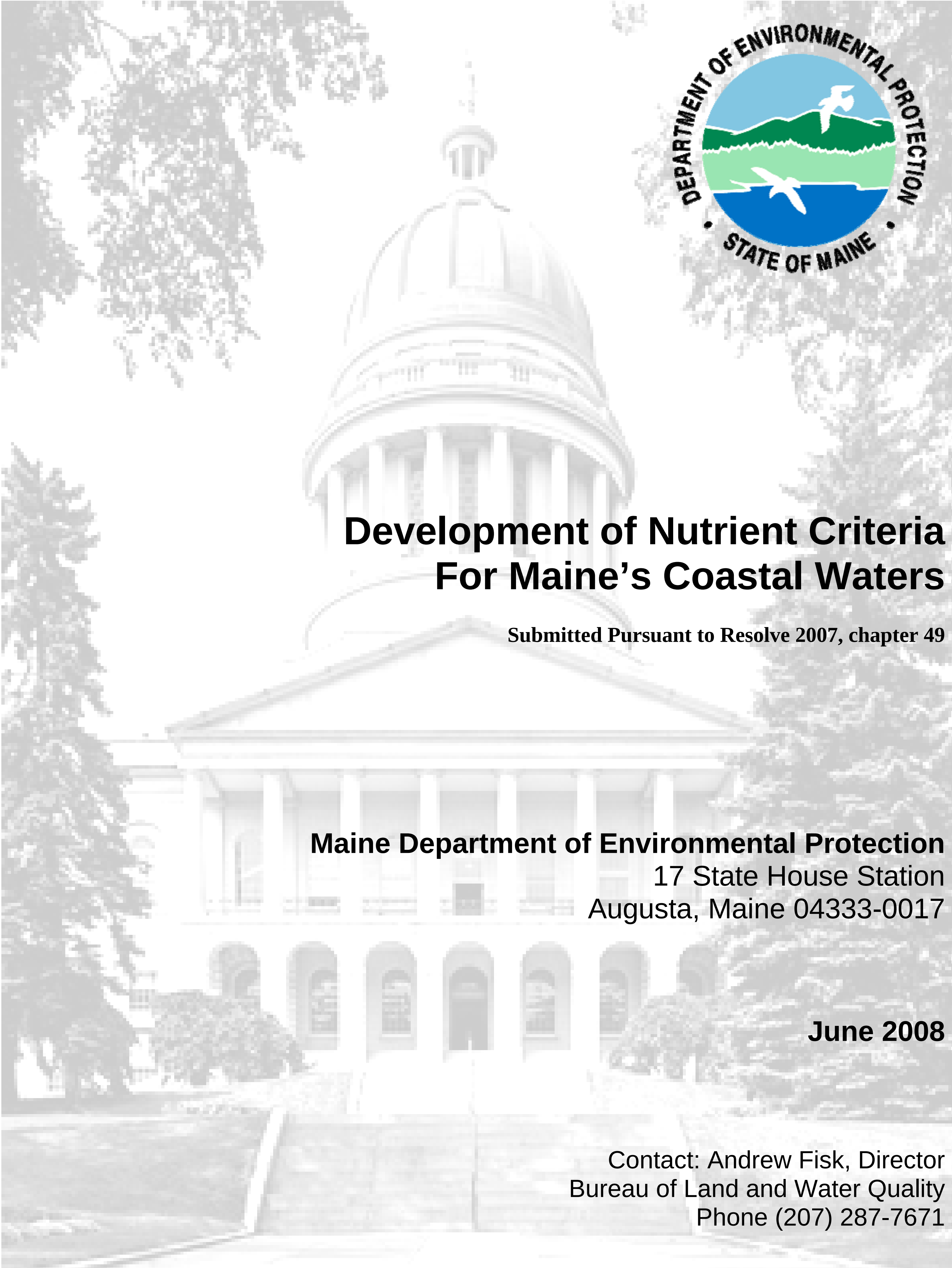

Development of Nutrient Criteria For Maine's Coastal Waters

Submitted Pursuant to Resolve 2007, chapter 49

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June 2008

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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.

Nitrogen Removal Theory

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.

Facility Cost Information

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