# Maine Ocean Acidification Study Commission

## Notes from the Second Meeting September 4, 2014

## Held at the Cross Office Room 206, Cross Office Building, Augusta, Maine

Present: Sen. Johnson, Rep. Devin, Rep. Welsh, Rep. Parry, Richard Nelson, Joe Payne, Larry Mayer, Joseph Salisbury, Jon Lewis, Susanne Miller, Kathleen Leyden, Mark Green, Meredith White, Bill Mook and Susie Arnold.

Absent: Sen. Langley

### 1. Meeting welcome and introductions.

Sen Johnson opened the meeting and noted the goal's needed to prepare for the final report: review the science on the subject - what we know/don't (but would like to were there data available) - and make recommendations for further research that is needed. The narrative and executive summary will include/cite conclusions based on existing data. He reminded that it is not an actual scientific study but neither is it an opinion piece; the recommendations must be connected to (conclusions based on) the data. The scope again: impact on marine resources and mitigations – science based. To begin to flesh out today.

The commission members introduced themselves.

### 2. Subcommittee updates and report recommendations

State of the Science subcommittee draft report.

Meredith White presented the subcommittee's draft report to the full commission. A copy of the draft report is available at http://www.maine.gov/legis/opla/oceanacidificationmtgmatrls.htm. In summary, the report addressed the causes and trends in the acidification of Maine waters that include the confluence of increasing atmospheric CO2 concentration, freshwater influences (timing and spatial extent of freshwater input) and the decoupling of photosynthesis/respiration leading to acid production. The subcommittee reviewed the scientific literature studying system conditions that make the Gulf of Maine especially susceptible to acidification. The subcommittee will present its final report to the commission at the commission's next meeting for content review. It recommended using language that mirrors and dovetails the Washington and NOAA reports to minimize duplication and connect to state and national efforts. The subcommittee will work with staff to incorporate its report into the commission's full report.

Summarized below is the commission's discussion of the initial findings in the subcommittee's report regarding the causes and trends of acidification of Maine waters, impacts on Maine fisheries and research and monitoring priorities.

(A). *Acidification in Maine - causes and trends*

- The variability amidst the overall warming trend. Questions were raised about the utility and predictive value of short-term (>2 years) data. There was general agreement that while there is temperature variability amid an overarching trend, long-term data (<30 years) can elucidate overall trends in the rate ocean temperatures have increased along Maine's coast and that there is predictive value in such data. It was stated that as acidification increases the oceans ability to absorb it decreases slightly and that the rate of change is the important factor not the degree of acidification. There appeared to be agreement among commission members that the rate of change is greater now than in the past based on available data, however, there remains a degree of uncertainty in the science.

- The role of and data needs for freshwater influences: direct runoff from land, land use practices and indirect impacts from the Scotian shelf.

- Decoupling photosynthesis (surface) and respiration (deep water). While nutrient blooms aren't grazed, eutrophication may actually help larvae in need of food in benthic column. Stratification and sedimentation: dissolved inorganics from deep water, carbon coming from mud rather than in carbon-rich deep benthic layer where there is minimal respiration.

- Effects on water chemistry – forcing (characteristics of freshwater runoff and ocean that interact to determine water chemistry). Factors that play into forcing include location and timing of fresh water runoff, geography and source of water *e.g.* slope waters or input from Northeast channel, higher nutrient in warmer water vs. colder Canadian water where there is lower nutrient level. The size of the watershed Nearshore/land based effects such as the shapes of estuaries and the size of a watershed are factors that can make species more susceptible at various times and life stages.

*(B) Impacts on Maine fisheries.* Acidification effects on commercial and noncommercial organisms including impacts other than survivability such as growth and development that affect the species marketability.

- It was noted that while some species' adaptability may preserve commercial value there are variables that have additive and synergistic impacts in the context of multiple stressors.

- A member of subcommittee stated that most studies are lab studies on a single-species during a specific life cycle under a single stressor but there are a few looking at zooplankton under field conditions. While zooplankton is not a commercial species it has an indirect commercial value as a food source for commercial species. The commission discussed the limitations of lab inquiries and agreed that there is a need for more field studies to understand the interplay of multiple stressors including chemical, geographic and other environmental interactions that affect the degree of acidification. A few field studies have

looked at coastal stressors on a few commercial species (urchins, oysters and mussels) but many more studies are needed to elucidate the effects of acidification on marine organisms. The rationale for studying urchins, oysters and mussels is due to the convenience of studying organisms with short life cycles and their transferability to human food and health.

*(C) Research/monitoring – priorities.* The subcommittee will summarize existing knowledge gaps and review scientific data to determine whether Maine waters have acidified. Specifically, the subcommittee will review PH data which can be extracted from the historic record based on boron isotopes and sea floor chemistry. The subcommittee underscored the need for further research on lobsters and obtaining data on elvers and other high-value commercial fisheries.

- A member of the commission gave the examples of how seawater temperature changes can quickly impact Maine's commercial fisheries. One example was the influx of lobster ("glut") during the warm summer of 2012 that resulted in a sharp decline in prices that had an immediate impact on the lobster fishery and lasted for 2 years. There was general agreement that the Legislature needs to be aware that these "sudden impacts" can and do occur and that recovery can take years.

- Upstream development has a significant impact on near shore acidification and while there are ongoing efforts by state and private entities to collect this data there are still significant gaps. The commission discussed the methodology used by citizen scientists to collect data and the usefulness of such data. In general, citizen science is not normalized and relying on the data may be problematic. It was pointed out that the purpose of the coastal monitoring alliance project is to standardize and coordinate volunteer data collection methods and objectives.

- The commission discussed Best Management Practices (BMP) used/recommended to control stormwater/wastewater inputs into riverine and marine systems. Need to determine whether Maine has the capacity to get a handle on this and are there more effective BMPs to use in Maine that the commission can recommend?

- There was agreement that a model is needed to understand disparate coastal and ocean impacts. More benthic measurements are needed. Rate of transformation is biggest data gap. Need cross section of water column strata from deep to shallow, to look at sources in off shore and near shore systems. There was discussion about setting boundaries around geography (e.g., should the 3 mi boundary for state waters be considered near shore) because scientists have used different boundaries for research purposes. An integrated approach is needed to understand what is occurring in the system as a whole. It was pointed out that the scope of the study is entire range of Gulf of Maine but the commission should focus its efforts on what can be mitigated and where it can effect change. A commission member suggested that addressing nitrogen input is something feasible at the state level.

- The commission created the model subcommittee to define inshore and offshore domains and what data should be collected to build a model of carbonate chemistry

that can be used to define and delimit those domains. The subcommittee was charged with identifying data needs (where, how and what to measure) to monitor commercially valuable species. Model subcommittee members include Joe Salisbury, Larry Mayer, Bill Mook, Mark Green and Joe Payne.

**Washington State Recommendations subcommittee.**

- Joe Payne presented the subcommittee's draft report to the commission. The subcommittee is planning to recommend the commission adopt 38 of the 42 recommendations in the Washington blue ribbon panel's report on ocean acidification. The subcommittee will work with staff to put its final report onto proper form for the commission's full report. The subcommittee noted that Maine's climate action plan (Pl 2003, chapter 237) was not refunded.

- Rep. Devin met with Washington Blue Ribbon panel lead Sen Rankin who encouraged the commission to utilize as much of the blue ribbon report as possible because he would like to see coastal states adopt ocean acidification plans. Sen. Rankin offered to come to Maine to talk about the findings and recommendation in the report.

**3. Understanding the science and draw conclusions from existing data and information**

- The commission needs to agree upon how to characterize the warming trend over time and how species respond. It is a very complex system with many drivers so need to be careful not to overly simplify it but also need to make it readable for a general audience.

- Despite the economic importance of lobsters to Maine's economy, there are not enough studies to make concrete recommendations on how acidification affects lobsters. The commission discussed the impact lobster bait may have of the release of nitrogen into the marine environment but it was pointed out that since the bait has a marine origin it is a sum zero gain.

- There is data over the last decade on shellfish safety and area closures that may provide useful information for purposes of near shore acidification.

- Need to look at co-stressors because acidification does not occur in a vacuum.

- Temperature and the solubility of calcite minerals and CO2 are linked to temperature and salinity. Water temperature is a cofactor, with direct affect on carbonate chemistry.

- Maine's marine environment is more complicated than most places because of coast, circulations, sedimentation, remineralization, unique estuarine environments. This

results in many complex drivers that lead to acidification making additional and ongoing studies necessary.

- Some taxa such as mollusks are showing an ability to adapt to acidification which may be exploited to produce commercial species that are resistant to acidification. Maine has the potential to be a leader in this area.

**3. Research and materials for the next meeting.**

- Commission members will identify possible acidification mitigation strategies that include methods for protecting species during life stages when they are particularly sensitive to acidification.

- Rep. Welch and Suzanne Miller will review the 2014 report on the state of greenhouse gas reduction and air quality in Maine.

- Members representing the Department of Environmental Protection, Department of Forestry and Agriculture and the Department of Marine Resources will pull together a summary of laws and regulations promulgated by the departments that relate to ocean acidification.

- Susanne Miller will schedule DEP and someone from the Maine Water Environment Association to provide a briefing regarding the role of wastewater management.

- Staff directed to contact nonprofits that may be conducting acidification related studies and what reports or data may be available to the commission.

- Joseph Salisbury will provide data on additional sensors for Buoy N (NERACOOS) data.

- Joe Payne and Larry Mayer will provide mudflat PH level data.

- Departments will bring 2012 MOAs between DACF, DMR and DEP on collaborations around test results and data sharing to deal with nutrient runoff and bacteria.

The commission adjourned at 3:00pm

# Development of Nutrient Criteria For Maine's Coastal Waters

**Submitted Pursuant to Resolve 2007, chapter 49**

**Maine Department of Environmental Protection**
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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 (NH4) + organic nitrogen + nitrate (NO3) + nitrite (NO2)

[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. (NH4 + 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.

**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<br>$2,549,824 |
| 1.0 – 10.0 | $1,742,000 | $6,977,206<br>$129,555 |
| > 10.0 | $588,000 | $1,833,267<br>$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

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**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 |
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| 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 |

| | | | |
|---|---|---|---|
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| 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 |
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| 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

MODEL & DATA SUBCOMMITTEE

Acidification models and their domains in the Gulf of Maine

Present: Joe Payne, Joe Salisbury, Bill Mook, and Larry Mayer were the OA commission members present; meeting was held at Friends of Casco Bay in South Portland 9/16/14. Damian Brady and Mike Doan (members of the public) were also present.

Importance of modeling. Uses include understanding the system, testing hypotheses, and setting up framework to develop tools for future protective legislation. All models are wrong; some are useful. Successful water circulation models will need to underpin more complex models with biogeochemical and biological components. Models should be developed iteratively and types/structure will evolve over time. Models will need to keep in mind the target commercial species, which have different vulnerabilities. For example, some species are dependent on carbonate saturation and others are not. The geography of models – hence spatial domain - will proceed from combining species vulnerabilities (as we now understand them), and acidification in different areas of the Gulf of Maine that is learned via observation and biogeochemical/hydrodynamic modeling.

Recommendations: Modeling is included in recommendations for further work. Different models should be employed at different scales, and targeted by current knowledge. Models should be tested against data, in historical and predictive ways, and should evolve over time. We think it premature to recommend specific models or geographic limits to them, at this time.

Freshwater monitoring is a clear need to enable nearshore models.

Other monitoring recommendations. Offshore and inshore time series. Productivity, oxygen demand, carbonate chemistry of Gulf of Maine and its inputs (buoy M instead of N for inputs to GME?), inshore buoys, shore-based facilities targeted as sampling platforms, cruises, Ca, nutrients, pH.

Data validation for pH measurements. QAPP's should be followed to enable data usage. Facilities and expertise of experienced professionals should be provided to help other samplers (e.g., citizen groups) to make measurements usable. Recognize that different levels of data quality exist and can be used for different purposes.

Bill Mook found strongly better development of larvae upon measuring input waters for pH, adjusting pH to improve when necessary.

**Maine Coastal Observing Alliance Member Responses:**

**Friends of Casco Bay**
**Contact**: Mike Doan, mdoan@cascobay.org
**Email response**: We have data on sediment pH, water column pH, DIN, TN (and more!). I have attached the 2012 and 2013 sediment pH data, and will send along the files with the other parameters tomorrow.
In 2012, we measured pH at 30 clam flats around Casco Bay - visiting each flat once. In 2013, we measured pH bi-weekly along a transect from high to low intertidal at one clam flat, in an effort to learn something about the spatial and temporal variability of pH on a flat. I am sure there will be many questions about these two data sets. Please do not hesitate to contact me!
**Attachments**: 2012 and 2013 raw sediment ph data

**Damariscotta River Association**
**Contact**: Sarah Gladu, sgladu@damariscottariver.org
**Email response**: I can tell you, as Coordinator of Damariscotta River Association estuary monitoring, we currently monitor dissolved oxygen, salinity, temperature, nitrates, water clarity at 7 locations in the estuary twice a month from May to October. While pH is of interest to us we are not currently monitoring it (independently of the MCOA project, which is). The DRA has not done anything with respect to shellfish closure data for many years.
**Attachments**: Maine Coastal Observing Alliance Regional Monitoring Project Description

**Georges River Tidewater Association**
**Contact**: Jonathan Eaton, jonathan.eaton3@gmail.com
**Email response**: I represent the Georges River Tidewater Association, a member organization of the Maine Coast Observing Alliance. Sarah passed along your request to me.

The GRTA has been monitoring pH, dissolved oxygen, and nutrients in the St. George estuary since 2012. The 2012 report is attached. The 2013 report is in preparation. The 2014 sampling is still underway and has been merged with the Maine Coast Observing Alliance sampling so we can get a broader picture of the Maine coast.

The most notable observations in the 2012 and 2013 sample seasons were a pronounced late-summer/autumn drop of pH in subsurface waters of the lower estuary, in habitat that is highly productive for lobsters and clams. Whether this will be repeated in 2014 is not yet clear, and whether the MCOA will observe this same phenomenon in other midcoast Maine estuaries is also yet to be determined by our ongoing sampling efforts.

I also serve as an alternate on the Georges River Regional Shellfish Management Organization (a five-town joint board administering our local clam ordinance) and was in the past the chair of that organization while serving on the Thomaston selectboard. From the clammers I hear that the river is thick with seed clams at this time. The shellfish board is trying to interest DEP, DMR, and Agriculture in a joint study of the St. George to address pollution closures. We are also trying to interest DMR in a pilot study to address wormer/clammer conflicts.
**Attachment**: State of the River 2012 PDF document.

**The Marine Environmental Research Institute (Blue Hill Bay)**
**Contact**: Ruby Nash, rnash@meriresearch.org
**Email response:** Dr. Susan Shaw and our Monitoring Coordinator, Abby Barrows, asked me to touch base with you regarding your request for information on our research for next week's legislative study group meeting. We will be happy to submit material about the work we do here at the Marine Environmental Research Institute.
**Attachment:**

**See next page for additional members**

## Maine Coastal Observing Alliance Member Responses: (Cont'd)

**Awaiting Responses from:**

**Rockport Conservation Commission**
**Contact:** Bob Kennedy, BobKennedy@email.com
**Email response:**
**Attachments**

**Medomak Valley Land Trust**
**Contact:** , mvlt@midcoast.com
**Email response:**
**Attachments**

**Kennebec Estuary Land Trust**
**Contact:** , info@kennebecestuary.org
**Email response:**
**Attachments**

**Sheepscot Valley Conservation Association**
**Contact:** , steve@sheepscot.org
**Email response:**
**Attachments**

**From:** Ruth Indrick [mailto:rindrick@kennebecestuary.org]
**Sent:** Wednesday, September 17, 2014 2:26 PM
**To:** Ames, Alison; Bentley, Curtis; Winston, Amy
**Cc:** Carrie Kinne
**Subject:** Ocean Acidification Research

Hello Alison,

Thank you for contacting me with questions about our current work regarding pH and ocean acidification.

As a part of our work with MCOA, we have started collecting data. The Kennebec and 6 other areas are getting monitored by boat 4 times during the months of August and September using uniform methods and consistent equipment. I believe there are 34 sites stretching from Rockport to Freeport. So far, each site has been sampled 3 of the 4 times. I am not sure about the status of the results.

Beyond the work that we are undertaking with the MCOA collaboration, we are also completing a few other projects to look at pH and its impacts on commercial species. We have a volunteer water sampling program that is sampling the coastal waters around Georgetown (9 sites) and Phippsburg (10 sites) between May and October. This is our second year sampling in Georgetown and 1st year sampling in Phippsburg. Using simple but consistent methods, the volunteers are measuring information about pH, dissolved oxygen, salinity, and temperature. The methods we use are relatively comparable to those used by the volunteer programs at Friends of Casco Bay and Georges River Tidewater Association. Attached is a copy of the report that analyzed the 2013 Georgetown results and a summary of that project. We are still compiling the 2014 data.

We have also collaborated with Professor Michèle LaVigne at Bowdoin College to focus specifically on acidification and its impact on shellfish - softshell clams. In 2013, her biogeochemistry class looked at clam shell thickness and how it varied between two different clam flats. The class put together a poster of their results that is attached. In summer 2014, Professor LaVigne and I guided 2 student fellows who were analyzing pH, alkalinity, and saturation state at a clam flat highlighted by the town's shellfish committee as one that used to be consistently productive and now has some sections that are vacant of clams. One of the students is currently analyzing the results and developing a poster to share those results. He will be presenting the poster on October 24th, and we will also be sharing the information with the Phippsburg Shellfish Committee.

As regards projects that focus more broadly on shellfish closures, we have been collaborating closely with local shellfish committees over the past 4 years. A summary and report on the results of one of those projects - The Kennebec Estuary Shellfish Area Project (KESAP) - is attached. Our collaboration with the shellfish committees and the Maine DMR helped carry out work that led to the opening of several closed clam flats and a loosening of the conditional area restrictions, allowing more flats to be open for more days of the year. We are currently working with members of 4 shellfish committees to focus on the impacts of green crabs and take action to understand and limit the crab populations.

For the future, we hope to continue our volunteer water sampling program in Georgetown and Phippsburg and expand that program, if possible. We are planning to continue our collaboration with Professor LaVigne through student research and class projects. A

research project is planned for the next year that will focus on pH variability in intertidal areas in the Kennebec using methods refined by the student fellows this past summer. We will also continue to collaborate with shellfish committees in the towns of West Bath, Phippsburg, Georgetown, Arrowsic, Woolwich, and Westport Island, lending support as needed and providing school and community outreach programs. We plan to continue monitoring and trapping green crab populations with interested shellfish committees and school groups.

Hope this helps! Please let me know if you have any questions or need any other information.

Thank you,

-Ruth

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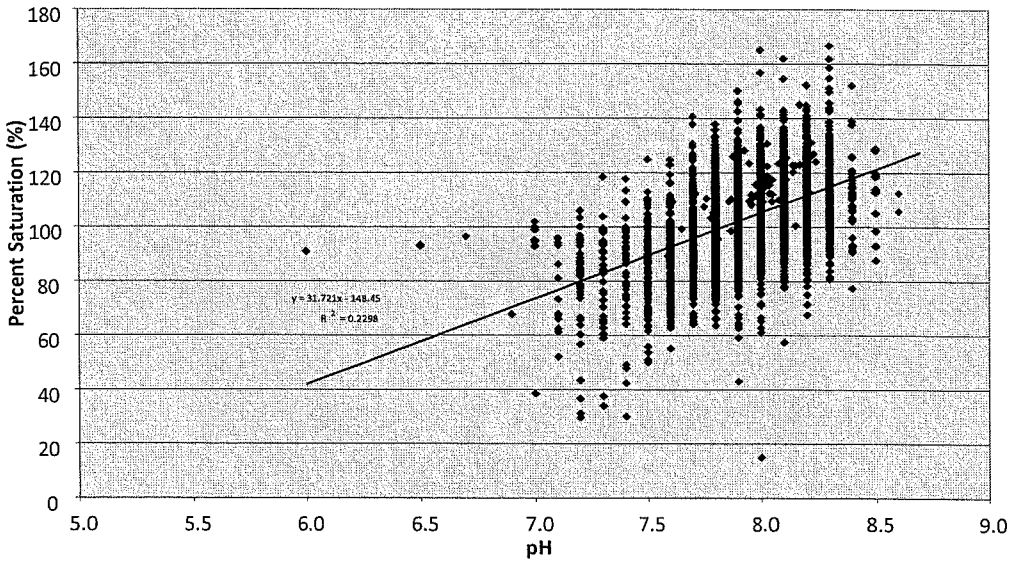
Ruth Indrick
Project Coordinator
Kennebec Estuary Land Trust
PO Box 1128 Bath, ME 04530
Office: 207-442-8400
Cell: 315-415-4160
rindrick@kennebecestuary.org

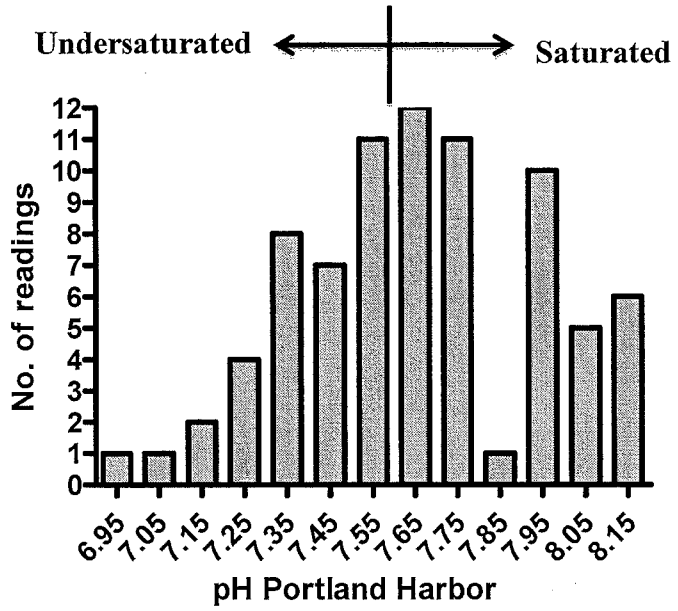
www.kennebecestuary.org

# Casco Bay DO and pH (1993-2008)

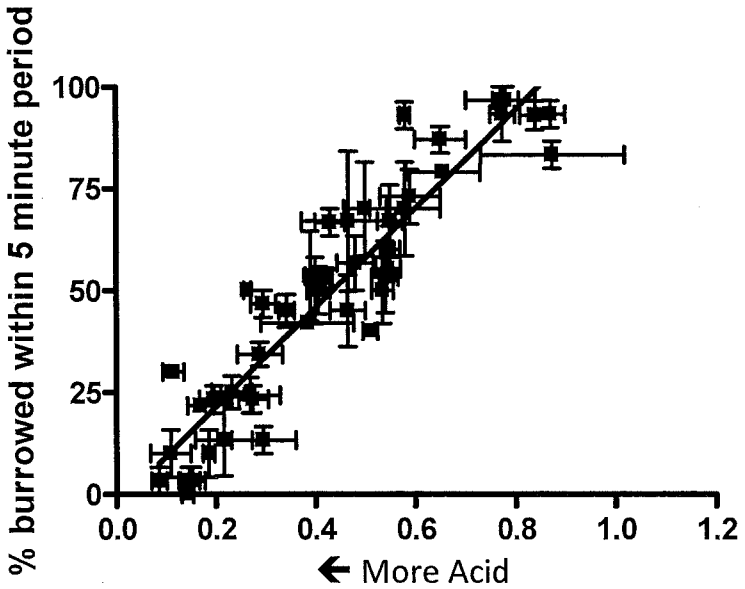


Acid production in the sediments:

Frequency distribution of pH at the sediment surface in Portland Harbor, Maine.

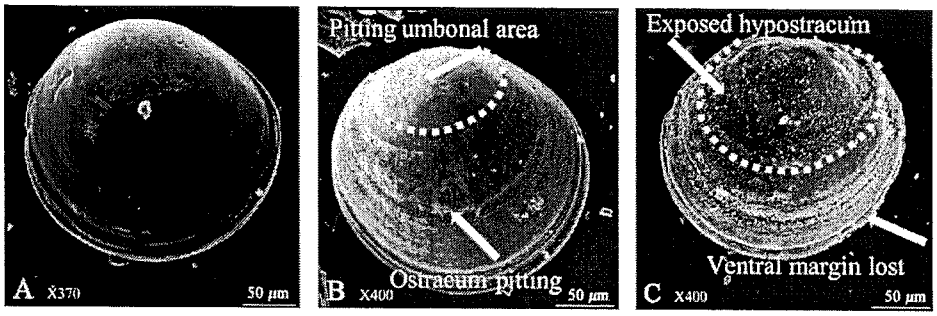



Settling clams won't burrow into acidic mud!




(Green et al., 2011)

# Mortality (Death by Dissolution)

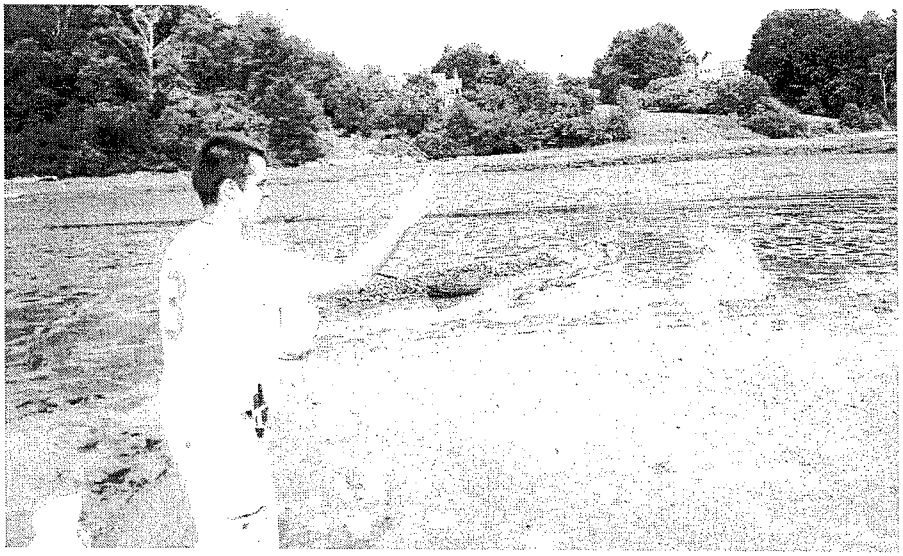


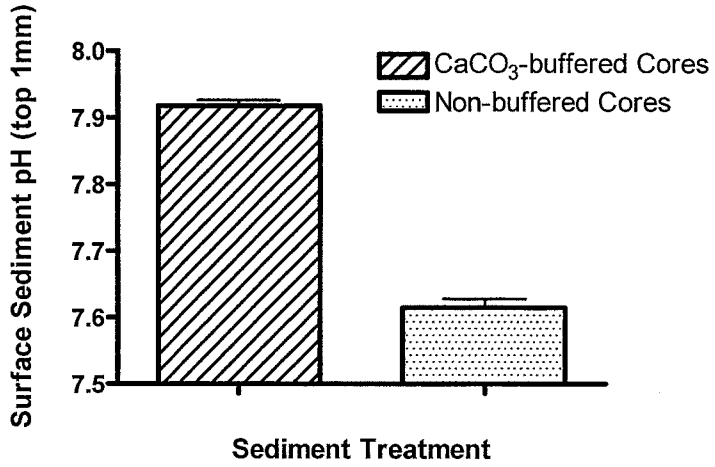

Day 0 Day 4 Day 7

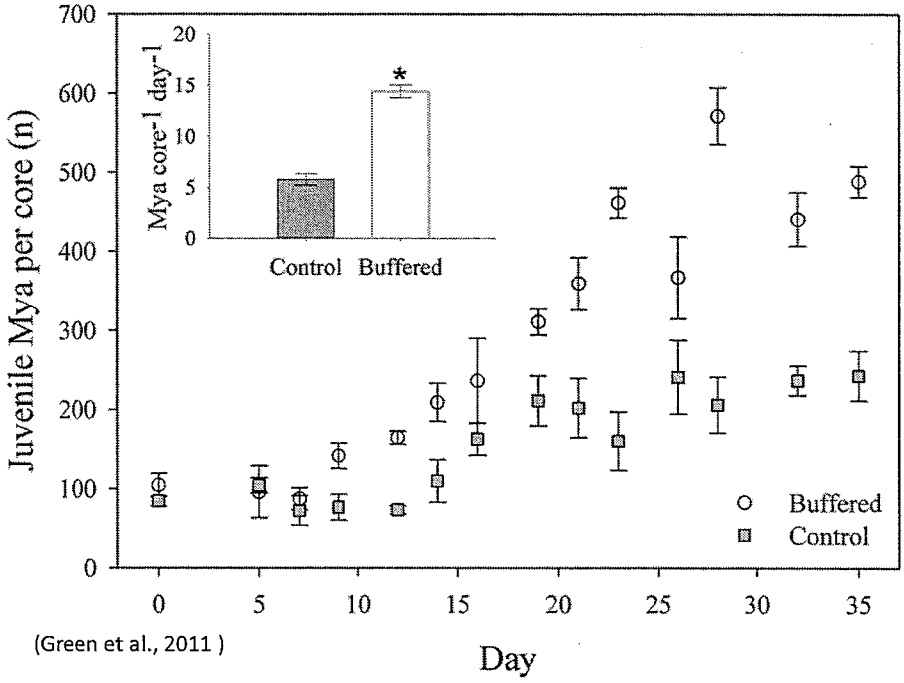
**Representative clams from 0.2 mm size class at 0.6 Ω**

**Notice area near umbonal is the remnant of the larval shell**

(Green et al. 2009)






(Green et al., 2011 )

Buoy N data

# A Multiyear Assessment of Biological Pertubations of $CO_2$ in the Northeast Channel of the Gulf of Maine

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Missoula, MT 59812, USA

*Abstract*—**The University of New Hampshire (UNH), in collaboration with the University of Maine at Orono (UMO) and the University of Montana, has been monitoring surface ocean dissolved carbon dioxide and oxygen in the Northeast Channel, at a site on the northeast flank, of the Gulf of Maine for the last several years. UMO has maintained a buoy at this site (Buoy N) since 2004, and UNH has deployed two instruments (the SAMI-$CO_2$ Sensor (Sunburst Sensors, LLC) and an Aanderraa Instrument Oxygen Optode 3835) since March 2008. The controls on the $CO_2$ system are examined to determine the dominating biological seasonal influences that occur alongside physical processes. We evaluate several approaches to isolate these factors and processes using the buoy data and following previous studies. Preliminary results suggest measurable interannual biochemical variability may be attributed to water mass dynamics at this site.**

***Keywords-$CO_2$ air-sea flux; ocean DIC; Gulf of Maine; ocean carbon cycle; biochemical sensors; dissolved oxygen***

## I. INTRODUCTION

Since the beginning of the industrial revolution, the atmospheric concentration of carbon dioxide ($CO_2$) has increased from 280 ppm to 380 ppm. Most of this increase resulted from the anthropogenic burning of fossil fuels, but to a lesser extent, from land use changes. Atmospheric concentrations of $CO_2$ have decreased from the oceanic uptake of $CO_2$. Several studies in this region show tis shelf region to be a weak source of atmospheric $CO_2$ but the data are insufficient to conclude that this is a persistent and long-term result [1]. However, the oceans ability to continue the uptake of anthropogenic released $CO_2$ is decreasing as sea surface temperatures increase and pH decreases [2]. Other factors influence the partial pressure of $CO_2$ ($pCO_2$) in seawater, such as temperature, salinity, the concentration of dissolved inorganic carbon (DIC), and alkalinity [3]. The atmospheric $CO_2$ that the ocean takes up increases that anthropogenic DIC component of seawater, which increases ocean acidification [3].

The $pCO_2$ in the surface waters of the ocean is controlled by a variety of parameters, including total $CO_2$, total alkalinity (TA), temperature, salinity, phosphate ion, and silicate [4]. There are physical (mixing and advection, warming and cooling, gas exchange with the atmosphere, and diffusive transport of $CO_2$), biological (photosynthesis and respiration), and chemical (carbonate formation and dissolution and photooxidation) controls on the total $CO_2$ (essentially DIC) in the upper mixed layer of the ocean [3, 5, 6].

What makes it difficult to quantify the controls that change $CO_2$ concentrations is that more than one factor is often responsible for $CO_2$ changes [5, 7]. Measuring dissolved oxygen ($O_2$) concentrations along with DIC can help determine which process is dominating control over $CO_2$ in the water column [7]. Reference [7] observed that an undersaturation of $pCO_2$ along with a supersaturation of $O_2$ with respect to the atmosphere implies photosynthesis dominating DIC; conversely a supersaturation of $pCO_2$ and an undersaturation of $O_2$ indicate net respiration. Variations in $O_2$ do not merely reflect biological processes, but also reflect air-sea gas exchange [8]. However, during strong blooms, $CO_2$ and $O_2$ fluxes can present a significant inverse correlation, which may be indicative of air-sea gas exchanges driven by biological processes [5]. Temperature changes often explain warming of surface waters that leads to outgassing and a corresponding decrease in $pCO_2$ [1].

Lack of coincident physical and biogeochemical observations associated with the $CO_2$ flux has made it difficult to determine the contributions of the coastal ocean to the global air-sea $CO_2$ flux [3]. $CO_2$ and DIC in the coastal ocean can be highly variable, with larger variability than seen in the open ocean [1, 3]. Some reasons for this are that the coastal ocean receives large inputs of organic and inorganic matter and nutrients from land and river runoff, exchanges large volumes of matter and energy with the open ocean across the continental slopes, and is one of the most biologically active areas of the biosphere [9, 10]. The coastal ocean has been largely neglected in global carbon budgets even though the flows of carbon and nutrients are disproportionately high in comparison with the surface area [9]. This neglect is largely caused by the uncertainty in the role of continental shelves in the air-sea exchanges of $CO_2$, and also because the exchange is highly variable with time and space [2].

In order to provide a reliable estimate of air-sea $CO_2$ exchange in the coastal environment, high temporal and

This research was supported by NSF grant OCE-0851447 and the UNH/NASA R&D program.

spatial coverage is needed [10]. Historically, sparse oceanographic measurements have limited our ability to quantify the air-sea flux of $CO_2$ on the continental shelves [2]. To remedy this, continuous measurements of physical and biogeochemical parameters are needed [1, 10]. One approach, which we will examine, is via autonomous biochemical sensors and several recent studies show that long-term ocean $CO_2$ observations can be achieved with reasonable accuracy [11].

### *A. Northeast Channel in the Gulf of Maine*

The Northeast Channel (NE Channel) in the Gulf of Maine is one of two deep water access points to the Atlantic Ocean (the other is the Great South Channel), and has a depth of approximately 230 m [12]. The NE Channel has several noteworthy features. There are strong semidiurnal tidal currents here that contribute a strong inflow on the eastern side of the NE Channel, and a strong outflow on the west side [13]. Most of the time, there is a deep inflow of slope water into the NE Channel, but occasionally, fresher surface water from the Scotian Shelf (SSW) is also observed [12, 13]. The SSW is distinguishable by its low salinity and temperatures [14]. UMO Buoy N is located at 42.33 N; 65.91 W on the NE flank of the channel (Fig. 1).

### *B. Buoy N Instrument Cluster*

The University of New Hampshire (UNH) and the University of Montana (UM) have been supporting nearly continuous biochemical observations in the NE Channel since March 2008. To our knowledge, this site represents the first offshore coastal shelf $CO_2$ time series in the NW Atlantic Ocean. Buoy N resides in 230 m of water, and consists of a string of autonomous physical oceanographic instruments attached at various depths (http://gyre.umeoce.maine.edu/data/gomoos/buoy/). At a depth of 3-5 m, an instrument cage holds two key instruments (Fig. 2) for this study, the SAMI-$CO_2$ Sensor (Sunburst, LLC) and the Oxygen Optode 3835 (Aanderraa Instruments). $CO_2$ data have been collected at this site over three separate deployments since April 19, 2008 at a depth of 3 m (Oceans Processing Analytical Lab, UNH). This analysis will look at time series data from April 19, 2008 until August 19, 2010 when the instruments on Buoy N were last serviced. Data on temperature, salinity, $pCO_2$ and dissolved oxygen are all measured at this site.

## II. Quality Control of $PCO_2$ Data

Studies have shown exceptionally long-term stability and sensitivity in the Submersible Autonomous Moored Instrument for $CO_2$ (SAMI-$CO_2$) sensor [11]. The operating characteristics have been calculated to having an accuracy of $\pm$ 1 μatm and a precision of $\pm$ 2 μatm [11]. The main difference between other $CO_2$ sensors and the SAMI-$CO_2$ is that the SAMI-$CO_2$ sensor is able to periodically renew its indicator solution, thus enhancing the stability and sensitivity in the sensor [11].

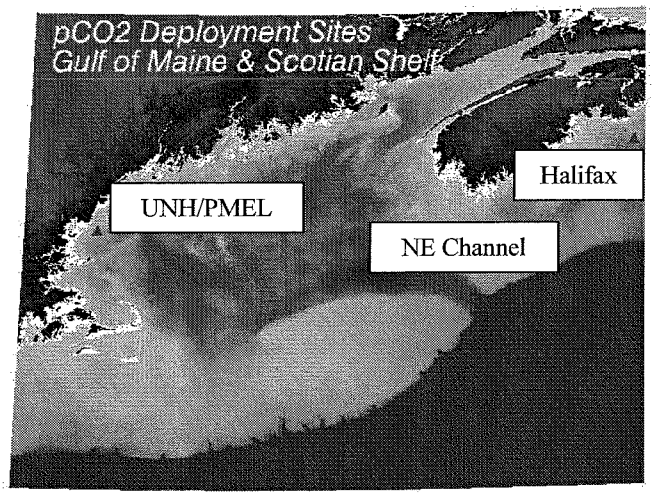


Figure 1. Map of the $pCO_2$ deployment sites in the Gulf of Maine and Scotian Shelf. The red triangles indicate where the $pCO_2$ monitoring sites are off the coast of Halifax, the Northeast Channel, and the UNH/PMEL buoy off the coast of Portsmouth, NH (image provided by D. Vandemark).

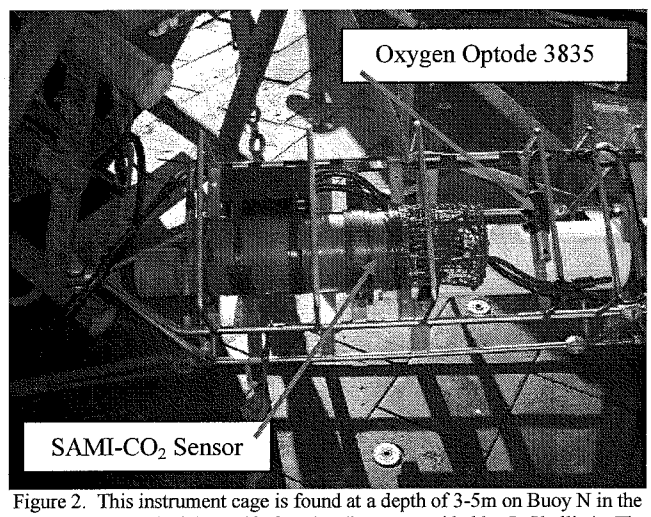


Figure 2. This instrument cage is found at a depth of 3-5m on Buoy N in the Northeast Channel of the Gulf of Maine (image provided by S. Shellito). The SAMI-$CO_2$ sensor and the Oxygen Optode 3835 collect the $pCO_2$ and the $O_2$ data for UNH.

The SAMI unit performs a calibration measurement using deionized (DI) water every 3.5 days. As a result, baseline measurements of the 440 and 620 nm (the absorbance maxima of the acid and base forms of the bromothymol blue indicator used by the SAMI-$CO_2$) are determined [11]. The resulting time series of blank measurements are used to inspect, adjust, and flag bad data within each 3.5 day block of data.

To further ensure the quality of the $pCO_2$ data, preliminary checks were performed. The entire time series of $pCO_2$ data were plotted. Any abnormally high or low values were removed from the data set (data valid between the tested operating range of 200 – 600 μatm, [11]). Additionally, $pCO_2$ was calculated from the DIC and the TA using the $CO_2$SYS program [15]. The measured $pCO_2$ data are (Fig. 3). In Fig. 3, there are times when the modeled $pCO_2$ and measured track

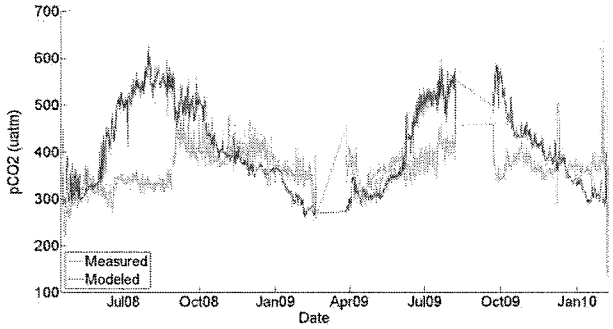


Figure 3. During the three year deployment, there were two gaps in the data where the buoy was removed for maintenance. Sometimes the modeled $pCO_2$ (magenta) tracks well with the measured $pCO_2$ (cyan), other times one is greater than the other which could indicate biological processes like photosynthesis and respiration. Short time scale jumps in the data could indicate the mixing of two water masses.

fairly close together. At other times, the modeled $pCO_2$ is greater than the measured, which could be due to biological activity drawing down inorganic carbon from the system for primary productivity. Other times, the measured $pCO_2$ is greater than the modeled, which could indicate periods of high respiration or ventilation of deeper waters. The two largest jumps in the data occur when the buoy was pulled from the water for servicing. Other smaller shifts in both the modeled and measured $pCO_2$ could indicate the mixing of two different water masses. Further quality control checks on the $pCO_2$ data are currently being performed at the University of Montana.

## III. Quality Control of $O_2$ Data

Several checks on the dissolved oxygen data were utilized to ensure that the data were of high quality. Biofouling on the Oxygen Optode sensor has often been observed after several months at sea, when algae grow on the oxygen sensor. The algae produce oxygen during periods of light, which causes the oxygen readings to be extremely high. During the night, autotrophy is minimal, and the probe measures ambient oxygen readings. This is apparent in the data when a time series plot of dissolved oxygen (Fig. 4) is produced and there is high noise in the data between May 2009 and June 2009. By separating out all the day and night data during these periods, the night data may be used. In order to determine whether the noise seen in the raw data is due to biofouling or known tidal variability, a shorter time series was generated (Fig. 5). Over a two week period (from May 13 to May 28, 2009 as depicted in Fig. 5), the oxygen peaks at unrealistic levels once a day and falls back to a lower values once a day. In order to correct for this biofouling, a program was written (minfilter.m, MATLAB). This program finds the minimum value of the oxygen data over intervals of 20 hourly samples over the length of the measured oxygen data. Only where biofouling is indicated will the minimum values replace the measured values of oxygen (Fig. 6, Deployment2).

There are a couple of methods employed to ensure quality in the oxygen data. Before each deployment, the Oxygen Optode is calibrated to a standard to ensure quality. Over the

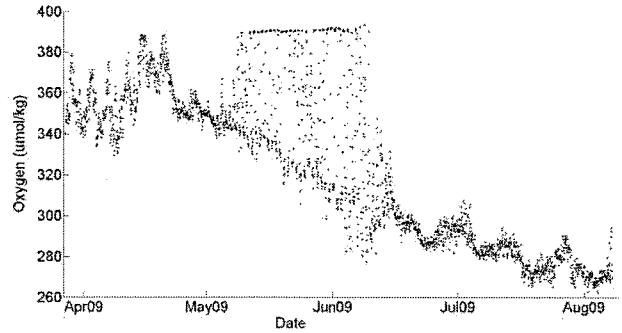


Figure 4. Between the period of May 2009 and June 2009, the measured oxygen data have a large noise signal, indicating biofouling on the sensor.

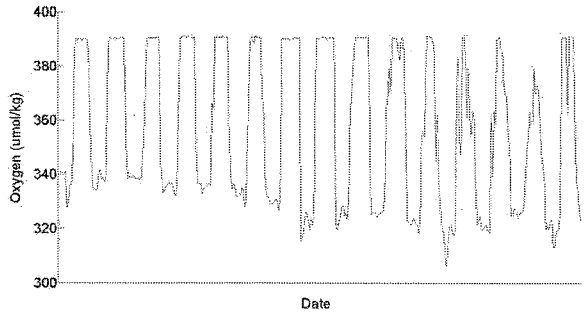


Figure 5. A closer look at the measured oxygen between May 13 and May 28, 2009 indicate that the noise in the data is due to biofouling. Peaks in the data occur once a day during daylight hours, and fall to ambient levels during the night.

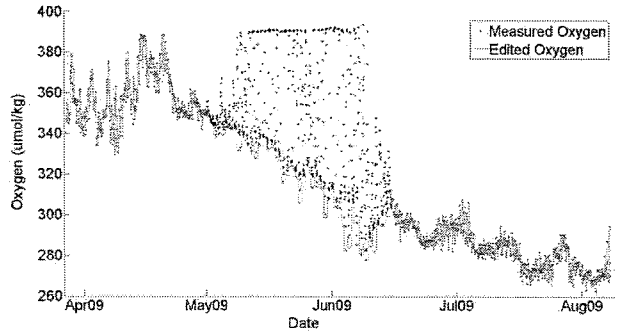


Figure 6. A times series plot of measured oxygen (black) during the second deployment of the Oxygen Optode shows high levels of noise in the data between May and June 2009. After applying the minimum filter to the data (green), the ambient oxygen signal is depicted and agrees with the nighttime values of the measured oxygen.

winter months, storms cause intense mixing in the surface waters in the Gulf of Maine. Consequentially, dissolved oxygen concentrations in the surface waters are in near equilibrium with the atmosphere, which means that the percent saturation of the surface waters is at or close to 100% saturation during the winter [16]. As a means of checking that the Oxygen Optode was providing accurate readings, all the data from the winter months (December, January, and February) were used to produce a time series plot of the

percent saturation (fig. 7). The average winter percent saturation for the first deployment was 100.6%.

## IV. Influences on DIC

In any aquatic environment, the entire inorganic carbon system can be modeled by knowing two parameters, such as pH and alkalinity, partial pressure of carbon dioxide ($pCO_2$) and alkalinity, or $pCO_2$ and dissolved inorganic carbon (DIC). In this case, only the $pCO_2$ was measured in situ. Following the total alkalinity (TA) modeled from [1],

$$TA_S = 43.2 \times S + 805. \quad (1)$$

Similarly, the abiotic DIC is modeled [1] as,

$$DIC_S = 46.5 \times S + 546.4. \quad (2)$$

However, both DIC and TA follow salinity to a first order. Using the salinity measurements and models from [1], TA and abiotic DIC were calculated.

There are several components influencing DIC, where

$$DIC(t) = \text{solubility} + \text{mixing}_h + \text{mixing}_v + R + P, \quad (3)$$

in the water column, and we can estimate all except the DIC due to R (respiration) and P (production). The abiotic DIC modeled from salinity accounts for the physical components influencing DIC (solubility and mixing). TA is mostly unaffected by multiple biological processes [3], so the modeled TA and measured $pCO_2$ will be used to determine the DIC. $CO_2$SYS program [15] is used for the calculation. The biotic DIC is then,

$$DIC_{bio}(t) = DIC - DIC_S \quad (4)$$

and the difference between the total DIC and the abiotic DIC (Fig. 8). As Fig. 8 shows, there are times when the biotic and abiotic DIC track relatively close to one another. This typically occurs during the winter months when productivity is

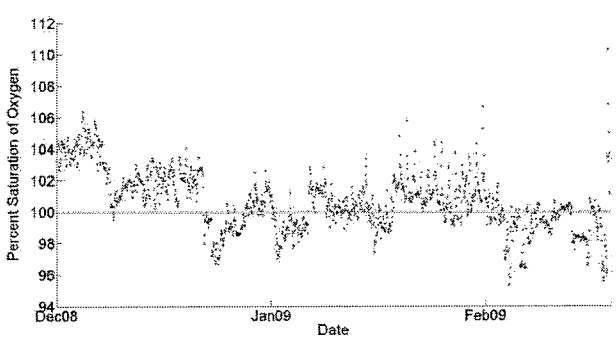


Figure 7. This times series of corrected percent saturation of oxygen is of all winter data (December, January, and February) during the first deployment (start-stop). The average percent saturation during the winter was 100.6% and the 100% saturation line indicated that during these months, the oxygen values were near equilibrium with the atmosphere. This supports the quality of the oxygen data collected towards the end of deployment one.

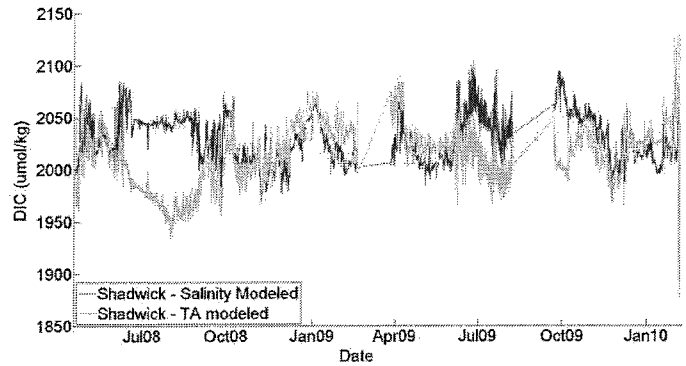


Figure 8. The abiotic DIC (red) shows the DIC modeled after salinity [13]. The DIC (cyan) was calculated from the total alkalinity (modeled from salinity [13]) and $pCO_2$. The difference between the two lines indicates the influences due to biological activity.

at its lowest. Other times of the year, there are large divergences. This is indicative of when biological activity is drawing down large amounts of DIC for primary production. Other divergences occur in the data, but occur relatively quickly. These divergences are typically due to the mixing of water masses.

On a seasonal scale, it is possible to determine the dominating influences on $pCO_2$. The $pCO_2$ data were first normalized to a constant, mean temperature (6.92 °C [1]).

$$pCO_2(T_{mean}) = pCO_{2(obs)}[\exp(0.0423(T_{mean} - T_{obs}))] \quad (5)$$

Multi-year $pCO_2(T_{mean})$ estimates (temperature normalized) were plotted as a function of measured temperature (Fig. 9). All winter data (December, January, and February) were plotted in magenta; spring data (March, April, and May) were plotted in red; summer data (June, July, and August) were plotted in green; fall data (September, October, and November) were plotted in blue. Deviations from the mean atmospheric level of 385 indicate that processes other than solubility control $pCO_2$. The summer (and fall) data show an early linear decrease with temperature through each season. In the summer, temperatures are increasing leading to out-gassing of $CO_2$, but the on-going summer photosynthesis overrides this and decreases the normalized $pCO_2$ in the water column. In the fall, temperatures decrease and $pCO_2$ increases in the water column as respiration rates and ventilation outpace photosynthesis and cooling, hence the normalized $pCO_2$ increases through the fall. In the winter, normalized $pCO_2$ concentrations remain relatively constant. In the spring, a large phytoplankton bloom occurs, which draws down $pCO_2$. As post-bloom recovery occurs, DIC is again resupplied to the water column and $pCO_2$ increases (as interpreted in [1, 17]).

## V. Discrete Measurements

Dalhousie University (DU) collected data along a transect intersecting the Northeast Channel. Data were collected on April 17 and April 18, 2008 at three locations within 0.5° of the buoy at a depth of 4 m. Our quality data starts on April 19,

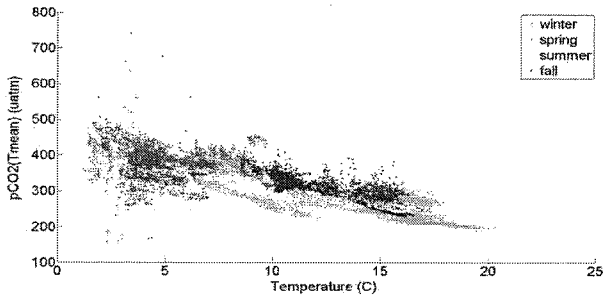


Figure 9. Plot of the $pCO_2$ corrected to a constant annual mean temperature (6.92°C) plotted against in situ temperature (°C). In the winter (magenta) $pCO_2$ values are relatively consistent. In the spring (red), low $pCO_2$ values are due to the phytoplankton bloom, while larger values are due to post-bloom recovery when DIC is resupplied due to respiration and remineralization. In the summer (green), $pCO_2$ is reduced due to on-going photosynthesis and out-gassing driven by warming waters. In the fall (blue) an increase in $pCO_2$ is observed due to decreasing temperatures.

2008, while the data begun collection in March 2008. For the purposes of direct comparison, data from April 17 and 18, 2008 was analyzed. A t-test (JMP 9.0) compares the DU data with the UNH data (Table 1). There was no significant difference found between the temperature, salinity, DIC, or TA data ($p \leq 0.05$). Additional discrete data collected near the site, ranging between 2008 and 2010, will soon be made available to allow improved validation of the mooring data set.

## ACKNOWLEDGEMENT

The authors would like to thank Neil Pettigrew and the Physical Oceanography Group of the University of Maine for deployment and maintenance of Buoy N. Further, the authors would like to thank Cory Beatty of the University of Montana for performing quality checks on the $pCO_2$ data. The authors would also like to thank Helmuth Thomas and Elizabeth Shadwick of Dalhousie University for supplying discrete data for comparison.

TABLE 1. Listing the DIC ($\mu mol \cdot kg^{-1}$) and TA ($\mu mol \cdot kg^{-1}$) calculated by UNH on April 19, 2008 and the discrete DIC ($\mu mol \cdot kg^{-1}$) and TA ($\mu mol \cdot kg^{-1}$) measured by Dalhousie University (DU) on April 17 and April 18, 2008.

| | Date | Location | Temp (°C) | Salinity (psu) | DIC ($\mu mol \cdot kg^{-1}$) | TA ($\mu mol \cdot kg^{-1}$) |
|---|---|---|---|---|---|---|
| UNH | 4/17/2008 | 42.33N, 65.91W | 4.85 | 31.892 | 2035.5 | 2182.7 |
| UNH | 4/17/2008 | 42.33N, 65.91W | 4.82 | 31.960 | 2038.4 | 2185.7 |
| DU | 4/17/2008 | 42.76N, 65.48W | 3.83 | 31.765 | 2055.1 | 2170.3 |
| DU | 4/17/2008 | 42.45N, 65.49W | 2.20 | 31.587 | 1970.6 | 2165.2 |
| UNH | 4/18/2008 | 42.33N, 65.91W | 4.90 | 31.926 | 2036.6 | 2184.2 |
| UNH | 4/18/2008 | 42.33N, 65.91W | 5.03 | 31.919 | 2035.9 | 2183.9 |
| DU | 4/18/2008 | 42.12N, 65.50W | 5.15 | 32.609 | 2062.7 | 2212.0 |

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Finally, the Department of Marine Resources and the Department of Agriculture, Food and Rural Resources entered into a Memorandum of Agreement in 2012 to address methods of coordination between the agencies to ensure the sustainability of both agriculture and shellfish safety. That Memorandum of Agreement is copied below.

# MEMORANDUM OF AGREEMENT

Between

The Maine Department of Agriculture, Food & Rural Resources
&
The Maine Department of Marine Resources

## Purpose of the Agreement

The purpose of this agreement is to ensure appropriate coordination between the Maine Department of Agriculture, Food & Rural Resources (DAFRR) and the Maine Department of Marine Resources (DMR) with respect to conditions or activities on farm land that is suspected to be a potential threat to water quality, and which may impact shellfish resources, based upon observations or water quality data.

This Agreement between the Department of Agriculture, Food and Rural Resources, and the Department of Marine Resources is intended to: (1) enhance the collaborative process between the DMR and the DAFRR; coordinate the review of conditions and activities on farm land to determine whether appropriate agricultural best management practices are being implemented; (2) establish appropriate best management practices for operations which may benefit from the adoption of revised or additional practices; and (3) clarify the roles and responsibilities of the two agencies in regard to responding to complaints or requests for opinions or determinations that affect farmland and shellfish resources in these areas.

## Background

### Department of Agriculture's Responsibilities:

7 MRSA §1 established DAFRR "for the improvement of agriculture and the advancement of the interests of husbandry". To further this mission, the Maine Legislature enacted 7 MRS, Part 1, Chapter 6, §151 - § 158 *The Maine Agriculture Protection Act*. The Maine Agriculture Protection Act provides DAFRR with the authority and responsibility to develop and enforce site specific best management practices for agriculture to protect the State's natural resources and to investigate all complaints about agricultural operations. The DAFRR also investigates complaints of improper manure handling under 17 MRS § 2701-B, and investigates farms for compliance under 7 MRSA Chapter 747 *The Nutrient Management Act*, the 01-001 Chapter 565 *Nutrient Management Rules*, and the 01-001 Chapter 10 *Rules for the Agricultural Compliance Program.*

Department of Marine Resource's Responsibilities:

The DMR Public Health Program's regulatory authority is outlined in 12 MRSA, Part 9, Chapter 607, § 6172 *Contaminated or Polluted Flats*, and also in 13-188 Chapter 23: *Standards for Closure of Contaminated or Polluted Flats.*

Agreements

In order to provide for coordination and cooperation between DAFRR and DMR with respect to their respective roles concerning farming operations and protection of the public health, the DAFRR and DMR agree as follows:

**Investigations, Determinations, Reports:**

1. When a need for a site visit has been identified or a complaint is received by the DMR concerning an existing or proposed farm or farming operation, DMR will contact the DAFRR Agricultural Compliance Supervisor at 287-7708. The Agricultural Compliance Program staff will contact the site owner or operator in a timely manner and make DMR aware of this contact. Requests for inspections may originate from the farm or farm operation, municipal officer, DMR employee, local harvester, or as a written complaint.

2. When a need for a site visit has been identified or a complaint is received by the DAFRR concerning an existing or proposed farm or farming operation that may be a potential threat to water quality and which may impact shellfish resources, the DAFRR shall notify appropriate regional DMR field staff and provide such information as is requested or required for DMR to take steps it determines necessary to protect the public health.

3. DAFRR and DMR staff will evaluate findings of investigations and jointly determine remedies, if required, concerning the situation, and develop written reports reflecting any additional or modified best management practices that have been recommended for adoption. However, this shall not in any way limit or restrict the DMR's authority to close or restrict shellfish harvesting to protect the public health in any areas that have been or may potentially be affected by the farm operations.

4. If additional or modified best management practices have been recommended for adoption, DAFRR staff will monitor the farm or farming operation to determine whether the appropriate practices are being implemented, and will share this information with DMR staff.

5. DMR staff will monitor the water quality in all areas that have been or may be affected by the farm operations, as required, to determine the biological status of these areas, determine whether area closures or restrictions are required, and to determine whether additional investigations or enhanced best management practices are required to attain required standards.

**Signature:**

For the Maine Department of Agriculture, Food and Rural Resources:

_____ _____

Walter E. Whitcomb, Commissioner date

For the Department of Marine Resources:

_____ _____

Pat Keliher, Commissioner date

STATE OF MAINE
DEPARTMENT OF MARINE RESOURCES
21 STATE HOUSE STATION
AUGUSTA, MAINE
04333-0021

PAUL R. LEPAGE
GOVERNOR

PATRICK C. KELIHER
COMMISSIONER

September 8, 2014

TO: Ocean Acidification Commission
FROM: Jon Lewis. DMR, Commission Representative

Re: DMR Programs to address nutrient runoff

The Maine Department of Marine Resources has few programs to address nutrient runoff from rainfall events. Most DMR water quality monitoring programs originate with the Bureau of Public Health and are administered to ensure shellfish sanitation safety and public health. They are designed to be more proactive to shellfish safety than as any ecological monitoring program.

The Water Quality Section of the Bureau of Public Health obtains nearshore water samples to obtain measurements of fecal coliform contamination to open or close waterbodies to the harvest of shellfish. Fecal coliform measurements currently are a poor proxy for establishing estimates of nutrient loading from rainfall runoff from land-based sources. At this time the Bureau of Public Health is unable to provide an analysis of historical trends in open versus closed status of shellfish beds.

The Bureau of Public Health addresses rainfall events with the assumption that rainfall events exceeding 2 inches in 24 hours warrants emergency flood closures due to the generally declining water quality that results from runoff. At some time in the 1990s or early 2000s the threshold of 2" was decreased from the previous limit of 3" of rainfall in 24 hours. These closures are on a case by case basis and vary with the extent of the rainfall events. These emergency rainfall closures are referred to as Area 500 Closures. Any trends in Area 500 closures are not currently available within DMR records although both electronic and paper files exist which would allow for such a trends analysis; albeit with a concerted effort required to review the files.

The DMR Bureau of Public Health also conducts shoreline surveys every 12 years in each growing area and identifies any potential or actual pollution sources. This includes private septic systems, animal waste, wildlife use, recreational use (marinas, beaches, campgrounds) and known point sources (pump stations, waste water treatment plant outfalls, overboard discharges). DMR also conducts stream sampling to evaluate the impact of non-point pollution. These efforts are used to track bacterial pollution as indicated by fecal coliform contamination not nutrient loading from runoff.

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**Overview of State Regulation of Water Quality Impacts Related to Agriculture**

Prepared by the Maine Coastal Program/Maine Department of Agriculture, Conservation and Forestry for the Ocean Acidification Task Force

September 2014

This document provides an elementary overview as general background on state laws that address management of agricultural sources of water pollution. Detailed review of these laws and potentially others would be needed to assess how they may apply in a specific situation.

Water pollution issues associated with agriculture are for the most part attributable to non-point sources, such as runoff from manure piles, cultivated areas, and farm yards. State efforts to manage agricultural non-point sources focus on implementation of "best management practices" (BMPs). The state non-point source pollution control program directs DACF to develop BMPs for agricultural activities. *See* 38 M.R.S. §410-J(1); http://www.mainelegislature.org/legis/statutes/38/title38sec410-J.html; and http://www.maine.gov/dacf/php/nutrient_management/documents/BMP-Manual-Final-January-2007.pdf (BMP manual for agriculture). DACF works with farmers to encourage use of BMPs to prevent and address water pollution problems. DACF also develops Compost Management Plans for farm operations as requested by the farmer. DACF works collaboratively with DEP and DMR to address agricultural runoff that impacts shellfish growing areas.[1]

The Nutrient Management Act, 7 MRS §4201, *et seq.* ; http://www.mainelegislature.org/legis/statutes/7/title7sec4201.html addresses water pollution issues associated with manure storage and use. 7 M.R.S. §4204 details which farm operations are required to adopt a nutrient management plan and the basic requirements for such a plan. In essence, the law directs certain farm operations to develop and implement a best management practices-based plan to manage manure storage and utilization. A nutrient management plan covered by the law is confidential and not subject to disclosure under Maine's public records law. 7 M.R.S. §4204(10). DACF has adopted rules, CMR 01-001, ch. 565, to implement the Act.

In addition, state law (38 M.R.S. §417-A; http://www.mainelegislature.org/legis/statutes/38/title38sec417-A.html ) expressly prohibits spreading of manure on frozen ground within a great pond watershed unless it is done in accordance with a conservation plan for the land that is filed with a state soil and water conservation district. Penalties were not established for non-compliance. Maine's 16 Soil and Water Conservation Districts (SWCD) function as elements of state government although they are staffed and run by private parties. Regarding forestry and agricultural activities, SWCDs provide technical assistance and public education programs in the communities they serve and address locally significant conservation issues[2].

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[1] The Ocean Acidification Commission requested and was provided a copy of an MOU that formalizes collaboration between DACF and DMR concerning shellfish growing areas.

[2] Some SWCDs also work extensively with municipalities providing certifications in erosion control for contractors , erosion control inspections, third-party inspections for development projects, shoreline surveys, watershed resource assessments, permit consultation, and offer adult and student education programs.

The commissioner of DACF has general authority to investigate any farm operation, method, or practice regarding animal waste to determine if it may be having an adverse effect on state waters. *See* 7 M.R.S. §17; http://www.mainelegislature.org/legis/statutes/7/title7sec17.html. More specifically, DACF is responsible for investigation of complaints regarding manure handling and, under certain circumstances where BMPs are not adopted to abate water pollution or other nuisance-related problems as directed by DACF, for referral of matters to DEP and the Attorney General for enforcement. *See* 17 M.R.S. §2701-B; http://www.mainelegislature.org/legis/statutes/17/title17sec2701-B.pdf. DACF has enacted rules, CMR 01-001, ch. 10, that detail this complaint response program which involves coordination with DEP. http://www.maine.gov/dacf/php/ag_compliance/index.shtml (link to rules is on this website which has other information about relevant DACF programs). DACF has also adopted rules (CMR 01-001, ch. 211) for the disposal of animal carcasses that serve in part to protect water quality.

The Nutrient Management Act establishes a Nutrient Management Board which is comprised of state agency and gubernatorially-appointed members and hears appeals of DACF's enforcement-related actions under the law. The Board must review and approve any changes to the Act's implementing rules. *See* 7 M.R.S. §4203.

Maine has delegated authority under the federal Clean Water Act to issue National Pollution Discharge Elimination System (NPDES) permits (called MEPDES in Maine) to authorize point source discharges. In consultation with DACF, DEP regulates large livestock operations that meet the definition of a "concentrated animal feeding operation" (CAFO) as a point source which may need to obtain a Maine Pollutant Discharge Elimination System permit (waste water discharge license). CAFOS without a discharge are not required to obtain a MEPDEP permit. *See* CMR 06-096, ch. 521, §6. Such a permit addresses requirements under pertinent state waste water discharge and water quality laws as well as those of the NPDES program. DEP staff estimates that there are about seven DEP-licensed CAFOs in Maine. CAFOs and certain other large livestock operations are also required to obtain a livestock operations permit from DACF. CMR 01-001, ch. 565, §7.

The state Right to Farm law, 7 M.R.S. §151, *et seq.* http://www.mainelegislature.org/legis/statutes/7/title7ch6sec0.html partially preempts municipal land use regulation of farming activities: "A method of operation used by a farm or farm operation located in an area where agricultural activities are permitted may not be considered a violation of a municipal ordinance if the method of operation constitutes best management practices ...." 7 M.R.S. §154. The law also provides farmers that use BMPs a shield against private and public nuisance law suits. 7 M.R.S. §156. The law establishes a complaint response program with DACF as the lead agency responding to, investigating, and as needed identifying and requiring adoption of best practices needed to abate water pollution or other problems. If a farm operation fails to adopt

BMPs required under this process, the Attorney General may initiate legal action to address the problem. 7 M.R.S. §158.

Contacts for additional information:

- Mark Hedrich; Mark.Hedrich@maine.gov ; 287-7608 (DACF's nutrient management activities)
- Brian Kavanah; Brian.W.Kavanah@maine.gov ; 287-7700 (DEP's compliance and enforcement-related work on agriculture-related issues)

Links to information regarding DACF's nutrient management-related programs

- DACF Nutrient Management Homepage -- http://www.maine.gov/dacf/php/nutrient_management/index.shtml

- Links to Agricultural compliance and nutrient management statutes and rules -- http://www.maine.gov/dacf/php/nutrient_management/statutes_rules.shtml

- Manual of Best Management Practices (BMPs) for agriculture in Maine -- (PDF, 749KB) or (Word) – 2007

- Brochures -- *Nutrient Management Plans* (PDF, 53MB); *Livestock Operations Permits* (PDF, 6.5MB); *The Maine Agricultural Compliance Program* (PDF, 44MB)

- Maine Soil and Water Conservation Districts (SWCDs) -- http://www.maine.gov/dacf/about/commissioners/soil_water/index.shtml

- Notification Form -- Notification to the Department Regarding Nutrient Management Plan Development or Update by a Certified Planning Specialist (Word)

- Variance Requests -- Request for Variance from Nutrient Management Plan Development and/or Implementation Deadlines (Word); and Request for Variance from the Winter Manure Spreading Ban (Word)

# Ocean Acidification – Regulatory Overview (MDEP)

This document provides basic summary of Federal/State laws that interface with water pollution (e.g., ocean acidification) as administered by the MDEP. Detailed review of these laws and potentially others would be needed to assess how they may apply in a specific situation.

## The Federal Clean Water Act and Maine Water Pollution Control Programs

The objective of the Federal Clean Water Act is to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" (33 USC Section 1251 (a) (1)). In the interim, the act strives to protect and propagate "fish, shellfish, and wildlife" and provide for "recreation in and on the water" (33 USC Section 1251 (a) (2)).

The Maine legislature intended that water resources be protected to: promote general welfare, prevent disease, promote health, provide habitat for fish, shellfish, and wildlife, provide recreational opportunities, and be used as a resource for commerce and industry (38 MRSA section 464 (1)). Moreover, the Maine legislature intends for water quality to be sufficient to protect and propagate fish, shellfish and wildlife and to provide for recreation in and on the water. (38 MRSA section 464 (1) (c)).

MDEP administers the Clean Water Act and the requirements of the Maine legislature. Maine has delegation from the US EPA to administer the program and it has incorporated some Maine specific requirements into this program (also approved by EPA). This means that at this time MDEP covers permitting programs, monitoring programs, and other water related programs throughout the state of Maine.

### *Setting Water Quality Standards*

MDEP has established classifications for Maine waters. Any authorized discharge in Maine must ensure that the water body retains its current classification (or improves) pursuant to 38 MRSA Chapter 464. It should be noted that the Maine includes groundwater in state water classifications (this goes beyond what is required at the Federal level).

In order to know how pollutants impact a water body, research and monitoring must take place. MDEP staff research the health of lakes, streams, rivers, estuaries, and marine habitats to understand impacts of water quality (both good and bad). To best protect "healthy" bodies of water, or to keep them from losing current classification, limitations need to be established to prevent any discharges that might make the body of water "less" healthy. To restore already "impaired" waterways, further limitations need to be established in the attempt to restore the water body until it is no longer impaired.

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Authorized discharges are designated in permits or licenses (see below). In order to determine how much of any pollutant can be discharged into Maine waters (or ground waters), research must be done to understand how much pollution the water body can handle. The following are some of the mechanisms to set limits through the permitting process:

- Technology based limitations: use of specific treatment technologies to reduce pollution at the source.
- Water quality based limitations: parameters that a facility must demonstrate they meet after discharge (e.g. by testing at the outfall/end of pipe):
    - Chemical specific based limitations (measuring chemical parameters)
    - Toxicity (whole effluent toxicity – WET) testing (measuring impacts on a key biological indicator to understand impacts from effluent)
    - Biological criteria assessments (assessing number and diversity of species)
    - Nutrient criteria (Total phosphorus and Nitrogen)

Technology based limitations are established by the EPA and MDEP for industrial categories through the rulemaking process. Industries must use the Best practical/available/demonstrated control technology currently available. Where a specific industrial category is not in place – permit writers must use their "best professional" judgment so long as it is not less stringent than something already in existence.

Specific criteria, or "water quality standards" are set by first using criteria already developed/recommended by the US EPA, but also by specific information provided by MDEP staff (based on research and monitoring) to best protect waters in Maine to meet the classification for Maine's waters. These criteria must be approved by the US EPA in order to be in effect. Information about how Maine water quality standards are developed and set is available at the MDEP website.

***Permitting and other licensing***

Permits are required when a pollutant is discharged to waters of the US. Permits allow for some pollutants to be discharged at set limits at set locations (outfalls) for a five year period of time. Without a permit – discharges of pollutants are prohibited. Within a permit are the maximum amount of pollutant that can be discharged, or effluent limitations, but also may be requirements for technology operational procedures, reporting, and inspections. The MDEP (and EPA) reserve the right to inspect a facility to ensure compliance.

There are different types of permits that MDEP administers per 38 MRSA Section 413:

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- Permits for point source discharges (this includes permits for wastewater discharges, manufacturing and industry, aquaculture, etc. Note that point sources related to land farming and agriculture are typically administered by the Department of Agriculture Conservation and Forestry, DACF).
- Permits for non-point source discharges (this includes storm water management) – these are different than land permits issued under the site location of development law (below). Storm water permits are typically required for certain activities including: construction activities, industrial activities, and in locations meeting the criteria for an MS4 (municipal separate storm sewer systems).

Both the EPA and MDEP have information to help a facility understand when it needs to obtain and/or be covered by a permit. MDEP provides information on its website about storm water permitting programs and waste discharge permit programs.

Licenses are required for overboard discharges (these are residential wastewater systems that are not tied to a city sewer or designed subsurface leach field system – e.g., the discharge goes to surface water). And in some cases, Class V underground injection wells may also require a license (most just require registration with the MDEP).

A water quality certification is required for any dam/hydropower system project in Maine. While the bulk of the process for licensing a dam/hydropower system rests with the Federal Energy Regulatory Commission (FERC); Section 401 of the Clean Water Act gives the MDEP independent authority to issue a water quality certification to ensure that the project meets state requirements. Typically the terms and conditions of the state water quality certification are included as part of the FERC dam/hydropower system license.

***Spill Prevention and Response***

Part of the intent of both Federal and state water protection programs is to prevent direct discharges through spill prevention programming and through spill mitigation (e.g., responding quickly to discharges).

The Federal Clean Water Act requires that certain facilities develop a Spill Prevention Control and Countermeasure Plan (SPCC). This program is a non-delegated program, meaning that it is administered by the EPA and not Maine. This program only applies to the potential for oil-related spills and only certain facilities.

In Maine, another plan also called a SPCC plan pertains only to "hazardous matter". This plan is voluntary but basically allows a facility storing any of over 400 substances to only notify the DEP in the event of a spill (instead of also the state police) and only over certain reportable quantities. This also allows a facility to have a better handle on its materials which could spill impacting the environment (and potentially impacting water quality).

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MDEP has a comprehensive Spill Response program that includes a statewide hazmat response team that manages spills throughout the state. Responders cover all materials including oil and hazardous matter, and work in conjunction with local hazmat teams, firemen, police, US Coast Guard and the US EPA on spills. MDEP maintains historical information about spills throughout the state.

## Federal Clean Air Act/ State Air Pollution Control Program

38 MRSA Section 575 and 576 required the reduction of GHG emissions within the State, in the short term, to 1990 levels by January 1, 2010; to 10% less than 1990 levels by 2020; and to eliminate any dangerous threat to climate in the long-term. Data on meeting these goals are reported to the legislature – the most recent report was provided to the 126th legislature *Fifth Biennial Report on Progress toward Greenhouse Gas Reduction Goals*, January 2014. MDEP maintains an annual GHG emissions inventory.

Maine is a member of the Regional Greenhouse Gas Initiative (RGGI), a cooperative effort by nine Northeast and Mid-Atlantic states to limit greenhouse gas emissions. RGGI is the first mandatory, market-based CO2 emissions reduction program in the United States.

Air emission sources throughout the state may need to obtain a license from the department. Maine has had an existing licensing program in place since the early 1970's for the licensing of major and minor sources of air pollution. In the Clean Air Act Amendments of 1990, licensing was mandated for major sources. Maine has been given the authority over this program in 38 M.R.S.A. Section 344 and 590 and requires Best Available Control Technology (BACT) for projects that exceed specified CO2 thresholds.

## Maine's Land Programs

MDEP is responsible for licensing, enforcement and oversight of various land development activities. This includes review of developments that may have a substantial effect upon the environment, and includes developing management programs and establishing environmental standards to prevent the degradation of, and encourage the enhancement of, Maine's natural resources. Most of these programs/laws relate to Ocean Acidification in that the activities regulated indirectly or even directly may impact water quality. Many of these programs also operate under dual LUPC jurisdiction (on lands that fall under the LUPC's purview).

### *Site Location of Development Act*

The Site Location of Development Act, 38 MRSA Section 481, requires review of developments that may have a substantial effect upon the environment. These types of development have been identified by the Legislature, and include developments such as projects occupying more than 20 acres, large structures and subdivisions, and oil terminal facilities. A permit is issued if the project meets applicable standards addressing areas such as storm water management, groundwater protection, infrastructure, wildlife and fisheries, noise, and unusual natural areas. Specific

provisions governing storm water under the site location law at 38 MRSA Section 420-D may differ from the Federal storm water program (identified above).

***Natural Resources Protection Act***

Under the Natural Resources Protection Act (NRPA), 38 MRSA Sections 480-A through 480-Z, A permit is required when an "activity" will be: located in, on or over any protected natural resource. Protected natural resources are coastal sand dune systems, coastal wetlands, significant wildlife habitat, fragile mountain areas, freshwater wetlands, great ponds and rivers, streams or brooks. An "activity" is (A) dredging, bulldozing, removing or displacing soil, sand, vegetation or other materials; (B) draining or otherwise dewatering; (C) filling, including adding sand or other material to a sand dune; or (D) any construction, repair or alteration of any permanent structure.

***Erosion and Sedimentation Control Law***

A person who conducts an activity involving filling, displacing or exposing earthen materials must take measures to prevent unreasonable erosion of soil or sediment beyond the project site or into a protected natural resource per 38 MRSA Section 420-C. Erosion control measures must be in place before an activity begins, and remain in place and functional until the site is permanently stabilized. No permit is required. Agricultural fields are exempt, and forest management activities conducted in accordance with Maine Land Use Planning Commission standards are deemed to comply.

***Mandatory Shoreland Zoning Act***

The purpose of the Mandatory Shoreland Zoning Act, 38 MRSA Section 436-436 is to: to further the maintenance of safe and healthful conditions; to prevent and control water pollution; to protect fish spawning grounds, aquatic life, bird and other wildlife habitat; to protect buildings and lands from flooding and accelerated erosion; to protect archaeological and historic resources; to protect commercial fishing and maritime industries; to protect freshwater and coastal wetlands; to control building sites, placement of structures and land uses; to conserve shore cover, and visual as well as actual points of access to inland and coastal waters; to conserve natural beauty and open space; and to anticipate and respond to the impacts of development in shoreland areas.

This act requires municipalities to adopt, administer, and enforce local ordinances that regulate land use activities in the shoreland zone. The shoreland zone is comprised of all land areas within 250 feet, horizontal distance, of the

- normal high-water line of any great pond or river;
- upland edge of a coastal wetland, including all areas affected by tidal action, and

- upland edge of defined freshwater wetlands; and
- all land areas within 75 feet, horizontal distance, of the normal high-water line of certain streams.

Shoreland Zoning Staff at the MDEP assist municipalities with shoreland zoning related questions and issues, as well as provide technical assistance and training on the shoreland zoning rules. DEP staff work closely with municipalities on ensuring this program is properly administered.

## Waste Programs in Maine

### *Materials Management*

The term 'materials management' refers to the life cycle management of materials and products as they trace their course through the economy, from raw material extraction to product manufacture, transport, use, source reduction, reuse, recycling and disposal. By reducing the amount of materials required in manufacturing, and capturing/diverting those materials from disposal, the demand for natural resources is lessened. Maine's Solid Waste Hierarchy prioritizes reducing, reusing and recycling and puts landfilling last. Beneficial use, which is the reuse of materials and consistent with Maine's solid waste hierarchy, offers economic opportunities and reduces GHG emissions. ***EPA estimates that forty percent of U.S. greenhouse gas (GHG) emissions are linked to use of material goods and their disposal.***

When preferred options in the solid waste hierarchy are not available, MDEP regulates the siting, design, and operation of landfills. This includes landfills for the disposal of municipal solid waste, special wastes, construction/demolition debris, land clearing debris, and wood wastes as well as for any special hazardous materials storage areas. Storage structures must be designed to withstand the stresses due to dynamic and static loading conditions and the effects of climatic changes expected over the life of the landfill. The Department helps prepare to manage surges of wastes that can be caused by severe storm events by reviewing the design and location when licensing chemical storage, hazardous and solid waste storage areas to prevent off-site transfer of contaminants. Proper treatment, storage, and disposal of hazardous waste protect the environment from harmful contamination. MDEP supports prevention by activities such as permitting and inspections.

MDEP also regulates composting and beneficial use programs as alternatives to landfilling waste. Similar to landfills, MDEP must review the siting, design and operation of these facilities to ensure that both ground water and surface water are minimally impacted.

## Maine's Remediation and Cleanup Programs

The Department oversees several programs to clean up contaminated properties.

***Uncontrolled/Abandoned Sites Programs***

The Uncontrolled Hazardous Substance Sites Program (Uncontrolled Sites Program) and Federal Superfund Program were created to respond to threats to human health and the environment posed primarily by abandoned hazardous waste sites. In Maine, hazardous substance includes hazardous matter, hazardous waste, toxic pollutants, hazardous air pollutants, any substance listed by the United States Toxic Substance Control Act, Section 7, and waste oil (this is a bit broader than the federal law). If it is concluded by the MDEP that a site poses a threat or hazard to the public health, safety or welfare of any person or to the natural environment, action(s) will be necessary to abate, clean up or mitigate the threat of hazard.

***Voluntary Remediation Action Program (VRAP)***

The VRAP, per 38 MRSA Section 342 and 343 allows applicants to voluntarily investigate and cleanup properties to the Department's satisfaction, in exchange for protections from Department enforcement actions. The VRAP is intended to encourage the cleanup and redevelopment of contaminated properties within the state.

DRAFT

September 9, 2014

To: Ocean Acidification Commission:
From: Jon Lewis, DMR

Among the many concepts to be discussed regarding localized remediation of ocean acidification during the next Commission meeting, I would like to add one more to the list for further investigation.

Background:
Upon hearing of shells dissolving in an acidic and electrolytic medium my thoughts turned to boats where dissimilar metals can disintegrate in the absence of a sacrificial anode. In boats, sacrificial anodes (typically zinc) are used to "give up electrons" in lieu of the protected material (cathode) giving up the electrons to the electrolytic solution (seawater). This may not be at all relevant as a sacrificial anode material with a greater electrical potential than calcium carbonate (cathode) has not been explored.

However:
Upon doing some investigating, I learned two things. In any anode/cathode system two things occur; 1) the pH in the area of the cathode is raised through the electrochemical process, and 2) this rise in pH tends to cause precipitation of calcium carbonate out of solution (as seen in carbonate scaling in water distribution piping that is cathodically protected) with subsequent deposition onto the cathode.

Removing growing shellfish from the idea of an anode/cathode process and merely placing them in proximity to such a process may have some merit. While the applicability of such a galvanic process will be too small in area to affect large bodies of water, it MAY have some application to very local areas such as shellfish bags, mussel rafts and perhaps localized mudflats and shellfish beds. A small anode/cathode system could be developed for localized deployment..

Validation;
I have briefly contacted three chemists to inquire about the feasibility of such a system on a localized area: Dr. John French, University of Alaska, Dept. of Chemistry (retired), Dr. Homero Castaneda-Lopez, University of Akron, Dept. of Corrosion Engineering, and Dr. Peter van Walsum, University of Maine, Dept. of Chemical and Biological Engineering. Each of these three thought the concept was worthy of additional exploration and each thought that a passive system without external voltage supply (instead of additional DC voltage driving the process) was possible.

From here:
I make no claims to the efficacy of such a system. I do think it may be worth some additional work by those whose expertise this more closely fits to determine if a localized increase in pH and calcium carbonate precipitation through a system of anodes and cathodes is a viable remediation method.

**Table 1.** Number of studies investigating organismal responses of Maine commercially important species to increased $p\,CO_2$ conditions. The number of studies are broken dov
total number of studies may not equal the sum of studies for all life stages or the sum of the references listed because some studies consider multiple life stages and some refe

| | Common Name *Scientific Name* | 2013 Landings Value ($) | Geography of Habitat | Life Stage: Reproduction/ Fertilization/ Eggs | Larvae | Juveniles | Adults | Total Studies |
|---|---|---|---|---|---|---|---|---|
| 4 | American lobster *Homarus americanus* | 378,736,030 | | 0 | 1 | 1 | 0 | 2 |
| 5 | Elvers (American eel) *Anguilla rostrata* | 32,926,991 | | 0 | 0 | 0 | 0 | 0 |
| 6 | Soft shell clam *Mya arenaria* | 16,915,005 | | 0 | 0 | 3 | 1 | 4 |
| 7 | Atlantic Herring *Clupea harengus* | 15,391,192 | | 2 | 2 | 0 | 0 | 2 |
| 8 | **Total Groundfish** | **7,626,795** | | | | | | |
| 9 | Pollock *Pollachius virens* | 2,560,807 | | 0 | 0 | 0 | 0 | 0 |
| 10 | White hake *Urophycis tenuis* | 1,477,447 | | 0 | 0 | 0 | 0 | 0 |
| 11 | Atlantic (Baltic) cod *Gadus morhua* | 736,154 | | 2 | 4 | 3 | 0 | 8 |
| 12 | Monkfish *Lophius americanus* | 726,130 | | 0 | 0 | 0 | 0 | 0 |
| 13 | Plaice *Hippoglossoides platessoides* | 779,015 | | 0 | 0 | 0 | 0 | 0 |
| 14 | Witch flounder *Glyptocephalus cynoglossus* | 576,799 | | 0 | 0 | 0 | 0 | 0 |
| 15 | Atlantic halibut *Hippoglossus hippoglossus* | 328,587 | | 0 | 0 | 2 | 0 | 2 |
| 16 | Haddock *Melanogrammus aeglefinus* | 211,279 | | 0 | 0 | 0 | 0 | 0 |
| 17 | Acadian redfish *Sebastes fasciatus* | 170,134 | | 0 | 0 | 0 | 0 | 0 |
| 18 | Cusk *Brosme brosme* | 17,618 | | 0 | 0 | 0 | 0 | 0 |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 19 | | Winter flounder *Pseudopleuronectes americanus* | Not enough data to report | | 0 | 0 | 0 | 0 | 0 |
| 20 | | Yellowtail flounder *Limanda ferruginea* | Not enough data to report | | 0 | 0 | 0 | 0 | 0 |
| 21 | | Bloodworm *Glycera* | 5,627,577 | | 0 | 0 | 0 | 0 | 0 |
| 22 | | Green sea urchin *Strongylocentrotus droebachiensis* | 5,291,790 | | 1 | 4 | 2 | 6 | 11 |
| 23 | | Sea scallop | 5,194,553 | | 0 | 0 | 0 | 0 | 0 |
| 24 | | Eastern oyster *Crassostrea virginica* | 2,415,764* *Landings value represents *C. virginica* and *Ostrea edulis* . Only *C. virginica* has been studied with respect to ocean acidification. | | 0 | 2 | 4 | 8 | 13 |
| 25 | | Blue mussel *Mytilus edulis* | 2,340,965 | | 1 | 0 | 1 | 13 | 14 |
| 26 | | Mahogany quahog *Arctica islandica* | 1,378,491 | | 0 | 0 | 0 | 2 | 2 |
| 27 | | Sand worm | 1,372,283 | | 0 | 0 | 0 | 1 | 1 |
| 28 | | Northern shrimp *Pandalus borealis* | 1,008,766 | | 1 | 2 | 0 | 1 | 3 |
| 29 | | Common periwinkle *Littorina littorea* | 869,083 | | 0 | 0 | 0 | 4 | 4 |

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 30 | | Hard clam *Mercenaria mercenaria* | 502,004 | | 0 | 3 | 6 | 6 | 15 |
| 31 | | **Total Macroalgae** | **464,728** | | | | | | |
| 32 | | Rockweed *Ascophyllum nodosum* | | | 0 | N/A | N/A | 1 | 1 |
| 33 | | Sugar kelp *Saccharina latissima* (formerly *Laminaria saccharina* ) | | | 1 | N/A | N/A | 2 | 2 |
| 34 | | Nori *Porphyra umbilicus* | | | 0 | N/A | N/A | 0 | 0 |
| 35 | | Dulse *Palmaria palmata* | | | 0 | N/A | N/A | 0 | 0 |
| 36 | | Sea cucumbers | 288,541 | | 0 | 0 | 0 | 0 | 0 |
| 37 | | Surf clam *Spisula solidissima* | Not enough data to report | | 0 | 0 | 0 | 0 | 0 |
| 38 | | Symbol explanations | | | | | | | |
| 39 | | ↑ (significant positive response to increased *p* $CO_2$) | | | | | | | |
| 40 | | ↓ (significant negative response to increased *p* $CO_2$) | | | | | | | |
| 41 | | ↔ (no significant response to increased *p* $CO_2$) | | | | | | | |
| 42 | | | | | | | | | |
| 43 | | Please Note: This table was assembled for the Northeast Coastal Acidification Network (NECAN) by Allison Candelmo, Chris Chambers, Chris Gobler, Andrew King, Nichole Price, Rick Wahle, Jesica Waller, and Meredith White. | | | | | | | |
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**Table 1.** Number of studies investigating organismal responses of Maine commercially important species to increased $p\,CO_2$ conditions. The number of studies are broken down into the distinct life stages of the organisms. The total number of studies may not equal the sum of studies for all life stages or the sum of the references listed because some studies consider multiple life stages and some references include multiple studies.

| | | | Life Stage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Common Name** ***Scientific Name*** | **2013 Landings Value ($)** | **Geography of Habitat** | **Reproduction/ Fertilization/ Eggs** | **Larvae** | **Juveniles** | **Adults** | **Total Studies** | **Comments** | **Reference** |
| European lobster *Homarus gammarus** (Maine Congener: American lobster, *Homarus americanus* ) | | | 1 | 2 | 1 | 0 | 2 | | Agnalt et al. 2013, Arnold et al. 2009 |
| Green crab *Carcinus maenas* | | | 0 | 0 | 0 | 3 | 3 | | Appelhans et al. 2012, Fehsenfeld et al. 2011, Landes & Zimmer 2013 |
| Dungeness crab *Cancer magister** (Maine Congers: Jonah crab *Cancer borealis* and Rock crab *Cancer irroratus* ) | | | 0 | 0 | 0 | 1 | 1 | Temperature: 10 °C | Pane & Berry 2007 |
| Edible crab *Cancer pagurus* * (Maine Congers: Jonah crab *Cancer borealis* and Rock crab *Cancer irroratus* ) | We should move this over to commercially important species- crabs (Jonah- Cancer borealis- are becoming big business in S. NE and may be soon in ME)- $672,373 (combo of crabs) | | 0 | 0 | 0 | 1 | 1 | Temperatures: 10-22 °C | Metzger et al. 2007 |
| Summer flounder *Paralichthys* | | | | 1 | 2 | 0 | 0 | 2 | Chambers et al. 2014 |
| Bay scallop *Argopecten irradians* * (Maine Congener: Sea scallop *Placopecten magellanicus* ) | | | | 0 | 7 | 2 | 1 | 8 | Gobler & Talmage 2013, Gobler et al. 2014, Ries et al. 2009, Talmage & Gobler 2009, Talmage & Gobler 2010, Talmage & Gobler 2011, White et al. 2013, White et al. 2014 |
| Nori *Porphyra haitanensis* * (Maine Congener: *Porphyra umbilics* ) | | | | 0 N/A | N/A | | 1 | 1 | Liu et al. 2013 |
| Nori *Porphyra linearis* (Maine Congener: *Porphyra umbilicus* ) | | | | 0 N/A | N/A | | 1 | 1 | Israel et al. 1999 |
| Nori *Porphyra leucosticta* (Maine Congener: *Porphyra umbilicus* ) | | | | 0 N/A | N/A | | 1 | 1 | Mercado 1998 |

Symbol explanations
↑ (significant positive response to increased $p\,CO_2$)
↓ (significant negative response to increased $p\,CO_2$)
↔ (no significant response to increased $p\,CO_2$)
* This species does not live in Maine, but is related to a Maine species.

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