are referred to as Biological Nutrient Removal (BNR). BNR typically involves creating conditions within the treatment facility whereby specific bacteria can convert soluble nitrogen to a nitrogen gas that is removed from the wastewater. As explained below, costs to establish BNR systems can be significant and influenced by many factors.

<u>Nitrogen Removal Theory</u>

Nitrogen occurs in wastewater in two general forms: unoxidized nitrogen and oxidized nitrogen. As the terms imply, unoxidized nitrogen has not chemically combined with oxygen while oxidized nitrogen has chemically combined with oxygen. In wastewater, unoxidized nitrogen is usually a form of the ammonium ion (NH_4^+) or organic nitrogen. The ammonium ion is very soluble in water. Some forms of organic nitrogen are soluble and some are bound in particles that can be removed from the water by settling or filtration. There is usually very little oxidized nitrogen in raw wastewater. Most of the oxidized nitrogen that is present is in the form of the nitrate ion (NO_3^-). The nitrite ion (NO_2^-) is much less stable and not found in raw wastewater unless there is a specific discharge of nitrite from an industrial source. Both forms of oxidized nitrogen are very soluble in water.

Removing nitrogen from wastewater involves several steps. Primary clarification can remove some particulate organic nitrogen. In the aerobic part of the treatment process, bacteria convert the soluble organic nitrogen to the ammonium ion (NH_4^+). A small amount of the ammonium (NH_4^+) is absorbed by the biomass of the treatment system and used to build proteins in the bacterial cells.

If the correct conditions are maintained, a specific type of bacteria called *Nitrosomonas* will use the ammonium ion (NH_4^+) as food and convert the ammonium to nitrite (NO_2^-). Another type of bacteria called *Nitrobacter* will use the nitrite (NO_2^-) as food and convert the nitrite (NO_2^-) to nitrate (NO_3^-). This process is called **nitrification**. The *Nitrosomonas* bacteria use almost three and one-half pounds of oxygen and more than seven pounds of alkalinity to convert one pound of nitrogen from the ammonium ion to nitrite. The *Nitrobacter* bacteria require another pound of oxygen to convert each pound of nitrite nitrogen to nitrate.

The *Nitrosomonas* and *Nitrobacter* bacteria grow more slowly than the other types of bacteria that are normally found in a wastewater treatment system. To maintain an adequate number of these bacteria to convert the ammonia in the wastewater to nitrate, the biomass in the treatment system must be at least 5 days old, and preferably older. *Nitrosomonas* and *Nitrobacter* are also temperature sensitive and do not grow well below about 5º C. These bacteria are very sensitive to pH. Since the *Nitrosomonas* bacteria use alkalinity, which helps keep the pH of wastewater near the neutral pH of 7.0, if the wastewater does not have adequate alkalinity, the growth of the *Nitrosomonas* bacteria can actually cause a drop in the pH, effectively poisoning both the *Nitrosomonas* and *Nitrobacter* and halting the nitrification process.

When the temperature, pH, oxygen levels and alkalinity are in the proper ranges, most secondary treatment systems will readily convert virtually all of the ammonium to nitrate. However, the nitrogen is just changed in form and not removed from the wastewater. In order to completely remove the nitrogen from the wastewater, a process called **denitrification** must take place. Denitrification is done by many different types of facultative bacteria. Denitrification requires a supply of these facultative bacteria, food in the form of organic matter, and anoxic conditions. When these conditions happen, the facultative bacteria will strip the oxygen from the nitrate ion leaving the free nitrogen which is given off to the atmosphere. At this point, the nitrogen has been removed completely from the wastewater.

Theoretically, nitrification and denitrification can remove all of the nitrogen from wastewater. In reality, even the most efficient treatment systems leave some residual nitrogen, in the form of soluble unoxidized and oxidized nitrogen and particulate organic nitrogen that are part of the total suspended solids in the effluent.

Biological Nutrient Removal (BNR) Technologies

There are a number of different wastewater treatment plant configurations that can be utilized to remove nutrients using biological treatment. The success of these configurations in removing the nutrients is greatly affected by a number of different factors. Those factors influence the operation whether a facility is being retrofitted to accomplish nutrient removal or if the facility is being completely reconstructed.

Factors affecting the treatment of nutrients include:

- Effluent quality targets
- Facility flow variation
- Aeration basin size and configuration
- Clarifier capacity
- Type of aeration system
- Sludge processing units
- Process control requirements

The common BNR systems are as follows:

- **Modified Ludzack-Ettinger (MLE) Process –** continuous flow suspended growth process with an initial anoxic stage followed by an aerobic stage used to remove total nitrogen.
- **A^2/O Process –** MLE process preceded by an initial anaerobic stage. This is used to remove both total nitrogen and total phosphorus.
- **Step Feed Process –** alternating anoxic and aerobic stages, however influent flow is split to several feed locations and the recycle sludge stream is sent to the beginning of the process. This configuration is used to remove total nitrogen.
- **Bardenpho Process (4 stage) –** continuous flow suspended growth process with alternating anoxic/aerobic/anoxic/aerobic stages that is used to remove total nitrogen.
- **Modified Bardenpho Process –** Bardenpho process with addition of an initial anaerobic zone that is used to remove both total nitrogen and total phosphorus.
- **Sequencing Batch Reactor (SBR) Process –** suspended growth batch process sequenced to simulate the four stage waste treatment process. This configuration is used to remove total nitrogen with a small amount of total phosphorous removal.
- **Modified University of Cape Town (UCT) Process** - A^2/O Process with a second anoxic stage where the internal nitrate recycle is returned. This configuration is used to remove total nitrogen and total phosphorus.
- **Rotating Biological Contactor (RBC) Process –** continuous flow process using RBC's with sequential anoxic/aerobic stages. This configuration is used to remove total nitrogen.
- **Oxidation Ditch –** continuous flow process using looped channels to create time sequenced anoxic, aerobic, and anaerobic zones. This configuration is used to remove both total nitrogen and total phosphorus.

These BNR systems are more complex than typical secondary systems and consequently they require more operator experience to operate successfully.

The effluent quality limits, combined with whether a retrofit design or a new facility design is chosen, drive the decision on what type of system is most appropriate. New plants will have more flexibility built into the design, whereas retrofit designs may be hampered by existing wastewater treatment components.

The comparison of these various biological nutrient removal system configurations for removing nitrogen from the waste water is summarized in Table 2.

Table 2: Comparison of, and Performance Data for, Common BNR Configurations

Wastewater Treatment Process	Nitrogen Removal Rating	Effluent Total Nitrogen Range
MLE	Good	6-8 mg/L
A^2/O	Good	Not available
Step Feed	Moderate	6-8 mg/L
Four Stage Bardenpho	Excellent	3 mg/L
Modified Bardenpho	Excellent	Not available
Sequencing Batch Reactor	Moderate	6-8 mg/L
Modified UCT	Good	Not available
Oxidation Ditch	Excellent	Not available

Source: Jeyanayagam (2005)

The only way to accurately evaluate what options exist for any particular wastewater treatment facility is for a qualified and experienced engineering consultant to evaluate the wastewater being treated and the existing system of treatment. The consultant will take all necessary considerations into account when evaluating options and ultimately making recommendations to either retrofit and upgrade the facility, or to recommend a more involved reconstruction of the facility.

<u>Facility Cost Information</u>

For the purposes of this report, estimating the costs of nutrient reduction of wastewater is challenging due to all of the factors involved. Existing plant conditions, including flexibility in design, remaining design capacity, layout of system, and remaining space may impact costs significantly. Therefore, comparisons of upgrade costs between plants of similar size and design may not prove to be equivalents.

Due to water quality problems associated with nitrogen levels in other states, namely the Chesapeake Bay and Long Island Sound areas, a number of wastewater treatment plants in Maryland (MD) and Connecticut (CT) have had to upgrade their facilities to be able to provide biological nutrient removal of nitrogen. Construction upgrade costs for 25 plants in Connecticut and 43 plants in Maryland were collected and tabulated in a report from the EPA entitled “Biological Nutrient Removal Processes and Costs” dated June 2007. These costs were tabulated and then broken into three different plant size categories, based on design flow in million gallons per day (MGD), for comparison purposes. Table 3 contains this cost information.

Table 3: Average Unit Capital Costs for BNR Upgrades at MD and CT Wastewater Treatment Plants (2006$)

Treatment Plant Flow (MGD)	Average Capital Costs per MGD	High and Low Values Cost per MGD
0.1 – 1.0	$6,972,000	$19,562,720 $2,549,824
1.0 – 10.0	$1,742,000	$6,977,206 $129,555
> 10.0	$588,000	$1,833,267 $58,650

Source: Based on MDE (2006) and CTDEP (2007).
Calculated from cost information from Maryland Department of the Environment for 43 facilities and Connecticut Department of Environmental Protection for 23 facilities; costs updated to 2006 dollars based on project completion date using the ENR construction cost index (7910.81)

The limiting aspect of this data comparison is that it is not possible to assess all of the pertinent factors that affected the cost of the project. However, the high and low project costs noted in each flow range indicate the variability of the factors involved in upgrading a plant and their effect on the overall project cost.

A complete listing of the plants and their associated upgrade costs are included in Tables 4 and 5 below.

Table 4: BNR Upgrade Costs for Maryland Wastewater Treatment Plants

Facilities with BNR (as of 10/30/06)	Design Capacity (MGD)	Treatment Process	Completion Date	Total Capital BNR Cost (2006$)1
Aberdeen	2.8	MLE	Dec-98	$3,177,679
Annapolis	10	Ringlace	Nov-00	$14,687,326
Back River	180	MLE	Jun-98	$138,305,987
Ballenger	2.0	Modified Bardenpho	Aug-95	$2,891,906
Broadneck	6.0	Oxidation Ditch	1994	$3,165,193
Broadwater	2.0	MLE	May-00	$6,892,150
Cambridge	8.1	Activated Sludge	Apr-03	$11,740,209
Celanese	1.25	Sequential step feed	Jun-05	$7,424,068
Centreville	0.375	SBR/Land Application	Apr-05	$7,336,020
Chesapeake Beach	0.75	Oxidation Ditch	1992	$2,158,215
Conococheague	2.5	Carrousel	Nov-01	$6,620,888
Cox Creek	15	MLE	May-02	$11,466,657
Cumberland	15	MLE	Aug-01	$12,929,990
Denton	0.45	Biolac	Dec-00	$4,203,767
Dorsey Run	2.0	Methanol	1992	$3,967,307

Table 4: BNR Upgrade Costs for Maryland Wastewater Treatment Plants

Facilities with BNR (as of 10/30/06)	Design Capacity (MGD)	Treatment Process	Completion Date	Total Capital BNR Cost (2006$)[1]
Aberdeen	2.8	MLE	Dec-98	$3,177,679
Emmitsburg	0.75	Overland	1996	$2,562,722
Frederick	8.0	MLE	Sep-02	$11,916,504
Freedom District	3.5	Activated Sludge	1994	$1,462,798
Fruitland	0.50	SBR	Jul-03	$7,546,764
Hagerstown	8.0	Johannesburg Process	Dec-00	$11,190,344
Havre DeGrace	1.89	MLE	Nov-02	$7,596,882
Hurlock	2.0	Bardenpho	Aug-06	$5,200,000
Joppatowne	0.95	MLE	Jul-96	$2,433,205
La Plata	1.0	MLE	Jun-02	$4,952,150
Leonardtown	0.65	Biolac	Oct-03	$2,811,448
Little Patuxent	18	A_2/O	1994	$7,263,879
Marlay Taylor (Pine Hill Run)	4.5	Schreiber	Jun-98	$4,986,641
Maryland City	2.5	Schreiber	1990	$1,375,866
Maryland Correctional Institute	1.23	Bardenpho	1995	$2,703,932
Mt. Airy	0.60	Activated Sludge	Jul-99	$5,235,575
Northeast	2.0	Activated Sludge	Oct-04	$4,225,029
Parkway	7.5	Methanol	1992	$15,869,228
Patuxent	6.0	Oxidation Ditch	1990	$2,106,763
Piscataway	30	MLE	Jul-00	$24,778,239
Pocomoke City	1.4	Biolac	Sep-04	$3,924,240
Poolesville	0.625	SBR	Jan-05	$1,593,640
Princess Anne	1.26	Activated Sludge	2002	$4,311,742
Seneca	5.0	MLE	Dec-03	$34,886,034
Sod Run	12	MLE	2000	$21,999,198
Taneytown	0.70	SBR	Apr-00	$3,808,298
Thurmont	1.0	MLE	Dec-96	$3,122,264
Western Branch	30	Methanol	Jul-95	$47,132,782
Westminster	5.0	Activated Sludge	Jan-01	$5,274,444

Source: MDDE (2006). mgd = million gallons per day.
[1] Total capital BNR upgrade costs eligible for Maryland Department of the Environment 50% cost share (http://www.mde.state.md.us/Programs/WaterPrograms/WQIP/wqip_bnr.asp) including engineering, pilot study, design, and construction, updated to 2006 dollars using the ENR construction cost index assuming that the completion date represents the original year dollars (2006 ENR index = 7910.81).

Table 5: BNR Upgrade Costs for Connecticut Wastewater Treatment Plants

Facilities with BNR	Design Capacity (MGD)	Treatment Process[2]	Year Process In Service	Total Capital BNR Cost (2006$)[1]
Branford	4.5	4-Stage Bardenpho	2003	$3,732,049
Bridgeport East Phase 1	12	MLE*	2004	$2,323,766
Bridgeport West Phase 1	29	MLE*	2004	$2,640,643
Bristol Phase 1	10.75	MLE*	2004	$649,320
Derby	3.03	MLE*	2000	$3,513,514
East Hampton	3.9	MLE*	2001	$860,548
East Windsor	2.5	MLE	1996	$1,407,617
Fairfield Phase 2	9	4-Stage Bardenpho	2003	$14,235,676
Greenwich	12	MLE*	1996	$703,809
Ledyard	0.24	SBR	1997	$4,752,461
Milford BB Phase 1	3.1	4-Stage Bardenpho	1996	$1,407,617
New Canaan	1.5	MLE	2000	$1,570,463
New Haven Phase 1	40	MLE*	1997	$11,134,336
New London	10	MLE*	2002	$3,495,615
Newtown	0.932	MLE*	1997	$1,436,601
Norwalk Phase 1	15	MLE*	1996	$1,548,379
Norwalk Phase 2	15	MLE	2000	$7,042,287
Portland	1	MLE	2002	$1,266,843
Seymour	2.93	MLE*	1993	$379,597
Stratford Phase1	11.5	4-Stage Bardenpho	1996	$1,126,094
Thomaston	1.2	SBR	2001	$1,451,708
University of Connecticut	1.98	MLE	1996	$1,489,259
Waterbury	25	4-Stage Bardenpho	2000	$22,074,225

Source: CT DEP (2007). mgd = million gallons per day [1] Total capital BNR upgrade projects financed by the Clean Water Fund through 2006, updated to 2006 dollars using the ENR construction cost index assuming that the year in service date represents the original year dollars (2006 ENR index = 7910.81). [2] Treatment process with an "*" are designed to meet interim TN limits of 6 – 8 mg/L; all other facilities designed to meet TN limits of 3 – 5 mg/L.

Site-specific factors such as existing treatment system layout and space availability may cause costs to vary significantly between treatment plants with the same design capacities implementing the same BNR configuration. For example, the La Plata and Thurmont wastewater treatment plants in Maryland both have design capacities of 1 mgd and were upgraded to a modified Ludzack-Ettinger (MLE) BNR system. However, total capital costs to retrofit the La Plata facility ($5.0 million) exceed those for the Thurmont facility ($3.1 million) by more than $1.8 million.

4. Workplan and Timelines

The Battelle study provides a projected timeline for the development of nutrient criteria for coastal waters of five to eleven years (see page 3 of the Battelle study in Appendix C). While this may appear to be lengthy, it is similar to what the Department has needed to prepare freshwater criteria. Marine nutrient management is more complex and there are still important data needs before the Department could confidently go forward with a proposal. Development of interim concentration-based criteria could probably be accomplished in a shorter time span, while the development of effects-based criteria will require a much greater amount of time. The planning and data gathering phases for concentration-based criteria can probably be collapsed together and completed in four years if resources are available to complete the needed tasks. While effects-based criteria cannot be developed soon, nevertheless it will be important for the Department to demonstrate ecological effects related to elevated nutrient concentrations as it goes forward with any concentration-based proposal.

It is recommended that the next two to four years be used to build a better coast-wide database, and to begin the monitoring of nutrient effects. There are other databases available that the Battelle study did not utilize due to their lack of time and resources. At the same time, additional sampling should continue at established sites to get a better grasp of sample variability, seasonal variation and so forth. In addition to developing the ambient water quality database, the Department needs to get a much better assessment of sources. The Department will begin acquiring information for Casco Bay from point source discharges in 2008 but will need to acquire similar information for the rest of the coast in future years. Nonpoint sources, affecting both Casco Bay and all coastal waters, have not been quantified. Estimates using a model (e.g. SPARROW) will need to be produced and the results evaluated to determine the quality of the information. The complexity of this task and the availability of information for model construction have not been determined. The timeline shown in Figure 1 represents an optimistic forecast, assuming available staff, funding, and stakeholder cooperation, toward development of draft criteria that could be presented for approval by the Board of Environmental Protection.

Figure 1: Timeline toward development of draft nutrient criteria for coastal waters

TASK	2008	2009	2010	2011	2012
Assemble additional existing databases (EPA)	■				
Sampling Casco Bay (FOCB)	■	■	■		
Sampling coast-wide (DEP)		■	■		
National Coastal Condition Assessment (EPA-DEP)			■		
Design response variables (DEP)	▒	■			
Measure response variables (ecological effects)	▒	■	■	■	■
Land-use analysis and nonpoint source modeling	▒	■	■		
Sample select point source discharges - Casco Bay	■				
Sample select point source discharges – coast-wide		■			
Technical workshop on nutrient criteria development			■		
Report on ambient nutrient conditions and relative source contribution of nitrogen				■	■
Draft criteria				▒	■

Funding

Funding to take on this additional criteria development has required the agency to seek additional sources outside the Department's present monitoring budget. As noted in the Battelle report, the Department has had to rely on outside databases to assess current nutrient conditions on the coast – databases such as those maintained by Friends of Casco Bay, National Coastal Assessment and the EPA-Gibson database. Further work will require the Department to find additional outside sources, such as:

- Maine Outdoor Heritage Fund (MOHF) – The Friends of Casco Bay, through sponsorship from DEP, has received a $25,000 grant from MOHF that would provide nutrient monitoring within Casco Bay at about 40 coastal sites and 10 offshore sites (~900 samples).

- EPA Region I has received a commitment from EPA headquarters for contractor technical support to assist Maine with marine nutrient criteria development including sampling design (additional Casco Bay and coast-wide monitoring), Quality Assurance Project Plan(s), a recommended classification based on waterbody type, and further data mining, database construction, and analysis. The grant would also provide funds to host a technical workshop on nutrient criteria development.

- National Coastal Condition Assessment (NCCA) – The next round of sampling through the National Coastal Assessment (renamed NCCA) is scheduled to begin in Maine in 2010. Planning has begun for this assessment in which Maine will participate.

- Maine DEP will be providing lab analysis cost for nitrogen monitoring of treatment plant effluents (~$5000 for 2008). This will be paid from existing federal monitoring funds (Section 106).

- Supplemental 106 Monitoring funds – Maine DEP has requested that $40,000 be made available from supplemental monitoring funds to monitor waters outside of Casco Bay based on the contractor-supplied sampling design (see second bullet above). These funds would become available for the 2009 sampling season through the 2010 sampling season, possibly targeting previous NCCA sites that are not collected in the 2010 resampling. These funds may also be used to begin monitoring nutrient-related ecological effects.

Additional resources also need to be identified for:

- Modeling of land source nitrogen loading both for Casco Bay and other coastal waters. This task may be accomplished by DEP staff, however the DEP does not have staff experienced in the use of SPARROW at this time. The SPARROW model is currently being updated to 2002 data by the USGS. Adequacy of the model will be dependent on completion of that update.

- Coastal monitoring for 2009 and beyond as may be determined after comprehensive data compilation is completed and data gaps are identified.

- Development of effects-based monitoring methods and data acquisition.

Appendix A

LD 1297 | **Resolve 2007, chapter 49** | **LR 1895** Item 1

SIGNED on 2007-06-04 - 123rd Legislature

Resolve, Regarding Measures To Ensure the Continued Health and Commercial Viability of Maine's Seacoast by Establishing Nutrient Criteria for Coastal Waters

Preamble. Whereas, nutrient pollution is a source of marine pollution, contributing to nuisance algal growth, harmful red tide, habitat impacts and oxygen depletion in Maine's coastal waters; and

Whereas, nutrient pollution is attributable to several forms of nitrogen entering Maine's coastal waters from diverse sources, including industrial, municipal, residential, atmospheric and nonpoint sources, as well as offshore inputs from natural phenomena; and

Whereas, bays and estuaries in states south of Maine already suffer significant water quality degradation from nutrient pollution; and

Whereas, as an example of known nutrient conditions in Maine, of 655 water samples collected over 6 years at a site in Casco Bay, 12% collected during the critical summer months exceeded the threshold for medium risk for impairment due to nutrients, as defined in national coastal assessments; and

Whereas, in 2001, the United States Environmental Protection Agency requested the State to establish nutrient criteria for state waters; and

Whereas, good progress has been made by the Department of Environmental Protection toward establishing freshwater criteria; however, little progress has been made toward establishing nutrient criteria for marine waters; now, therefore, be it

Sec. 1. Nutrient criteria planning process established. Resolved: That the Department of Environmental Protection, referred to in this resolve as "the department," shall initiate the development of water quality criteria for nutrients in state coastal waters by developing:

1. A conceptual plan to establish appropriate nutrient criteria for all coastal areas of the State;

2. A work plan and timeline leading to approved nutrient criteria for coastal waters;

3. A report on available technological approaches to nutrient reduction of wastewater, including projected costs on a per unit basis; and

4. An inventory of significant point and nonpoint sources of nutrients to the waters of Casco Bay; and be it further

Sec. 2. Consultation. Resolved: That, in order to identify a reasonable plan for establishing appropriate nutrient criteria, in developing the information and material under section 1, the department shall initiate a series of discussions with wastewater treatment facilities and interested organizations to solicit input and gather information. The department shall request some affected entities to suggest work plans and timelines for complying with nutrient criteria; and be it further

Sec. 3. Casco Bay priorities. Resolved: That the department shall initially focus on the waters of Casco Bay due to its:

1. Being the receiving water for the most populated watershed in the State;

2. Bordering one of the most residentially and industrially developed regions in the State;

3. Facing the effects of future development;

4. High concentrations of nutrients; and

5. Comprehensive set of available nutrient data; and be it further

Sec. 4. Legislation authorized. Resolved: That the department shall report its findings and submit the material developed pursuant to section 1 and any necessary legislation to implement its findings to the Joint Standing Committee on Natural Resources no later than January 31, 2008. The Joint Standing Committee on Natural Resources is authorized to submit legislation to the Second Regular Session of the 123rd Legislature.

Appendix B

List of participating stakeholders.

	Town	**Contact**	**Email**
Dept. of Inland Fisheries & Wildlife	New Gloucester	Tim Knedler	timknedler@securespeed.us
Dept. of Inland Fisheries & Wildlife	Gray	Greg Bell	bellgreg@securespeed.us
S.D. Warren Company	Westbrook	Tom Howard	Tom.howard@sappi.com
Portland Water District	Westbrook	Paul Francoeur	
Town of Yarmouth	Yarmouth	Michael Crosby	
Freeport Sewer District	Freeport	Thomas Allen	
Portland Water District	Portland	Michael Greene	
South Portland Water Pollution Control Facility	South Portland	Patrick Cloutier	
Saco Waste Water Treatment Facility	Saco	Howard Carter	
Falmouth Water Pollution Control Facility	Falmouth	Robert "Peter" Clark	pclark@town.falmouth.me.us
City of Portland	Portland	Bradley A. Roland	
Maine Wastewater Control Association		Dave Anderson	danderson@pwd.org
Maine Rural Water Association		Steve Levy	levy@mainerwa.org

Maine Pulp and Paper Association		Mike Barden	mbarden@pulpandpaper.org
Friends of Casco Bay		Joe Payne	jpayne@cascobay.org
Friends of Casco Bay		Cathy Ramsdell	clramsdell@cascobay.org
Casco Bay Estuary Partnership		Karen Young	kyoung@usm.maine.edu
Department of Inland Fisheries and Wildlife		Peter Bourque	Peter.bourque@maine.gov
Department of Marine Resources		John Sowles	John.sowles@maine.gov
Woodard & Curran		Jim Fitch	jfitch@woodardcurran.com
Wright-Pierce		Paul Birkel	pfb@wright-pierce.com
Olver Associates Environmental Engineers		Annaleis Hafford	annaleis@olverassociatesinc.com
Olver Associates Environmental Engineers		Bill Olver	oaenveng@aol.com
Camp Dresser & McKee, Inc.		Daniel Bisson	bissondp@cdm.com
USEPA		Jennie Bridge	Bridge.jennie@epa.gov
Camp Dresser & McKee, Inc.		John Gall	galljj@cdm.com
IFW		Russ Danner	Russell.danner@maine.gov
City of South Portland	South Portland	Jim Jones	jjones@southportland.org
Earth Tech		Aubrey Strause	Aubrey.strause@earthtech.com

Wright-Pierce		Doug Hawkins	wdh@wright-pierce.com
Portland Water District		James West	jwest@pwd.org
Friends of Casco Bay		Mike Doan	mdoan@cascobay.org
PDOT	Portland	Judith Harris	jh@portlandmaine.gov
City of Portland	Portland	Doug Roncarati	dar@portlandmaine.gov
Bureau of Land and Water Quality Maine DEP		Andrew Fisk, Director	Andrew.c.fisk@maine.gov
Bureau of Land and Water Quality Maine DEP		Brian Kavanah	Brian.w.kavanah@maine.gov
Bureau of Land and Water Quality Maine DEP		Dave Courtemanch	Dave.l.courtemanch@maine.gov
Bureau of Land and Water Quality Maine DEP		Sterling Pierce	Sterling.Pierce@maine.gov
Bureau of Land and Water Quality Maine DEP		Ken Jones	Ken.jones@maine.gov
Bureau of Land and Water Quality Maine DEP		Stuart Rose	Stuart.m.rose@maine.gov
Bureau of Land and Water Quality Maine DEP		Matt Hight	Matt.hight@maine.gov
Bureau of Land and Water Quality Maine DEP		Fred Gallant	Fred.c.gallant@maine.gov
Bureau of Land and Water Quality Maine DEP		Norm Marcotte	Norm.G.Marcotte@maine.gov

Appendix C

CONCEPTUAL PLAN FOR NUTRIENT CRITERIA
DEVELOPMENT IN MAINE COASTAL WATERS

A report prepared by:
Battelle
Brunswick, ME

February 2008

Battelle
The Business of Innovation

February 2008

Conceptual Plan for Nutrient Criteria Development in Maine Coastal Waters

EPA REGION 1, MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION, AND
EPA OCEAN AND COASTAL PROTECTION DIVISION

CONCEPTUAL PLAN FOR NUTRIENT CRITERIA DEVELOPMENT IN MAINE COASTAL WATERS

Prepared for:

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And

Maine Department of Environmental Protection
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Augusta, ME 04333

And

Oceans and Coastal Protection Division
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Prepared by:

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EPA Contract No. 68-C-03-041
Work Assignment No. 4-53
Project No. G921353

February 22, 2008

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1.0 INTRODUCTION

The Clean Water Act (CWA) directs the U.S. Environmental Protection Agency (EPA) to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Under the CWA, the EPA has established a Water Quality Standards Program to help achieve this objective, and EPA Region 1 has worked closely with the New England states over the past decade to develop and incorporate nutrient criteria into state water quality standards. While good progress has been made by states like Maine towards establishing freshwater criteria, little progress has been made in establishing nutrient criteria for marine waters.

EPA published a National Nutrient Strategy (EPA 1998), which describes the approach for adopting nutrient criteria to meet the goals of the Clean Water Action Plan. The establishment of nutrient criteria is critical to the process of managing our water resources. Nutrients are essential for aquatic ecosystems, but they are also a major factor in the environmental degradation of our rivers, streams, lakes, ponds, estuaries and coastal waters. Geographically, there are large variations in the natural physical, chemical, and biological characteristics of water resources (and adjacent lands) that influence how a particular waterbody responds to changes in nutrient loads. In order to take these variations into account, nutrient criteria must be established on appropriate spatial scales and not merely dictated on a national scale. Therefore, the major focus of the National Nutrient Strategy has been the development of technical guidance documents for specific waterbody types (i.e., lakes/reservoirs, rivers/streams, estuarine/coastal waters). Temporal scales may also be considered as nutrient dynamics can change seasonally.

A technical guidance manual for developing nutrient criteria in estuarine and coastal marine waters was published in 2001 (EPA 2001). The guidance manual provides an in depth review of nutrient issues facing US coastal waters including eutrophication, red tides, hypoxia, and loss of seagrass and other benthic habitats. The guidance focuses on causal (nitrogen and phosphorous) and response (chlorophyll, dissolved oxygen, and water clarity) variables, but highlights the importance of N as the limiting nutrient in most coastal marine waters. The document also specifies a variety of approaches that could be used to develop criteria and noted that other approaches may also be appropriate given the dynamic nature of estuarine and other near shore marine waters. Overall, the guidance acknowledges that nutrient criteria and the associated nutrient management plan must be scientifically defensible, economically feasible, and practical and acceptable to the communities involved. These three factors served as the guiding principals for the data examination, examples, discussion, and recommendations contained in this report.

Battelle was contracted to assist EPA Region 1 in working with the Maine Department of Environmental Protection (ME DEP) and other stakeholders to plan the nutrient criteria development process for marine waters in Maine. This report focuses on existing coastal data for the State of Maine collected by EPA and the Friends of Casco Bay (FOCB) to describe current ambient conditions. These data have been incorporated into the report to provide context for a plan to develop nutrient criteria for Maine coastal waters. This report details the steps and methods used to acquire FOCB and EPA data, develop an MS Access database, and conduct preliminary data analyses. The results of these analyses describe current levels of nutrients and other key water quality parameters in Maine coastal waters and are presented as an example of how nutrient criteria may be developed using a pragmatic approach. It should be noted that the data collection effort was neither exhaustive nor comprehensive and was focused on three datasets with limited temporal and spatial resolution. However, it is one of the largest statewide nutrient datasets available for Maine coastal waters. The overall objective for this report is to establish a plan for moving forward with nutrient criteria development in Maine coastal waters.

1.1 Development Process

Maine, like many states, has been focused on the development of nutrient criteria in freshwater systems (lakes/reservoirs and rivers/streams). These systems represent clearly defined water bodies that have been monitored by ME DEP over the past few decades. The development of nutrient criteria for Maine's estuaries and coastal waters has taken a back seat until recently. This has also been the case on the national level as only a few states have developed estuarine nutrient criteria for N, P or response parameters (HI, MD, DE, VA, CT, and NY). The Maryland, Delaware and Virginia criteria were developed as part of the Chesapeake Bay criteria effort (EPA 2003) and the Connecticut and New York criteria are only for dissolved oxygen in Long Island Sound. The difficulty in developing estuarine and coastal criteria was understood by EPA and evident in the order in which EPA published the technical guidance manuals for nutrient criteria development. The lakes/reservoirs and rivers/streams manuals were published in April and July 2000, respectively (EPA 2000a and 2000b), while the estuary/coastal manual was published a year and a half later (EPA 2001).

In Maine, the process of developing estuarine and coastal water nutrient criteria was pushed forward in 2007 with passage of LD 1297[1] by the 123rd Maine State Legislature. Work Assignment 4-53 was supported by EPA Region 1 to assist ME DEP in their efforts to comply with LD 1297 and this report serves as an initial step in the development of a conceptual plan for establishing estuarine and coastal nutrient criteria in Maine.

From the start, the timeframe for nutrient criteria development has been seen as a multi-year process (Figure 1). This report skips over the initial planning phase and the efforts covered in this report fall in the data assessment phase. However, there are clearly understood goals underlying the effort to establish the criteria (e.g. maintain water quality to sustain fisheries, human activities, ecological health, etc.) and the variables to examine (at least initially) are limited to the data in hand or the data that will be collected for ongoing programs. Thus, the major step that has been passed over is classification of waterbodies.

There are a wide range of waterbody types along the Maine coast – from highly river influenced systems such as Penobscot Bay and Merrymeeting Bay to semi-enclosed, long residence time embayments like Quahog Bay and the New Meadows River. At this time, the lack of readily available physical and hydrographic data to classify these systems, as well as the limited amount of nutrient data available, makes both classification of water bodies and development of waterbody type specific criteria essentially impossible. Thus, we have used readily available data on total nitrogen (TN), dissolved inorganic nitrogen forms, chlorophyll, and DO to attempt to examine potential approaches to developing criteria for these waters. The efforts documented in this report focus on the data gathering and assessment phase and provide examples on how to proceed with the next phase of actually developing criteria. Note, however, that we may need to revisit some of the planning phase (i.e. classification) that this pragmatic approach skips when it comes time to apply criteria statewide.

[1]LD1297 – *Resolve, Regarding Measures To Ensure the Continued Health and Commercial Viability of Maine's Seacoast by Establishing Nutrient Criteria for Coastal Waters* complete text available at http://janus.state.me.us/legis/ros/lom/LOM123rd/RESOLVE49.asp

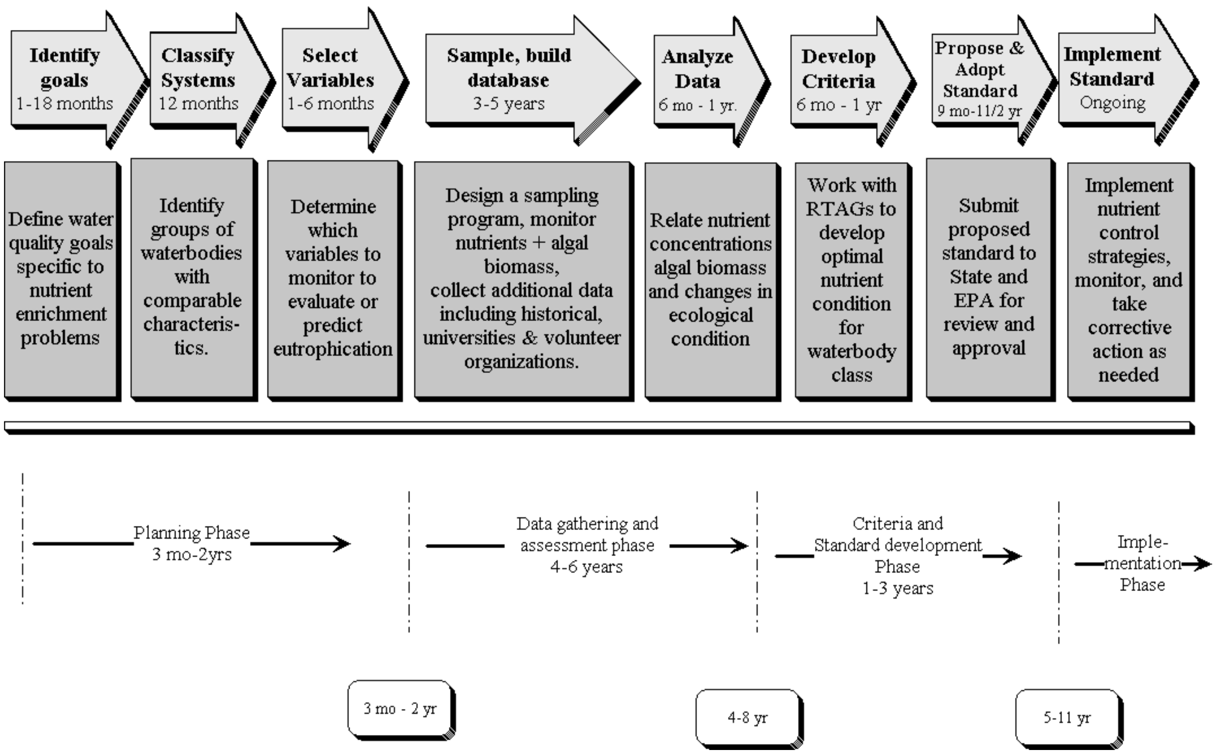

Figure 1. Nutrient criteria development process timeline (reproduced from EPA xxxx).

1.2 Approaches

There are a number of approaches that can be taken to develop nutrient criteria. The relative value and attributes of each are summarized below.

Reference Condition Approach – This approach relies on the use of nutrient data collected in areas that are determined to be relatively pristine and minimally impacted (i.e. Class SA waters). Nutrient concentration thresholds are selected from the distribution of the collected nutrient data (e.g. 90th percentile).

Advantages:

- High confidence that waters attaining the nutrient criteria are good quality with all uses protected.
- Relatively simple means to calculate threshold.
- Simple to implement.

Disadvantages:

- Lack of reference sites where data can be collected or historical reference quality data.
- Subjective selection of threshold value. Some "reference" waters may be above the nutrient threshold, therefore, in violation of the criteria (even if unperturbed and high quality).
- Does not account well for other factors that can affect nutrient function.

Data Distribution Approach – This approach utilizes all nutrient data collected from waters of all designated classes and conditions. As with the reference condition approach, thresholds are selected from the distribution of the data (e.g. usually a lower percentile because some large fraction of the data is assumed to be from waters with altered or impaired quality). A reasonably low percentile needs to be selected so there is reasonable expectation that most waters will attain. Selection of threshold(s) should include examination of expected attainable conditions based on implementation of best attainable treatment and best management practices for all discharging facilities. This approach sets a goal of bringing all waters to some nutrient concentration target that should put most waters in attainment. The burden of implementation is on the sources (point and nonpoint) to meet technology standards.

Advantages:

- Data available (expect additional data will be needed).
- Multiple thresholds may be selected representing different conditions based on classification (SA, SB, SC)
- Relatively simple means to calculate threshold. Most waters could attain criteria and maintain designated uses.
- Simple to implement.

Disadvantages:

- Requires data that includes the range of conditions good to poor that are expected to occur.
- Subjective selection of nutrient concentration threshold value, may not be ecologically defensible.
- Does not account well for other factors that affect nutrient function.

Predictive Model Approach – This approach selects criteria thresholds based on use of predictive models (e.g. regressions) that correlate nutrient concentrations with other environmental effects.

Advantages:

- Can account for other factors that can influence nutrient function in the environment.
- Multiple thresholds may be selected representing different conditions based on the State's current classification system (SA, SB, SC)
- Commonly used for other criteria development.
- Simple to implement.

Disadvantages:

- Requires development of one or more models that correlate nutrient levels to various environmental effects. Models need to be calibrated for Gulf of Maine.
- Limited availability of data for model construction (nutrient, other independent variables, and dependent response variables) across range of conditions good to poor that are expected to occur.
- Difficult to control amount of error (variance) in the model(s).

Effects-based Approach – This approach establishes nutrient criteria as "screening" values (they are not enforced until some other impaired "response" is demonstrated). Appropriate response criteria need to be established (e.g. oxygen, chlorophyll, cell counts, marine life, etc.). The screening thresholds for nutrient concentrations are developed by one of the above approaches.

Advantages:

- High confidence that designated uses are attained (direct measurement of designated use). Attainment is based on response criteria (actual detection of negative effects in the ecosystem).
- Takes into account other variables that affect nutrient function.
- Multiple thresholds may be selected representing different conditions based on classification (SA, SB, SC)
- Opportunity for site-specific criteria.

Disadvantages:

- Lack of data on suitable response criteria (preferably already existing in statute or rule, e.g. oxygen). Limited set currently available for marine waters.
- Need to develop relationship of nutrients to response criteria.

- Several response criteria are required to assess water quality condition and designated uses that could be affected by nutrients.
- Two data types required to make an assessment (nutrient and response criteria).
- Increased monitoring cost.
- Implementation is complex. Results not always clear if nutrients are low and response criteria are violated or, conversely, the measured nutrients are high and there is no violation of response criteria.

Under this work assignment, Battelle was tasked with examining three sets of nutrient data. Given the limitations associated with this dataset and keeping in mind that nutrient criteria should be scientifically defensible, economically feasible, and practical and acceptable to the communities involved, we used the data to illustrate a pragmatic approach that is a hybrid of the Reference Condition/Data Distribution approaches. The ultimate decision on how to proceed with estuarine and coastal nutrient criteria in Maine is most likely to be a management policy decision. The increase in confidence gained by the modeling or effects based approaches comes with increased costs associated with the levels of complexity and associated efforts each entail. Thus for this report, we have used the available data and our best professional judgment to describe current conditions and provide an example of what this pragmatic approach might lead to and what additional data or other efforts it may require.

2.0 DATA ACQUISITION AND MANIPULATION

2.1 Data Sources and Sampling Locations

Three sources of data were specified for this work assignment: Friends of Casco Bay, EPA National Coastal Assessment (NCA) Program, and EPA Coastal Marine Program data. The data for FOCB were obtained directly from the organization. The EPA NCA data were downloaded from the NCA Northeast Region data pages[2]. The Casco Bay Estuary Partnership (CBEP) provided the EPA Coastal Marine Program data. Information on each of these datasets is provided in the following paragraphs.

The FOCB monitoring program has been ongoing since 1993. The program is carried out with the aid of volunteers who sample at more than 80 shore-based stations and assist FOCB staff at 11 profile stations located throughout Casco Bay. The parameters measured include standard oceanographic parameters of temperature, salinity, pH, Secchi depth, dissolved oxygen, plus ancillary air and water measurements. The program was expanded to include measurements for dissolved inorganic nutrients in 2001 and chlorophyll and total kjeldahl nitrogen (TKN) in 2007 as a subset of stations (Figures 2 and A-5). The FOCB stations were sampled for nutrient parameters on a monthly basis over the summer. Battelle had a database for the 1993-2004 FOCB data from an earlier project. Additional MS Excel files were provided by FOCB for 2005-2007 data.

The EPA NCA program data were available for 2001-2004. The data included a range of standard oceanographic parameters and nutrients though not all parameters were available for each of the years nor was the same set of data available for each state for each of the years. In general, dissolved inorganic nutrients, dissolved oxygen and chlorophyll data were available for MA in 2000 and 2001, NH in 2001, 2002 and 2003, and in ME for all five years. Total nitrogen and total phosphorous were only available for MA and NH in 2003 and in ME for 2003 and 2004. EPA NCA station locations are redistributed each year and are presented in Figure 2 and by individual states in Figures A-2 to A-4. The NCA stations were sampled only once per year during the summer. All of the NCA data were directly downloaded from the internet as MS Excel files.

[2] http://www.epa.gov/emap/nca/html/regions/northeast.html

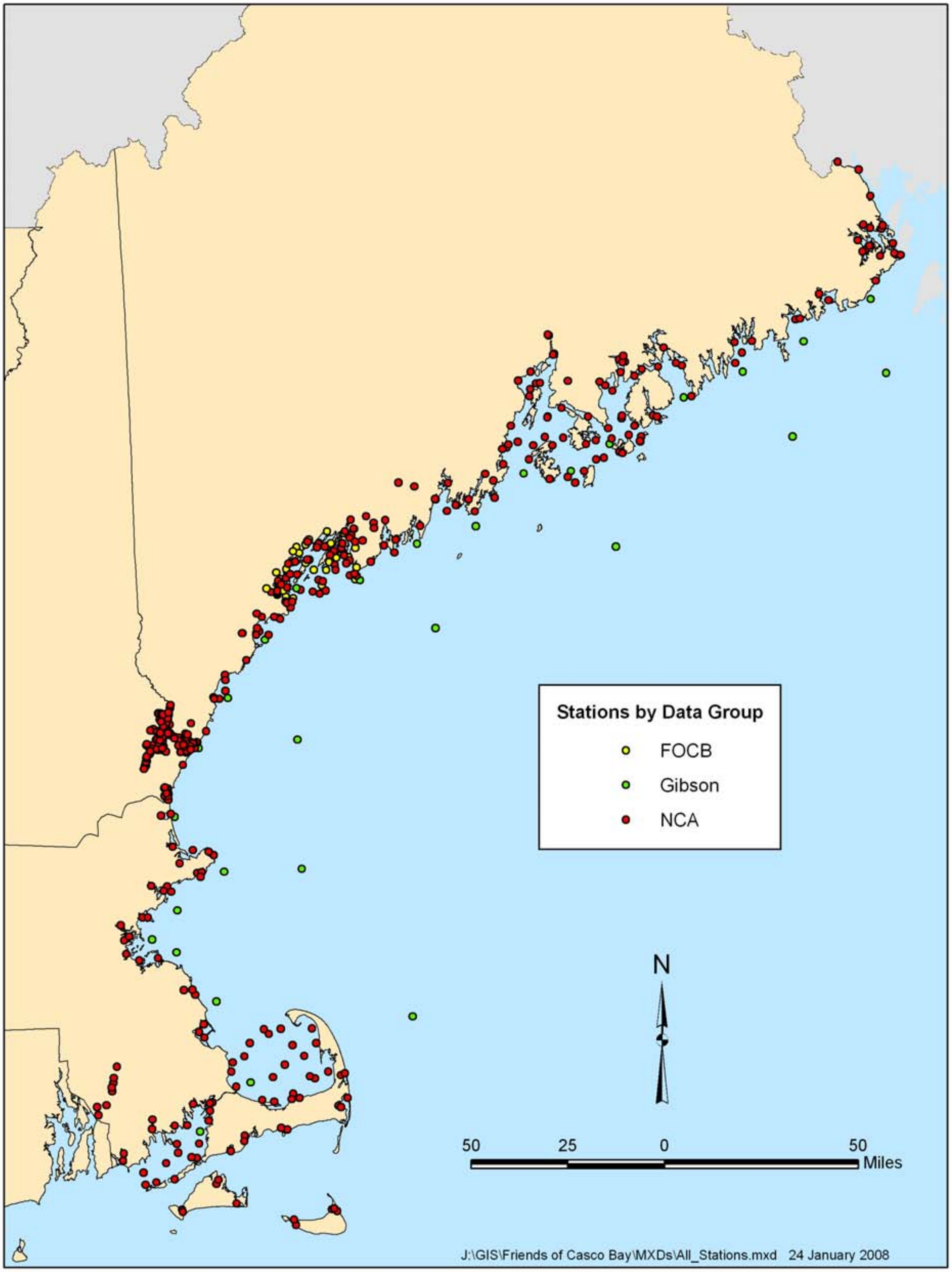

Figure 2. Locations of all stations sampled by the three programs included in this report. Not all parameters were sampled at each station and stations may have been sampled single or multiple times. Individual program stations are also presented in Appendix A with station IDs.

The EPA Coastal Marine program data were collected in 2004 and 2005 at twenty nine stations extending from the Canadian border to south of Cape Cod (Figures 2 and A-1). Data were collected for *in situ* parameters, chlorophyll *a*, TN, and TP. Both of these surveys were conducted during the month of June. Note that this dataset is often referred to as the "Gibson" data herein (George Gibson led the effort and the name took on a life of its own during database development and analyses). The Gibson data were provided by CBEP in a single MS Excel file.

2.2 Database development

The FOCB MS Access database that Battelle had developed for a previous project served as the basis for the new Maine Nutrient Criteria database. The various excel files were imported into the database. Three separate tables were set up to contain the NCA station location, nutrient and *in situ* data. For FOCB data, the same process occurred except the nutrients and *in situ* data were in one table along with all of the location information. The Gibson data had to be significantly reformatted before it was brought into Access; 2004 data was formatted into one excel sheet, 2005 data was in a separate sheet, and the location information (coordinates and some *in situ* data) into a separate sheet.

Once all of the data was imported, the units were updated to be consistent (µM for all nutrients, mg/l for dissolved oxygen and PSU for salinity). The nutrients were then imported into a crosstab table (parameters as column headers). If duplicates/replicates were in the original nutrient tables, then they were averaged prior to being imported. Additional columns were added to the Crosstab nutrient table to accommodate *in situ* data. Location information was also appended at the same time.

Access queries were then run to populate the *in situ* columns. The queries were based upon joins between station name, collection date and water column depth (i.e. surface, mid or bottom). Numerous records were not updated for the NCA data files because of inconsistencies in the data. Occasionally, nutrient records did not have corresponding *in situ* data, while at other times there was *in situ* data, but no nutrient data. In some of the original *in situ* data files the same data was reported for surface and bottom layers. These records had to be assigned to the appropriate nutrient records manually and then a "find duplicates query" was run to ensure that no duplicates were in the database. The final step was to query the table containing all of the *in situ*, nutrient, and location data for just the summer months- June, July, August and September. This query built a table called Just Summer Data.

Our initial plans called for an examination of the data for potential outliers and typical range of values checks of all data. However, since the planned analyses were relegated to summary statistics (including percentiles) and box and whisker plots, there was no need to conduct this examination as outliers would be noted during analysis. In fact, Battelle was specifically requested to make sure that the datasets were complete and not arbitrarily filtered for outlier values. That said, there are a number of values that are surprisingly high and well outside of expected (or even unexpected) ranges (specifically some of the dissolved inorganic nitrogen values in the FOCB dataset). In the future, it is recommended that the database be thoroughly examined prior to loading of additional data and conducting final analyses for criteria development.

2.3 Data Selection

The technical guidance manual specifies a set of causal and response variables appropriate for criteria development. The causal enrichment variables are total nitrogen (TN) and total phosphorous (TP) and the response variables cited are chlorophyll *a*, water clarity/turbidity, and dissolved oxygen (DO). We chose to focus on TN, but also included TP, chlorophyll *a*, DO, and dissolved inorganic nitrogen (DIN) species ammonium (NH_4) and nitrate+nitrite (NO_3+NO_2) for some of the data summaries. Total nitrogen was measured for the NCA and Gibson programs, but for FOCB TKN was measured and we calculated TN from TKN and NO_3+NO_2. This is one of the caveats in the TN analyses presented. The other is that TN data from multiple years have been pooled together for the summary statistics and box plots.

Several other a priori decisions were made in the selection of data for analysis. First, only summer data were examined and the season was defined as date collected from June through September. The reasons for this are two fold. The summer season is the time when most of the negative responses to nutrient enrichment would be expected to be most noticeable and problematic (e.g. hypoxic DO conditions) and the NCA and Gibson data were collected only once per year and sampling occurred from June to September. We also decided to focus on surface data since this depth was sampled at each station and it provided a single set of data for comparisons. The only exception was for DO where bottom data were used.

2.4 Data Analyses

The data analyses entailed developing summary statistics and graphical presentations of the surface, summer data from all stations. The data were also broken down into a series of spatial and program based groupings for comparison. The first level of grouping was at the State level with all MA NCA and Gibson data (stations R1-20 to R1-29), NH NCA data, and ME inshore data. The ME inshore data included all NCA and FOCB data, but only the inshore Gibson stations (R1-2, R1-3, R1-4, R1-6, R1-7, R1-8, R1-9, R1-11, R1-12, R1-13, R1-15, R1-16, R1-17, and R1-19). The offshore Gibson stations (R1-1, R1-5, R1-10, R1-14 and R1-18) were not included in the overall ME group for the state to state comparisons. The second level of groupings broke the Maine data into four groups – NCA data, inshore and offshore Gibson data, and FOCB (also referred to as Casco Bay) data. Finally, the FOCB Casco Bay data were split into four groups ranging from inshore to offshore and across the bay – Portland Harbor/Coast, Western Bay, Eastern Bay, and Offshore. These Casco Bay groups are presented in Figure A-5 for reference. Summary statistics and box plots were run for the key parameters for each of these groupings of data.

The summary statistics were calculated in SAS and included overall mean, minimum and maximum values, standard deviation, and percentiles (10^{th}, 25^{th}, 75^{th}, and 90^{th}) for each parameter of interest (TN, TP, chlorophyll *a*, DO, and the dissolved inorganic nitrogen concentrations). Frequency plots were produced in MS Excel to describe the overall data distribution, and GIS maps were produced to depict the spatial distribution of these parameters. Box and whisker plots were produced in SAS using the GLM procedure which uses the method of least squares to fit general linear models. The GLM procedure also provides an indication of whether there are significant differences among the groups analyzed. When the data for the groups were found to be different, the Duncan's multiple range test was employed (SAS) to determine which station groups were significantly different from one another.

3.0 DATA RESULTS

3.1 Summary Statistics

The summary statistics for all summer, surface data are presented in Appendix B (Tables B-1 and B-2) for each of the data groupings. The mean values are summarized in Table 1 for comparison across areas. Mean TN concentrations are highest in Maine compared to the other states. The elevated levels are driven by higher TN concentrations (mean 37.1 µM) in the FOCB Casco Bay dataset in general, and specifically the elevated TN concentrations measured by FOCB in western Casco Bay (37.4 µM) and Portland Harbor/Coast (42.9 µM). As stated in Section 2, the FOCB TN data were not directly measured, but rather calculated from TKN and NO_3+NO_2. It is unclear at this time whether the TN comparison across states and across the Maine datasets is compromised by the difference in methods. However, comparisons across Casco Bay are internally consistent and clearly show higher mean TN concentrations in Portland Harbor/Coast and western Casco Bay compared to Offshore and Eastern Bay areas. The TN data are examined in more detail in Section 3.2.

The TP dataset is very limited (total count of 139 data points), but on average the ME concentrations were slightly lower than NH and MA (Table 1). There was little difference between the inshore and offshore Gibson TP data for Maine, but as seen for TN the Maine NCA data were lower than the inshore Gibson data. Total phosphorous data have not been collected for the FOCB program in Casco Bay. Chlorophyll *a* concentrations were also lower for ME than MA or NH. There was good agreement between the ME NCA, Gibson inshore, and FOCB datasets with mean concentrations of ~1.8 µg/L. The use of comparable fluorometric methods likely contributed to this consistency. Offshore chlorophyll *a* levels were lower than inshore levels in the Gibson dataset and concentrations were higher in the vicinity of Portland than in western Casco Bay. A quick look at the maximum concentrations observed across the states (Table B-1) shows that chlorophyll levels in NH and MA achieve maxima of >30 µg/L, while the highest ME reading was 10.6 µg/L and levels within Casco Bay peaked at ~5 µg/L).

Table 1. Mean concentrations of key parameters for specified levels and groupings of stations. Calculated for summer data (June-Sept) using surface data for all parameter except DO which used bottom water results. Complete set of summary statistics is provided in Appendix B.

Level	Grouping	TN (µM)	TP (µM)	Chl *a* (µg/L)	DO (mg/L)	DIN (µM)	NH_4 (µM)	NO_3+NO_2 (µM)
States	Maine (inshore)	26.0	0.72	1.79	8.44	8.04	4.24	3.61
	Massachusetts	18.2	0.85	2.90	7.64	8.93	3.61	5.06
	New Hampshire	22.5	1.11	4.56	7.70	12.26	6.90	4.47
Maine	ME NCA Stations	10.3	0.62	1.79	8.14	6.84	2.20	2.59
	ME Gibson inshore	23.1	0.96	1.88	9.83			
	ME Gibson offshore	24.0	0.89	1.07	8.36			
	Casco Bay	37.1		1.75	8.57	8.09	4.44	3.67
Casco Bay	Portland Harbor/Coast	42.9		2.00	9.00	9.04	4.87	4.21
	Western Bay	37.4		1.19	8.90	6.78	3.74	3.04
	Eastern Bay	19.3			8.19	6.23	3.89	2.34
	Offshore	29.2			8.67	14.01	6.34	7.81

Bottom water mean DO concentrations were all relatively high and not indicative of any wide spread DO problem. Maine levels were higher than those in MA or NH. In Casco Bay, the lowest mean value was for the Eastern Bay, which tends to have restricted flows in some of the embayments (Battelle 2005). The relatively high bottom water DO concentrations are not surprising as even in Boston Harbor and Massachusetts Bay, which some might suspect are more heavily enriched than most Maine waters, bottom water DO levels seldom reach levels below 6 mg/L (Libby *et al*. 2007). In regards to low DO, areas of concern have been noted for Maine (Kelly and Libby 1996, Kelly 1997) and within Casco Bay (Battelle 2005). An examination of the minimum bottom water concentrations (Table B-1) shows ME and NH reaching minima of ~4.3 mg/L and a minimum of <1 mg/L in MA. All of these minima are below the level that EPA has proposed as a standard (4.8 mg/L) for the waters from Cape Cod, MA to Cape Hatteras, NC (EPA 2000c) and could be detrimental to biota exposed to them for prolonged periods. Clearly such hypoxic levels as measured for the MA minimum are cause for concern.

The results of this data evaluation are similar to those found for Maine and Casco Bay during studies conducted by the Wells National Estuarine Research Reserve (NERR) and Maine Department of Environmental Protection (MEDEP) in 1995 and 1996 (Kelly and Libby 1996, Kelly 1997). Most importantly, each of these studies found that overall Maine and Casco Bay DO levels are generally high and not problematic, though they highlighted areas of concern that may be more susceptible to low DO in the future. The 1996 Wells NERR and MEDEP study also measured chlorophyll and various nitrogenous nutrients and the results indicated that conditions in Casco Bay were relatively good in comparison to eutrophic coastal waters. Chlorophyll concentrations in Casco Bay (as well as the rest of the locations along the coast of Maine) were consistently low (means < 2.5 μg/l) and dissolved inorganic nitrogen concentrations were not indicative of eutrophic conditions.

An examination of the dissolved inorganic nitrogen (DIN) data for the current set of data supports these earlier findings. On average, the ME mean DIN concentrations are lower than those reported for MA and NH and Portland Harbor/Coast are higher than western and eastern Casco Bay levels, but lower that those measured at the offshore stations (Table 1). Dissolved inorganic nutrients were not sampled as part of the Gibson dataset and thus the Offshore FOCB data are the best representation of what typical concentrations for unimpacted coastal waters might be for the summer period. As mentioned previously, the data have not been screened for outliers for this analysis and there were a number of very high NH_4 (>100 μM) and NO_3+NO_2 (500 μM) results that are likely suspect. A more detailed review of these data is necessary to clarify the distribution of elevated levels of these nutrients. The mean levels of these nutrients, however, are not problematic and, as mentioned above, the highest levels of DIN were measured at the presumably least impacted locations of outer Casco Bay.

3.2 Total Nitrogen Analyses

A more in depth analysis was conducted for TN results using statistical and graphical tools. As noted above, FOCB used a different method (TKN) than the other programs, but comparison of Gibson and NCA data is not necessarily a direct comparison either given that NCA data were collected in more localized areas in July-Sept 2003 (Kennebec to Penobscot) and August-September 2004 (Casco Bay to NH) and Gibson data regionally distributed in June of both 2004 and 2005. When interpreting the results, the spatial and temporal disconnects in these datasets must also be acknowledged. With the expectation that additional data will become available in the future, we proceeded with comparisons across the groupings to gain some insight into the regional distribution of TN levels.

As observed in the comparison of State means, Maine had the highest TN concentrations compared to the other states, the widest interquartile range (IQR; 25^{th} to 75^{th} quartiles), and was the only state with outliers >100 μM (Figure 3a). The SAS GLM procedure indicated that there were no significant differences among the three state groupings (P=0.32). The high outliers in the Maine data were all from the FOCB data (Figure 3b).

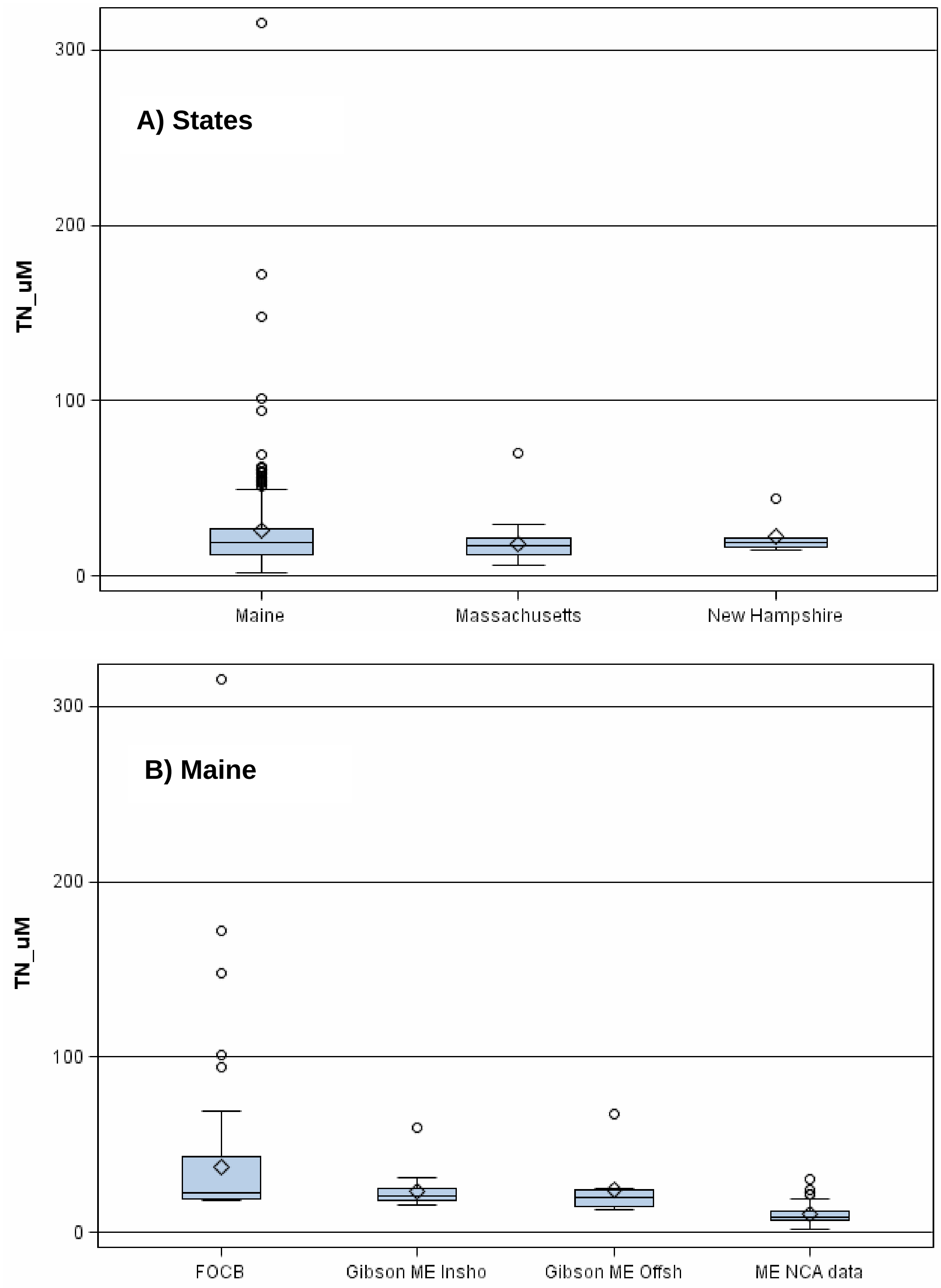

Figure 3. Box and whisker plots of summer, surface TN concentrations (µM) at the A) State and B) Maine level of groups. The groupings are described in Section 2.4. The various symbols represent values as follows: the box = 25th to 75th quartile range, the line in the box = median, the diamond = mean, open circles are outliers, and the whiskers extend to the furthest value below and above the quartiles that is within 1.5 times the interquartile range (IQR).

The influence of the outliers on the overall distribution of data and summary statistics is illustrated by a comparison of the high mean TN (37.1 µM) in the FOCB Casco Bay dataset with a median of 22.2 µM. The mean is skewed higher due to the outliers. The SAS GLM procedure indicated that there was a significant difference among the Maine data groups ($P<0.0001$). Duncan's multiple range test was run to determine which of the means were significantly different (Table 2). As suggested by the plots in Figure 3b, the FOCB and ME NCA data means (37 and 10 µM) were significantly different from each other. A comparison of the median values suggest less of a difference between the FOCB and Gibson datasets (22.2, 21.1 and 20.4, respectively) than numerically indicated by the means (Table 2). There was very little difference between the inshore and offshore Gibson TN data. The median value for the ME NCA data was 9.2 µM. The comparison of median values suggests that the TN values calculated for FOCB may be more appropriate for comparison to the Gibson TN data than was suggested by the examination of the means and range.

Table 2. Results of Duncan's multiple range test (SAS) comparing the data from the four Maine data groups. Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	Grouping
A		37.06	92	FOCB
A	B	24.00	10	Gibson ME Offshore
A	B	23.06	28	Gibson ME Inshore
	B	10.27	60	ME NCA data

The highest TN concentrations measured in Casco Bay were observed in Portland Harbor/Coast and western Casco Bay (>100 µM; Figure 4). A comparison of means showed a decreasing trend from Portland Harbor/Coast to Western Bay to Offshore with the lowest mean observed in Eastern Bay (Table 1). However, the means for the Offshore and Portland Harbor/Coast are skewed upward by a few high TN concentrations as shown by the median lines almost even with the 25th percentiles in the box plots (Figure 4). When the median concentrations are examined the Western Bay stations are highest (31 µM), followed by Portland Harbor/Coast (20.8 µM) and then Eastern Bay and Offshore (both 18.7 µM). The comparisons of means, medians, and outliers for these Casco Bay groups indicates that there are intermittent incursions of high TN waters in both Offshore and Portland Harbor/Coastal waters and that TN levels are more consistently elevated in western Casco Bay than the other areas. Also it seems that TN concentrations in eastern Casco Bay are very consistent and quite low by comparison – though it should be noted that the number of samples is especially small for both Offshore (n=9) and Eastern Bay (n=12).

The TN data were also examined on a station by station approach showing the average surface values at each station and year sampled (Figure 5). Total nitrogen levels of 35-50 µM (~0.5-0.7 mg/L) are generally within the range of values that potentially start to elicit negative responses. A review of stressor-response models using TN and chlorophyll *a* shows elevated chlorophyll *a* levels occurring at these TN concentrations or higher (Dettmann and Kurtz 2006). Researchers in the Gulf of Mexico have proposed summertime TN standards of <35 µM for Pensacola Bay (Hagy *et al.* 2008). Pensacola Bay is clearly not comparable to Casco Bay, but is referenced here as one of the few TN criteria that has been proposed for marine waters.

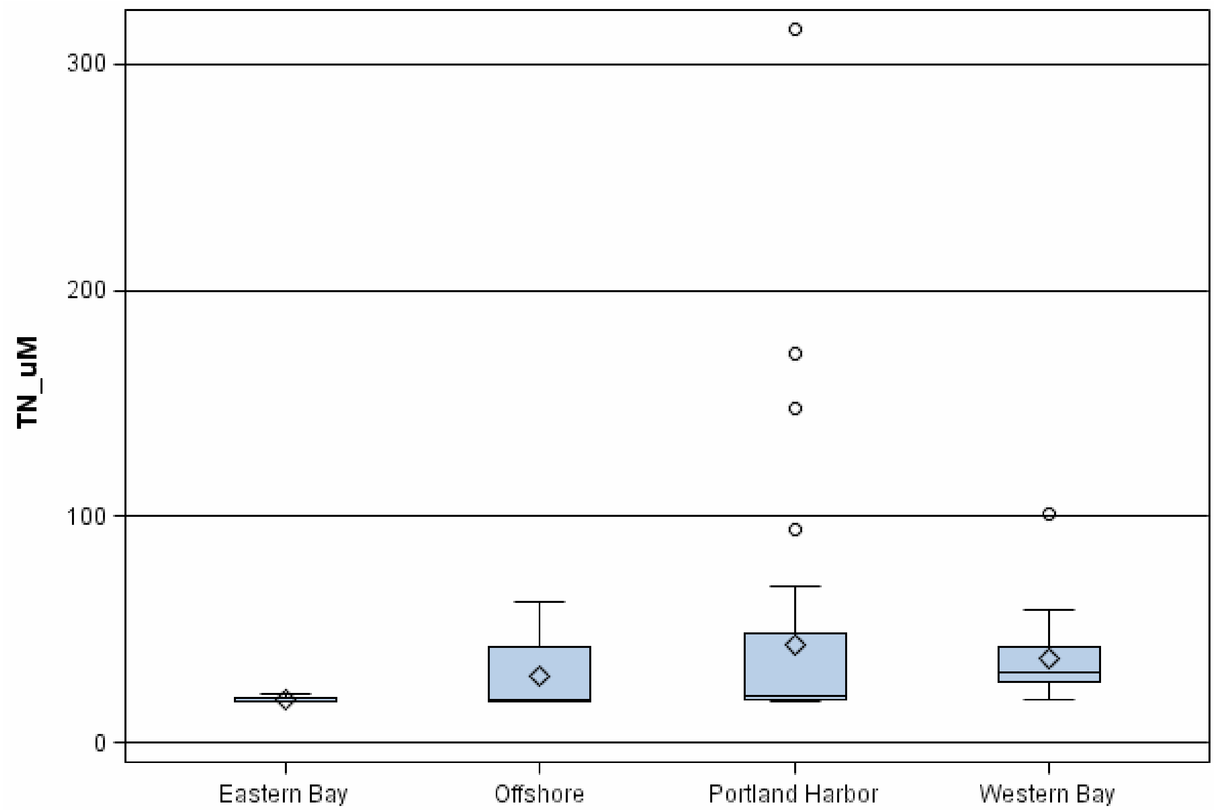

Figure 4. Box and whisker plots of summer, surface TN concentrations (µM) for the FOCB Casco Bay groups. The stations in the groupings are described in Section 2.4 and depicted in Figure A-5. The various symbols are described in Figure 3.

In 2003, levels in Maine surface waters were all <35 µM and most <20µM (Figure 5). The highest TN concentration was measured in Boston Harbor (70 µM) and a high TN concentration (57 µM) was measured in Great Bay, NH. The distribution of NCA stations in Maine in 2003 was focused on the Mid Coast region from the Kennebec River to the Penobscot River. In 2004, TN levels were generally low across the region with most NCA data values <20µM (collected July-September) and Gibson data were slightly higher on average with most stations having TN levels in the 20-25 µM range.

Only Gibson data were available for 2005. The levels and distributions of TN were similar to 2004 from MA to Penobscot Bay, but there were very high concentrations measured in eastern Maine waters (Figure 5). Total nitrogen concentrations at these two inshore and offshore stations were 60 and 67 µM, respectively and comparable to levels measured in Boston Harbor and Great Bay in 2003. For 2007, the only data available is from the FOCB program. These data represent averages of surface water TN measurements made on a weekly to monthly basis. The highest mean TN concentration (73 µM) was measured in Portland Harbor, but levels of 35-50 µM were also measured at stations in the vicinity of Portland, at the mouth of the Presumpscot River, and at the offshore station south of Small Point in eastern Casco Bay. This eastern station has been shown to be influenced by not only offshore oceanographic conditions, but also the Kennebec River plume. Overall, the mean summer, surface TN levels for Casco Bay in 2007 are comparable to those observed during the other three years.

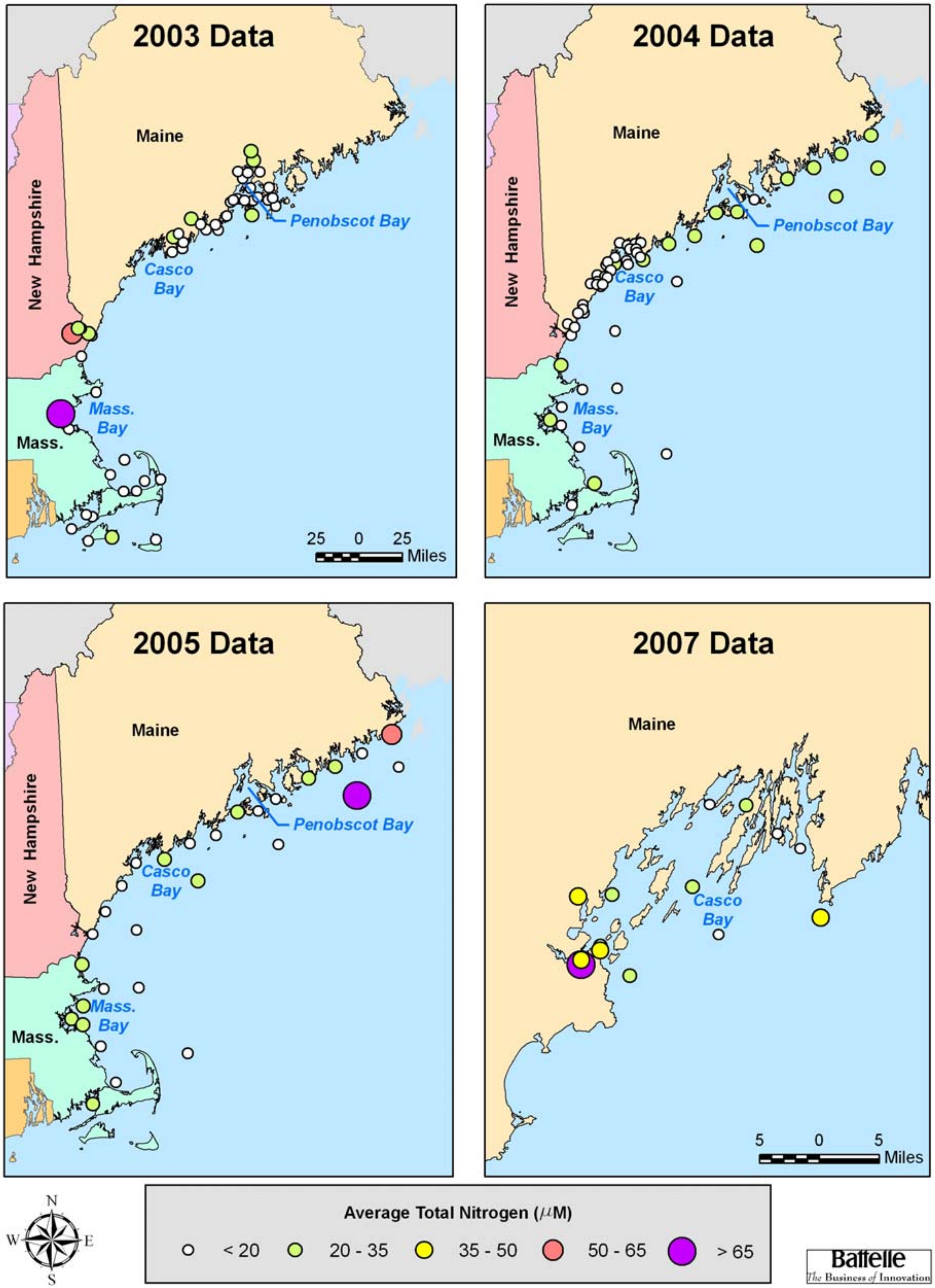

Figure 5. Spatial distribution of surface mean summer TN concentrations for each year measured. Note that the following datasets were available for each year plotted: 2003 only NCA data, 2004 NCA and Gibson data, 2005 only Gibson data, and 2007 only FOCB Casco Bay data. For reference, TN concentrations of 35-50 µM are approximately equal to 0.5-0.7 mg/L.

It is likely, however, that nutrient criteria will be implemented on an individual sampling basis much as most other water quality criteria, rather than a summer average. The data distribution approach discussed in Section 1 could examine the frequency distribution of summer, surface TN concentrations. In Figure 6, these data are presented for all of the ME and MA&NH datasets and the percentiles (10^{th}, 25^{th}, 75^{th} and 90^{th}) are presented in Table B-1 for comparison. In Maine, the 90^{th} percentile for surface TN values during the summer period is 48.6 µM. The values are lower for both MA and NH (25.7 and 44.2 µM, respectively) as Figure 6 suggests with only a few values higher than 30 µM. For this comparison, it must be noted again that the MA and NH surveys represent only single surveys per year, while the ME data includes the weekly to monthly FOCB data for Casco Bay. The 35 and 50 µM values are highlighted in Figure 6 to show the limited number of measurements above these levels and this is further supported by the calculated 90^{th} percentiles.

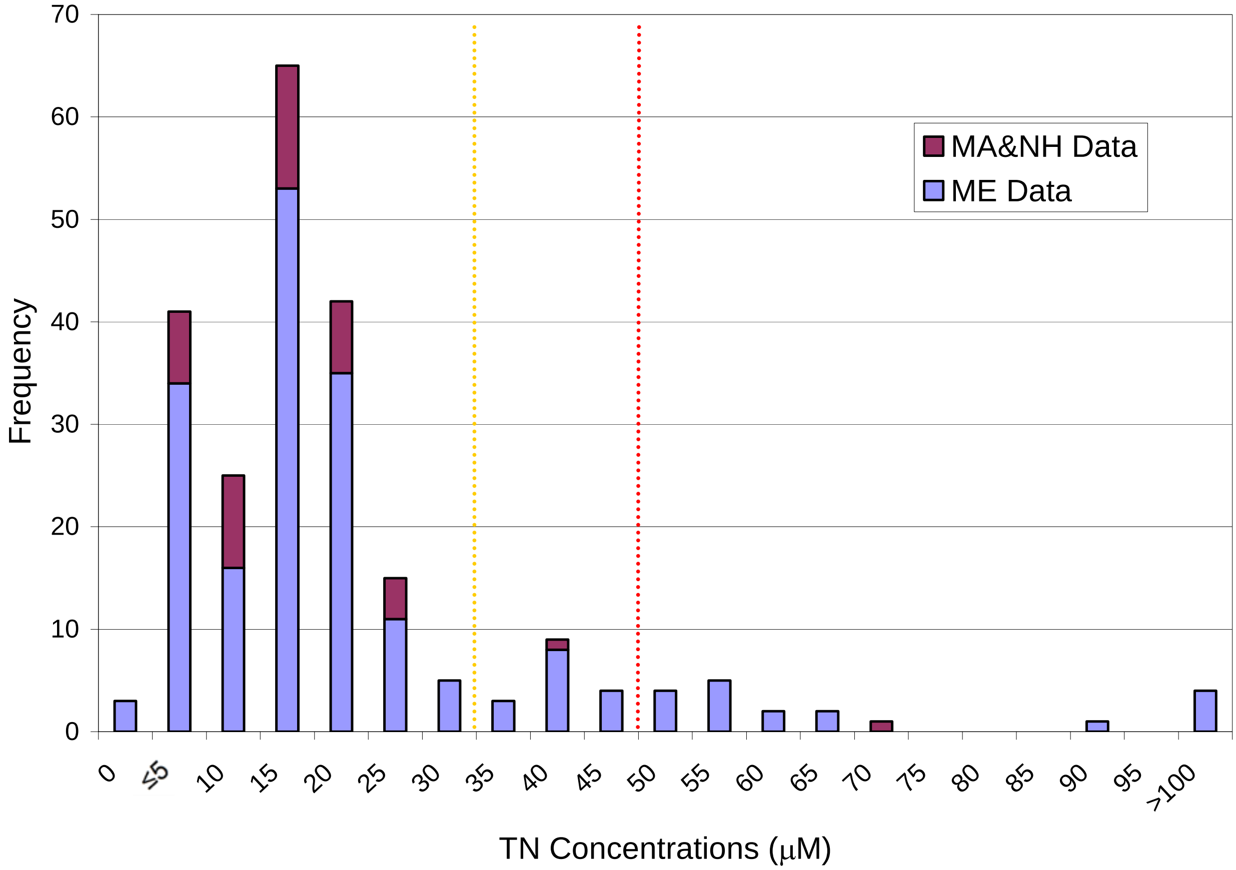

Figure 6. Frequency distribution of summer, surface TN values for Maine, Massachusetts and New Hampshire. The yellow and red lines represent values within the 35-50 µM (~0.5-0.7 mg/L) range of TN concentrations.

4.0 DISCUSSION AND RECOMMENDATIONS

This report is a preliminary step towards the development of nutrient criteria in Maine's coastal waters. EPA started the process in 1998 with the National Nutrient Strategy for adopting nutrient criteria to meet the goals of the CWA and continued by providing guidance on the development process in 2001 (EPA 2001). From the beginning, it has been acknowledged that the development of nutrient criteria for coastal waters will be a long process due to the complexities associated with nutrient dynamics in estuarine and coastal waters. Maine has taken a major step forward in the process with passage of LD 1297 in 2007. Only a handful of States have established nutrient criteria for coastal waters and most of them have been able to do this because of the availability of extensive datasets (Chesapeake Bay States) or because poor water quality conditions have spurred public outcry for action (Long Island Sound States). This report may constitute a small step forward, but it is envisioned that it will keep Maine at the forefront of the estuarine and coastal nutrient criteria development process.

4.1 Approaches used in other Regions

A summary of the various approaches for establishing nutrient criteria was provided in Section 1.2 and a few examples of what is being done in other regions have been touched upon in the report and are briefly summarized here for reference and comparison to the proposed approach for Maine. In Chesapeake Bay, criteria have been developed for DO, water clarity, and chlorophyll *a* (EPA 2003). DO criteria have been assigned to five different regions of the bay defined by uses and depth and water clarity criteria have been assigned to four different salinity regimes. For chlorophyll *a*, a narrative standard was established for the entire bay. The fact that criteria were able to be established for so many different regions of Chesapeake Bay is a testament to the extraordinary amount of research that has been conducted in that area and the vast amount of data associated with those efforts.

In Long Island Sound (LIS), problems with seasonal hypoxia/anoxia in the western portion of the Sound led to establishment of the Long Island Sound Study in 1985. After 15 years of monitoring and related modeling and synthesis, a Total Maximum Daily Load (TMDL) for nitrogen loading to the Sound was approved by the EPA and the states of New York and Connecticut. This TMDL was established in order to meet DO water quality criteria in LIS and a multiyear effort has been phased in by the States to meet the TMDL of a 58.5% reduction in nitrogen loading by 2014[3]. As was the case with Chesapeake Bay, the LIS DO criteria was established after many years of monitoring and data evaluation.

More recent efforts to create nutrient criteria have been conducted by the EPA for pilot studies in Yaquina Estuary, OR and Pensacola Bay, FL (Brown *et al*. 2007, Hagy *et al*. 2008). In Yaquina Estuary, existing data were used to examine spatial and temporal trends and a "weight of evidence" approach was used to develop criteria. Criteria were derived for the 'dry season' (May-October) and, given the estuarine nature of the system (~50% tidal), it was divided into two zones for criteria development. Zone 1 is highly influenced by offshore coastal water and nutrient loading from the ocean. Zone 2, in the upper estuary, is influenced by riverine and point source nutrient inputs. Overall, water quality conditions in the estuary were good and support the existing seagrass habitat (one of the goals for establishing criteria). Following the EPA guidance (EPA 2001), criteria were proposed using median values from the existing dataset for DIN, phosphate, chlorophyll *a*, and water clarity (Brown *et al*. 2007). Oregon has an existing water quality standard for DO of 6.5 mg/L and although this was closer to the 25th percentile it was recommended to keep this standard for Yaquina Estuary because the only apparent DO problem was an intermittent incursion of hypoxic waters that enters the estuary from offshore coastal waters.

A weight of evidence approach was also used in Pensacola Bay (Hagy *et al*. 2008). The use of historical data to develop a reference condition was evaluated, but for this bay the historical condition was more

[3] http://www.longislandsoundstudy.net/pubs/reports/tmdl.pdf

nutrient enriched than the current state. Nutrient loading to the system had decreased since 1980 and present water quality was considered protective of the desirable uses. Hypoxic conditions appear to be the result of natural processes and a propensity toward low DO in the system and loss of seagrass in the bay were related to pre-1980 degraded water quality. Their goal was to keep water quality at its current levels and not to have it degrade as the region continues to grow economically and in population. As in Oregon, criteria were proposed for Pensacola Bay based on the relative freshwater and seawater influences along the salinity gradients with separate criteria for oligohaline (<5 PSU), mesohaline (5-18 PSU), and polyhaline (>18 PSU). The summer median levels were proposed as criteria for chlorophyll *a*, Secchi depth, DIN, phosphate, TN (<35 µM), and TP (Hagy *et al*. 2008).

These two pilot studies did not attempt to use any embayment classification scheme as they were focused on single waterbodies. However, in both cases, the systems were divided based upon salinity regimes. The importance of freshwater inputs will need to be taken into account for any statewide criteria development in Maine, but due to the limited dataset this was not possible in this report. Classification of systems is one of the main steps in the planning phase for criteria development (Figure 1). This aspect of the process was beyond the scope of the current study, but will be necessary at some scale in the future. The diversity of waterbodies along the Maine coast precludes site by site classification; but, at a minimum, freshwater-dominated versus limited-freshwater inputs and high and low residence time need to be considered. A more extensive set of factors influencing susceptibility of waterbodies to eutrophication is presented in the EPA guidance manual (EPA 2001) as developed by the National Research Council (2000). This list of 12 factors ranges from physiographic setting to nutrient load to residence time/flushing to rates of denitrification. It is an ambitious list of measures for any monitoring program and not one that could be applied in Maine in totality in the near future. An evaluation of these measures should be made to consider whether come could be readily incorporated into a monitoring program

A different type of classification scheme has been presented in work by Dettmann and Kurtz (2006). They propose using stressor-response relationships to group waterbodies by how they respond to nitrogen loading as the stressor. They focus on two separate responses – extent of eelgrass habitat and phytoplankton biomass response (as measured by chlorophyll concentration). For our purposes, we'll take a closer look at the phytoplankton response findings. Ambient concentrations of chlorophyll and TN were directly compared and the relationships between these two parameters were compared across ten estuarine/coastal systems. There were clear year to year variations within and between systems, but when average summer (June-August) data were examined from each system, the ten systems separated out into two groupings – coastal embayments and riverine dominated systems. In the four coastal embayments examined (LIS, Boston Harbor, Tampa Bay, and Peconic Estuary), the slopes of the regressions for log transformed chlorophyll vs. TN concentrations were statistically the same, while the intercepts were statistically different. The differences in the intercepts were related to the level of total suspended solids (TSS) in the system. It was concluded that there is a consistent phytoplankton response related to ambient TN concentrations, but that other factors (water clarity in this case) may reduce the response (lower light availability at higher TSS leads to lower production). The riverine influenced systems had similar relationships, but it was more complex given the wide range in TSS levels. Regardless, this classification approach provides two types of systems to examine and provides a possible mechanism for linking ambient TN levels to the response variable chlorophyll. Even with this stressor-response relationship, a decision on what level of stressor is protective of waterbody uses still needs to be determined.

Additional classification schemes are available and should be examined for applicability and ease of use for Maine coastal waters. The Coastal and Marine Ecological Classification Standard (CMECS) was developed in conjunction with NOAA and it classifies habitats and ecological roles from head of tides in estuaries, to the coast, and out into the oceans of North America (Madden *et al.* 2005). The EPA has promoted the use of coastal Level III ecoregions as a mechanism for classifying systems and is heavily involved in the evaluation and development of additional classification approaches (Kurtz *et al*. 2006). Another obvious option is for the State to develop criteria based on the current classification scheme (SA, SB, SC) that focuses on attainable uses. Nonetheless, a thorough evaluation of the classification schemes should be undertaken as part of the next phase of nutrient criteria development in Maine coastal waters.

4.2 Summary of Maine Approach

In this report, we propose and have provided an example of an approach similar to that taken in the Yaquina Estuary and Pensacola Bay pilot studies. We have examined the data currently available, compared TN levels across the region, state, and Casco Bay and the data have been presented in a manner by which median or percentile levels could be chosen as a potential criteria level. A similar approach could be used to examine the other parameters of interest (DIN, chlorophyll, and DO). Although we embarked on this approach by necessity given the limited dataset, an understanding that there are limited funds available, and a push by the state to move the process forward, it is similar to the weight of evidence approach taken in these two pilot studies. As in Yaquina and Pensacola, Maine has relatively good water quality along the coast with some localized problems. The pragmatic approach taken in this report should provide reasonable initial values that could be proposed and discussed by the various stakeholders prior to institution of the criteria.

The current study not only provides an example of how Maine might approach criteria development, but it also highlights a number of problems or issues that will have to be addressed during the process of nutrient criteria development. First, and foremost for this study, is the issue of data acquisition and database development. In this study, we used three clearly defined datasets. The first from a long term monitoring program in Casco Bay and the other two from short term EPA studies in the region. One would hope that such datasets could be readily integrated, but differences in format, units, methods, and years sampled all led to database problems or caveats in our interpretation of the results. As Maine proceeds with criteria development, clear database structure and management procedures need to be developed. This will be important no matter what approach ME DEP decides to pursue – whether it be data mining, additional monitoring, effects based or predictive modeling, or some combination of these. There will be more data acquired and it needs to be managed/stored in a clearly defined manner.

A project Battelle is currently undertaking with the EPA is the development of a Gulf Nutrients Data Management Platform (GNDMP) that is intended to identify and gather existing water quality data and compile it in a standardized platform that will be available via the web to a broad range of users. The GNDMP is intended to support work to protect habitat and address problems of nutrient enrichment in Gulf of Mexico estuaries and coastal systems, primarily by providing manageable data for use in the analysis of status and trends. Currently, data exist in various institutions and formats and have been generated using various collection and analytical methods. All of which make it difficult to make broad assessments of the overall health of the Gulf waters. The GNDMP is taking advantage of existing data that have been collected by numerous government and academic organizations. The GNDMP will organize and standardize the data and provide an intuitive web based interface with which to discover, access, and use these data. A similar effort should be undertaken in Maine – not only the database development, but also data mining as there are clearly many datasets that have not been accessed for the current analysis (including the datasets cited for Wells NERR and ME DEP). As mentioned, there are inherent issues involved with integrating relatively disparate datasets, but data identification and acquisition is a more cost effective approach than instituting new, large scale monitoring efforts.

The findings in this report suggest that water quality in the coastal waters of Maine is relatively good, which is consistent with the findings of recent national water quality assessments (i.e. EPA 2007 and Bricker *et al*. 2007). The analysis has also identified a few areas of concern as have also been suggested in the national assessments and numerous state and locally based reports (e.g. Kelly and Libby 1996, Kelly 1997, Battelle 2005). The TN values presented in Figure 5 show elevated levels in Portland Harbor as one might expect, but also in offshore waters south of Machias in Downeast Maine at a station that was presumably selected as a potential reference site. This highlights the difficultly of ascribing criteria in such a complex environment for parameters that can be quite variable. However, the distribution of TN data in Figure 6 suggest that a criteria value of 35-50 µM (0.5-0.7 mg/L) might be appropriate given the limited number of exceedances of these levels. In Yaquina Estuary and Pensacola Bay, they proposed using the median values of parameters for criteria, but for the Maine waters this would be too restrictive and not acknowledge the natural productivity of our coastal waters. For example, the median value for inshore Maine data was only 19 µM, which is far too low for a standard as ambient levels of DIN often exceed 10 µM in Maine coastal waters. The 90th percentile for the Maine TN data is just under 50 µM. The use of the 90th percentile to establish criteria could appear to be too lenient; but, based on the data in hand, it may be protective of proscribed uses.

There are obvious limitations associated with the TN example presented in this report. Not the least of which is the limited amount of data used. Nevertheless, the approach has merit and led to a proposed TN level that appears to be scientifically reasonable, economically feasible, and conceivably acceptable to stakeholders. It is envisioned that a similar approach could be taken with a more comprehensive set of data to develop nutrient criteria for TN and other parameters for Maine estuarine and coastal waters. One advantage to this approach is that it could get reasonable criteria in place on a timescale of a few years rather than 5-10 years (see Figure 1). An additional advantage is that the data collected as part of federal, state, local, or industry sponsored monitoring programs instituted to assure compliance with the criteria would be available to validate and potentially modify the criteria as necessary. These data would also support further analysis using predictive or other types of models and effects based approaches once they are more refined and robust. Ultimately, the State must make a management policy decision as to what approach to use. In the current economic climate, the modified data distribution approach presented in this report is a pragmatic and viable option.

4.3 Recommendations

A series of recommendations are included below. These are based on a combination of the data analyses presented here, experience on other nutrient criteria related projects, discussions with stakeholders and managers, review of relevant literature and reports, and best professional judgment. The recommendations are broken out into various categories and are made with the understanding of the current economic climate and fiscal feasibility of undertaking these activities. Although it would be scientifically interesting to pursue predictive modeling and effects based approaches, they are not included in the recommendations at this time because they are not deemed economically feasible.

Nutrient Criteria Development

- Identify and acquire available nutrient related data from other sources – federal, state or local monitoring efforts, scientific research efforts, etc. This should include data that could be used to classify waterbodies in the future if that approach becomes more feasible.
- Explore methods of classification of systems as an option for development of more fine tuned criteria (e.g. freshwater dominated vs. offshore dominated systems).
- Develop a comprehensive database for this data with established data management procedures.
- Apply the data distribution approach to the other parameters to evaluate potential criteria.
- Examine the applicability of stressor-response models as they become more robust and accepted in the literature (e.g. Dettmann and Kurtz 2006)
- Evaluate federal mechanisms for funding nutrient criteria development activities – from field work to data mining to public outreach.
- Continue to collect data for this effort on a local and statewide basis as funds allow as described in the next two categories.

Casco Bay Monitoring and Pilot Study

- Continue nutrient study in 2008 and subsequent years as necessary to establish criteria and monitor effectiveness once in place.
- Switch to analysis of TN rather than TKN to minimize potential impact of laboratory methods when comparing to TN data.
- Collect additional chlorophyll *a* samples – increase number of samples collected concomitantly with TN samples.
- Expand number of sampling sites to better characterize the apparent gradient in TN and other parameters – high in and near Portland Harbor and rivers (Presumpscot and Royal) and decreasing to eastern Casco Bay.

Statewide Monitoring

- Develop a plan that fits the approach recommended by ME DEP. If the recommended approach is similar to the approach taken in this report, then sampling that is a modification of the NCA and Gibson surveys would be appropriate – spatially distributed as with the Gibson surveys, but more stations. A more in-depth evaluation of suitable station locations needs to be undertaken prior to initiating a statewide monitoring program.
- Sample for standard suite of oceanographic parameters including parameters necessary for criteria development.

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APPENDIX A - STATION MAPS

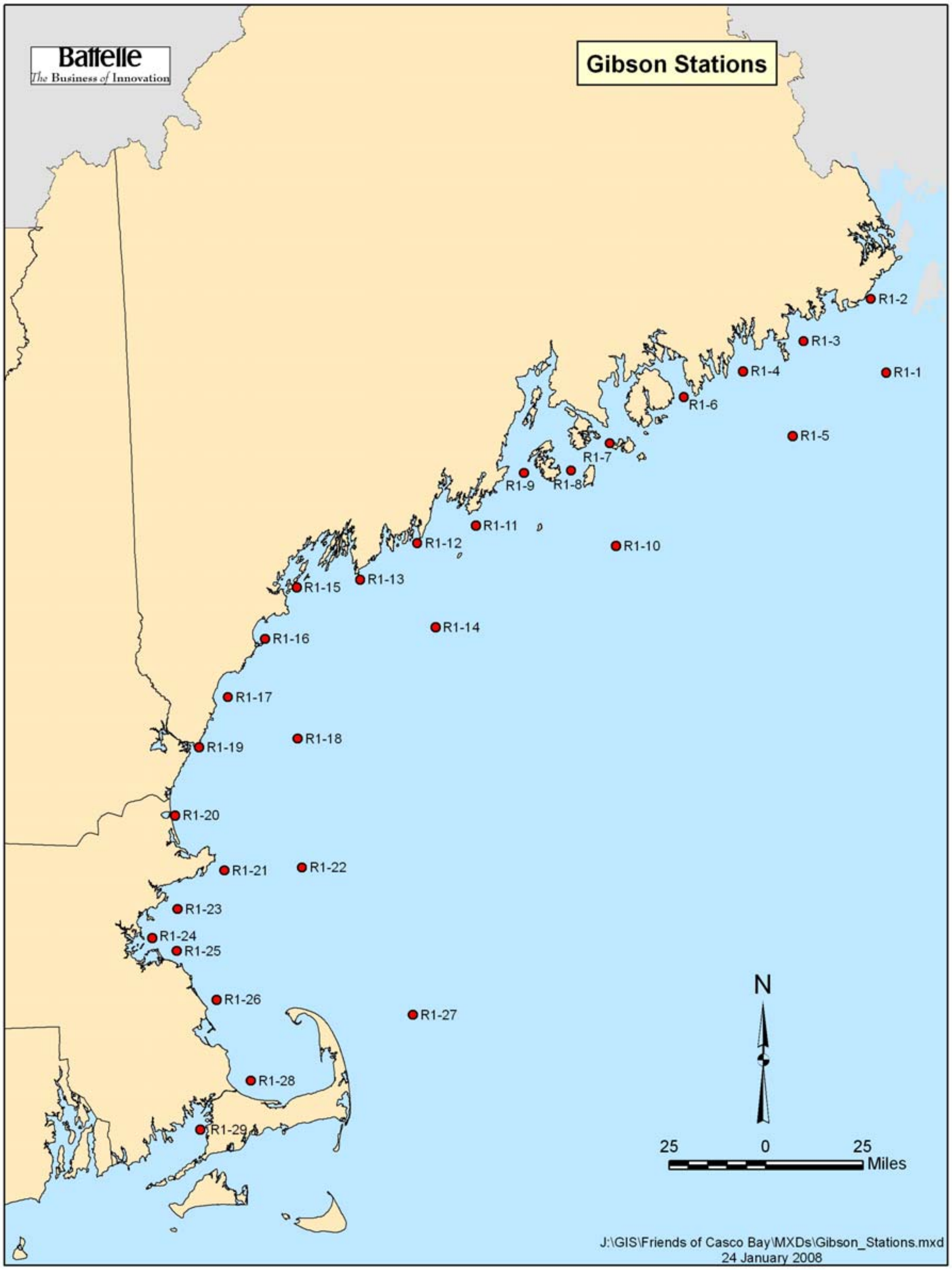

Figure A- 1. EPA Coastal Marine Nutrient Survey stations. These stations have been termed "Gibson" stations in this report.

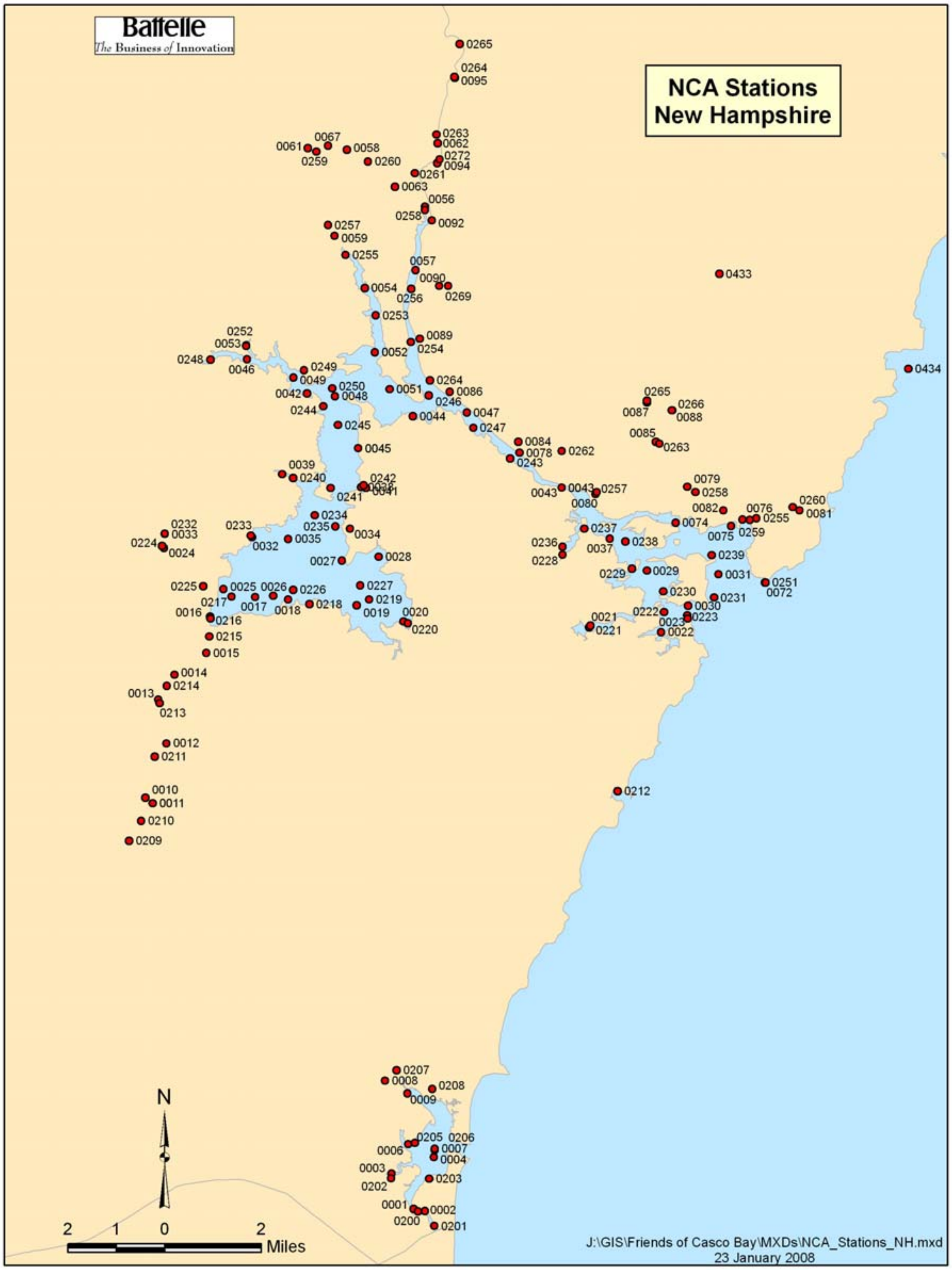

Figure A- 2. New Hampshire National Coastal Assessment stations. First two digits in station ID represent the year sampled.

Figure A- 3. Massachusetts National Coastal Assessment stations. First two digits in station ID represent the year sampled.

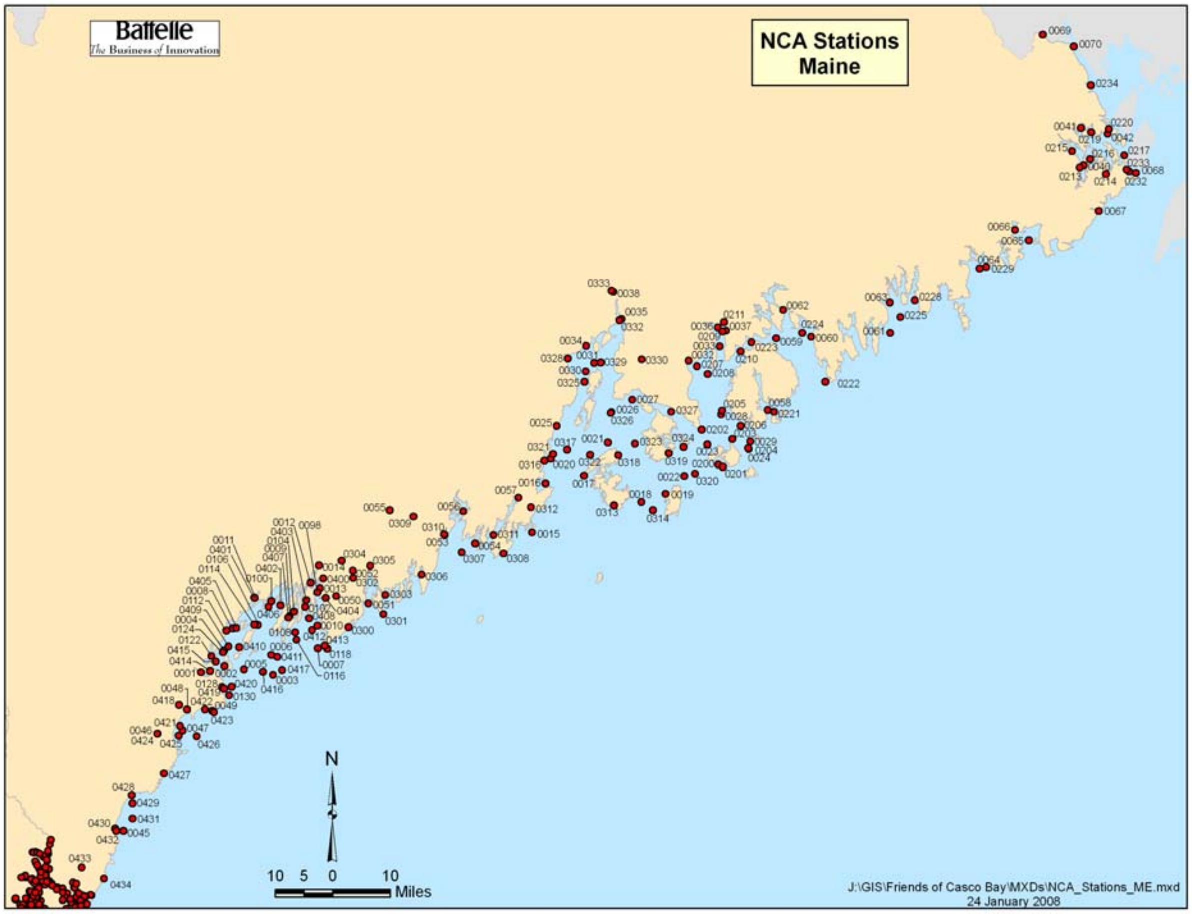

Figure A- 4. Maine National Coastal Assessment stations. First two digits in station ID represent the year sampled.

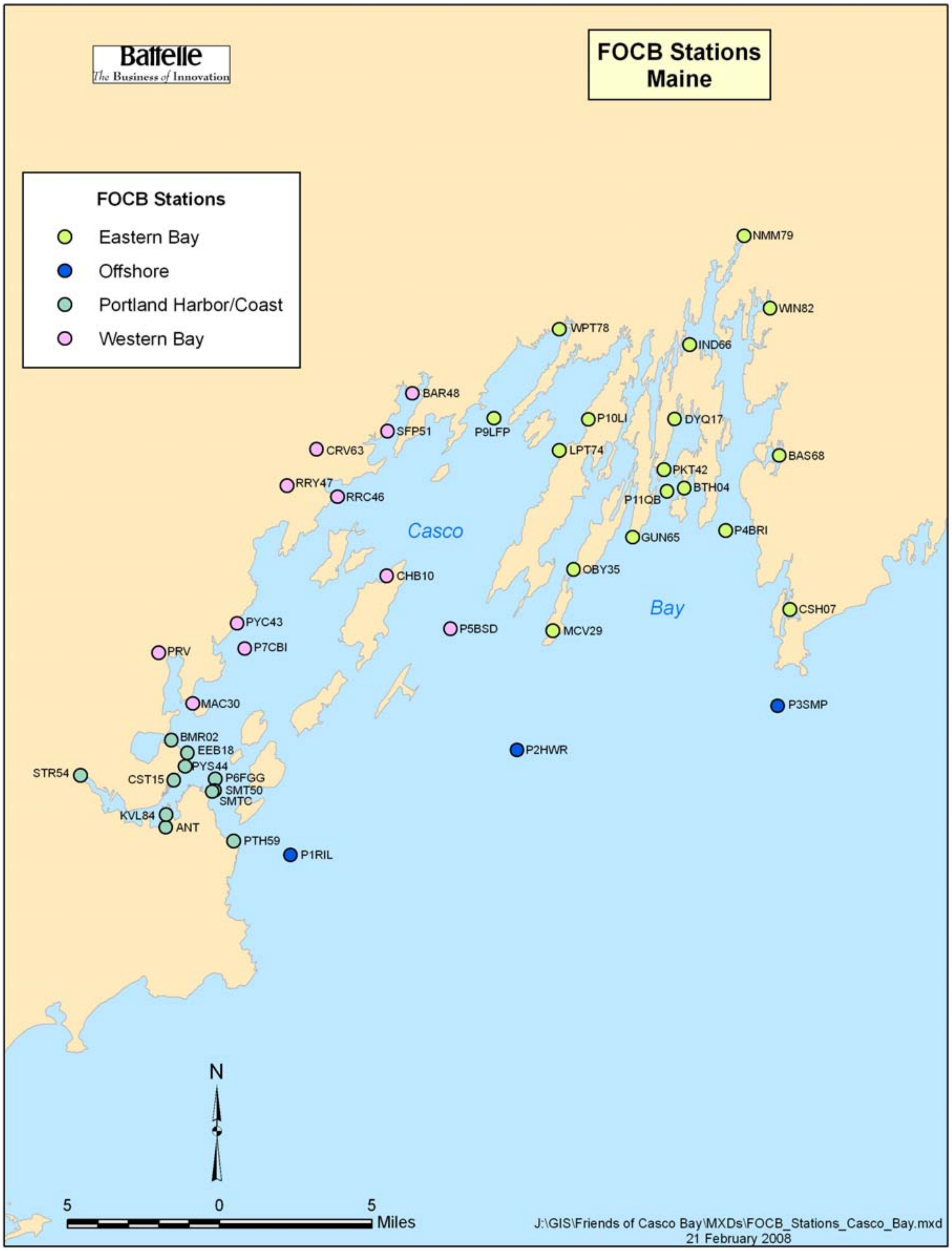

Figure A- 5. Friends of Casco Bay stations.

APPENDIX B - SUMMARY DATA TABLES

Table B- 1. Summary statistics for summer (June-September), surface water total nitrogen, total phosphorous, and chlorophyll *a* data and bottom water dissolved oxygen data for each of the water body groupings defined in the report.

Grouping	Parameter	Units	n	Mean	Min	Max	SD	10th	25th	75th	90th
Maine	TN	µM	180	25.96	1.50	315.41	30.54	7.14	11.82	26.69	48.55
Massachusetts	TN	µM	35	18.15	6.07	70.29	11.00	7.50	12.21	21.79	25.71
New Hampshire	TN	µM	6	22.51	14.71	44.21	11.00	14.71	16.36	22.00	44.21
ME NCA Stations	TN	µM	60	10.27	1.50	30.36	5.36	5.71	6.64	11.82	17.86
ME Gibson inshore	TN	µM	28	23.06	15.71	60.00	8.49	16.43	17.86	25.00	30.00
ME Gibson offshore	TN	µM	10	24.00	12.86	67.14	15.74	13.57	15.00	24.29	46.07
Casco Bay	TN	µM	92	37.06	17.91	315.41	38.80	18.41	19.04	42.88	58.92
Portland Harbor	TN	µM	47	42.92	18.28	315.41	51.41	18.80	19.32	48.13	69.44
Western Bay	TN	µM	24	37.42	18.76	100.93	17.76	22.35	26.69	42.54	55.66
Eastern Bay	TN	µM	12	19.29	18.08	22.03	1.45	18.36	18.40	19.93	21.79
Offshore	TN	µM	9	29.20	17.91	62.54	16.54	17.91	18.26	42.87	62.54
Maine	TP	µM	88	0.72	0.19	1.41	0.24	0.39	0.55	0.90	1.03
Massachusetts	TP	µM	35	0.85	0.48	1.65	0.32	0.54	0.58	1.10	1.29
New Hampshire	TP	µM	6	1.11	0.74	1.87	0.40	0.74	0.90	1.13	1.87
ME NCA Stations	TP	µM	60	0.62	0.19	1.10	0.20	0.39	0.47	0.74	0.90
ME Gibson inshore	TP	µM	28	0.96	0.69	1.41	0.15	0.79	0.85	1.04	1.16
ME Gibson offshore	TP	µM	10	0.89	0.57	1.36	0.28	0.58	0.60	1.04	1.32
Maine	Chlorophyll a	µg/L	260	1.79	0.15	10.60	1.40	0.62	0.85	2.28	3.39
Massachusetts	Chlorophyll a	µg/L	93	2.90	0.14	52.30	6.00	0.49	0.89	2.85	5.01
New Hampshire	Chlorophyll a	µg/L	93	4.56	0.15	33.59	4.91	0.77	1.63	5.75	9.83
ME NCA Stations	Chlorophyll a	µg/L	184	1.79	0.15	10.60	1.52	0.53	0.82	2.20	3.42
ME Gibson inshore	Chlorophyll a	µg/L	28	1.88	0.37	3.71	0.97	0.69	1.03	2.78	3.36
ME Gibson offshore	Chlorophyll a	µg/L	10	1.07	0.41	2.74	0.65	0.54	0.68	1.23	2.01
Casco Bay	Chlorophyll a	µg/L	48	1.75	0.85	5.09	1.08	0.85	0.85	1.70	3.39
Portland Harbor	Chlorophyll a	µg/L	33	2.00	0.85	5.09	1.18	0.85	0.85	2.54	3.39
Western Bay	Chlorophyll a	µg/L	15	1.19	0.85	2.54	0.54	0.85	0.85	1.70	1.70
Maine	DO	mg/L	500	8.44	4.34	30.40	1.47	7.01	7.67	9.20	9.86
Massachusetts	DO	mg/L	88	7.64	0.95	14.80	2.04	5.73	6.25	8.58	9.79
New Hampshire	DO	mg/L	108	7.70	4.30	11.69	1.29	5.77	7.03	8.55	9.24
ME NCA Stations	DO	mg/L	188	8.14	4.34	10.76	0.99	6.81	7.53	8.71	9.40
ME Gibson inshore	DO	mg/L	14	9.83	9.10	10.38	0.33	9.42	9.62	10.04	10.08
ME Gibson offshore	DO	mg/L	5	8.36	7.10	9.17	0.82	7.10	8.16	8.96	9.17
Casco Bay	DO	mg/L	298	8.57	5.10	30.40	1.69	7.10	7.70	9.30	9.99
Portland Harbor	DO	mg/L	37	9.00	7.40	10.40	0.78	7.90	8.50	9.40	10.20
Western Bay	DO	mg/L	60	8.90	6.90	30.40	2.98	7.40	7.80	9.10	9.95
Eastern Bay	DO	mg/L	117	8.19	5.10	10.70	1.23	6.50	7.40	9.10	9.80
Offshore	DO	mg/L	84	8.67	6.20	10.94	1.07	7.50	7.90	9.60	10.20

Table B- 2. Summary statistics for summer (June-September), surface water dissolved inorganic nitrogen, ammonium and nitrate+nitrite data for each of the water body groupings defined in the report.

Grouping	Parameter	Units	n	Mean	Min	Max	SD	10th	25th	75th	90th
Maine	DIN	µM	1337	8.04	0.00	620.00	31.06	0.39	1.28	7.63	14.45
Massachusetts	DIN	µM	52	8.93	0.72	69.29	14.34	1.50	2.33	7.64	13.93
New Hampshire	DIN	µM	82	12.26	1.36	165.43	19.40	2.29	3.50	15.07	22.57
ME NCA Stations	DIN	µM	54	6.84	1.18	22.07	4.86	2.57	3.43	8.38	12.28
Casco Bay	DIN	µM	1283	8.09	0.00	620.00	31.69	0.37	1.22	7.55	14.60
Portland Harbor	DIN	µM	510	9.04	0.00	620.00	28.76	1.44	2.87	8.59	18.27
Western Bay	DIN	µM	281	6.78	0.00	130.21	10.14	0.40	1.10	9.71	15.56
Eastern Bay	DIN	µM	390	6.23	0.00	620.00	32.45	0.16	0.80	4.84	9.92
Offshore	DIN	µM	102	14.01	0.00	620.00	64.62	0.05	0.28	5.99	16.16
Maine	NH4	µM	1404	4.24	0.00	127.33	9.69	0.14	0.80	4.50	8.14
Massachusetts	NH4	µM	75	3.61	0.07	15.21	3.30	0.64	1.71	3.79	7.93
New Hampshire	NH4	µM	95	6.90	0.43	162.86	16.84	0.93	2.07	8.21	12.14
ME NCA Stations	NH4	µM	124	2.20	0.07	16.00	2.71	0.14	0.36	2.93	5.79
Casco Bay	NH4	µM	1280	4.44	0.00	127.33	10.09	0.13	0.86	4.62	8.36
Portland Harbor	NH4	µM	508	4.87	0.00	120.00	7.51	0.81	1.62	5.45	10.34
Western Bay	NH4	µM	281	3.74	0.00	127.33	8.64	0.16	0.87	4.53	7.42
Eastern Bay	NH4	µM	390	3.89	0.00	120.00	9.59	0.01	0.52	4.10	7.56
Offshore	NH4	µM	101	6.34	0.00	120.00	21.02	0.00	0.06	3.19	8.14
Maine	NO2+NO3	µM	1353	3.61	0.00	500.00	23.90	0.09	0.12	2.47	6.92
Massachusetts	NO2+NO3	µM	55	5.06	0.12	56.29	12.03	0.33	0.51	2.17	9.50
New Hampshire	NO2+NO3	µM	85	4.47	0.36	33.50	6.29	0.64	1.14	5.33	13.21
ME NCA Stations	NO2+NO3	µM	73	2.59	0.15	13.71	2.65	0.44	0.71	3.43	5.54
Casco Bay	NO2+NO3	µM	1280	3.67	0.00	500.00	24.56	0.09	0.12	2.39	7.03
Portland Harbor	NO2+NO3	µM	508	4.21	0.00	500.00	22.72	0.25	0.77	3.07	7.45
Western Bay	NO2+NO3	µM	281	3.04	0.00	19.15	4.56	0.09	0.12	4.11	10.16
Eastern Bay	NO2+NO3	µM	390	2.34	0.00	500.00	25.42	0.05	0.09	0.84	2.11
Offshore	NO2+NO3	µM	101	7.81	0.00	500.00	50.00	0.00	0.09	2.10	7.64