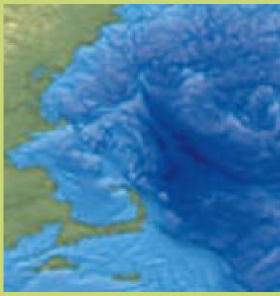
Workshop Report

2001: Managing Nitrogen Impacts in the Gulf of Maine

Prepared by the NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), the Gulf of Maine Council on the Marine Environment, and NOAA's National Ocean Service



Workshop Report

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Introduction

The following document describes the results of a workshop held November 28-29, 2001 in Portsmouth, NH. The purpose of the workshop was to review issues related to the management of nitrogen contamination and its impacts in the Gulf of Maine and the surrounding estuaries and embayments.

The workshop was the result of two separate initiatives. The Gulf of Maine Council on the Marine Environment (see Appendix 5), which includes representation from NOAA's National Ocean Service, identified impacts related to nitrogen loading to the waters of the Gulf and its embayments as significant and warranting action. Consequently, the Council sought more detailed information about the status and impacts of nitrogen loading and recommendations for Gulf-wide nitrogen management strategies. These would be considered as part of the Council's current 5-year Action Plan.

The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) (see Appendix 5), located at the University of New Hampshire, sought to identify current technologies for monitoring nitrogen levels and impacts and assess the need for new technologies.

Consequently, 50+ participants gathered in Portsmouth, New Hampshire to help provide further insight into these issues. Each participant was provided background information in the form of three white papers (see Appendix 2), descriptions of the goals and desired outcomes from the workshop (see Section 2), and draft topics for discussion (see Appendix 4). Three speakers provided information on:

1. The current status of knowledge of nitrogen inputs and impacts in the Gulf of Maine itself,
2. Nitrogen management in "rural" embayments around Buzzards Bay (MA), and
3. Nitrogen management in "urbanized" embayments around Long Island Sound (NY/CT).

Three break-out groups, working in parallel, addressed each of the following topic areas:

- The status of knowledge about nitrogen impacts in the embayments around the Gulf of Maine,
- Technological approaches to nitrogen management, and
- Nitrogen management options available at the watershed (local and state) level.

The break-out sessions reported out summaries of their discussions, followed by a general review and prioritization of the items proposed. Recommendations for action were forwarded to the Gulf of Maine Council and to CICEET.

The Workshop

Overall Intent

An overall focus of the workshop was to "be a regional workshop of experts to look at the state of science and management actions needed to address issues related to nitrogen inputs and impacts in the Gulf of Maine in support of the Gulf of Maine Council's Action Plan."

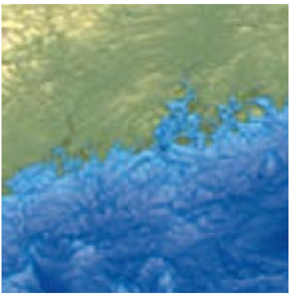
Workshop Objectives

- Identify sources and estimate loads of nitrogen to estuaries surrounding the Gulf of Maine.

- Assess the susceptibility of Gulf of Maine estuaries to eutrophication due to nitrogen loading.

- Examine the effectiveness, costs, and benefits of possible management actions.

- Identify new technologies that have the potential to address nitrogen-related issues in the Gulf of Maine.



Desired Outcomes

- A series of prioritized recommendations for consideration by the Gulf of Maine Council in finalizing the Nitrogen Contaminants section of the next five-year Action Plan.

- A recommended methodology for assessment of the susceptibility of a particular estuary (or estuarine type) to eutrophication caused by nitrogen inputs.

- Out of the workshop activities, a compilation of research topics to improve understanding of nutrient dynamics and impacts in the Gulf of Maine and its estuaries.

- An articulation of what management tools are currently available and, where possible, estimates of the social, economic, and ecological impacts of their use as an aid in making decisions.

Discussion Topics

Workshop discussions were designed to address the following topics:

- Nutrient Assessment, Monitoring, and Prediction
- Nutrient Control Strategies
- Policy and Implementation

These discussions led to a series of prioritized recommendations for consideration by the Gulf of Maine Council. The most highly ranked of these are provided on the following pages.

Recommendations to the Gulf of Maine Council

The workshop resulted in the following recommendations, subsequently forwarded to the Gulf of Maine Council for appropriate action.

Recommendations Implicit in all of the following recommendations is that, wherever possible, efforts should take advantage of existing knowledge and information.

Nutrient Assessment, Monitoring, and Prediction

The Gulf of Maine Council Should:

1. **Support** the immediate development and application of a classification system for embayments around the Gulf in order to determine their susceptibility to eutrophication. A rapid characterization can be done within several months for many embayments by examining load, residence time, and present and projected population in the adjacent watershed. Habitat types may prove to be another important characteristic. This effort will utilize existing reports (*e.g.*, Sowles and Kelley, Bricker *et al.*) and ongoing efforts (*e.g.*, the program beginning in southeastern Massachusetts by that state's Department of Environmental Protection and the University of Massachusetts Dartmouth through Dr. Brian Howes) as starting points and extend the application of the classification system to other embayments in the Gulf of Maine including those in Canada.

2. **Support** the further characterization of embayments already identified as impaired or susceptible utilizing such parameters as loadings of nutrients, residence time of waters in the embayments, and human populations in adjacent watersheds to verify the "impaired" or "susceptible" classification.

3. **Support** the application of the classification system to other embayments in the Gulf of Maine—in both Canadian and US waters. This effort will identify other embayments that may be already impaired or at risk.

4. **Support** the development of a suite of indicators of eutrophication impacts appropriate to each class of embayments—with particular emphasis on those that may provide an "early warning system". Indicators must clearly demonstrate impairment due to nutrients. This effort should be done in conjunction with Item 2 above.

5. **Advocate** the use of an iterative process to refine the indicators as well as the modeling and monitoring strategies. The Gulf of Maine Council may serve as a referral service in this process.

6. **Support** the dissemination of information developed as part of the characterization and assessment process through two steps, 1) development of an easily understood fact sheet of impaired, susceptible, and non-impaired estuaries around the Gulf of Maine and 2) coordination of a workshop of state and local officials, NGOs, and outreach organizations to help familiarize the region with impairment likelihood and to solicit their support for further outreach and local discussion.

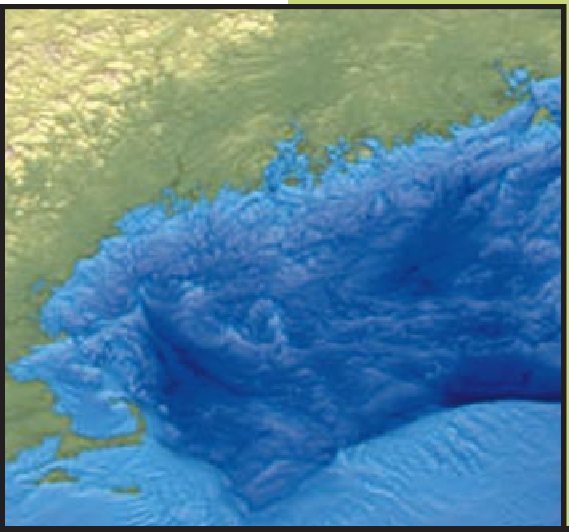
7. **Advocate** the use of the classification system to municipalities, provinces, and states as a screening tool.

8. **Establish** a Monitoring Coordinator position to facilitate interactions between various monitoring efforts in the Gulf of Maine and to nurture citizen-based monitoring efforts. Workshop participants felt this person would play an important role in facilitating and integrating monitoring data into the development of indicators, monitoring, and modeling strategies.

9. **Support** the development of a comprehensive Gulf-wide plan for monitoring nutrient loading into embayment waters from point source and riverine discharges. Point sources include such things as municipal wastewater treatment plants, fish processing plants, pulp and paper mills, and aquaculture facilities. Such monitoring could be done in the US portion of the Gulf through the NPDES permitting process.

   There is currently very little routine nutrient monitoring being conducted in tributaries to the Gulf of Maine that would provide good annual or seasonal loadings of nutrients to coastal waters. As such, accurately determining amounts of nutrients discharged to coastal waters and whether these loadings are changing with time is not possible.

10. **Support** research efforts to define nutrient impacts from aquaculture.



Nutrient Control Strategies

The Gulf of Maine Council Should:

1. **Advocate** resolution of known nutrient contamination problems (especially municipal discharges of untreated waste). The workshop identified a number of medium-sized to large municipalities discharging minimally treated waste into embayments of the Gulf of Maine.

2. **Support** the evaluation of Best Management Practices (BMPs) for their effectiveness in managing nutrients. Of particular importance are the BMPs related to integrated aquaculture operations (combined finfish, shellfish, and marine plants), lawns and golf courses, and storm water. The workshop specifically identified such things as buffer strips, forestry management practices that enhance nutrient removal and retention, and riparian corridors for consideration in this effort.

3. **Support** the development of nutrient control strategies for finfish aquaculture and lobster impoundment operations where appropriate.

4. **Disseminate** information on the availability of existing tools and techniques that have been shown to be effective in controlling nutrient inputs. These may include:
- Advanced wastewater treatment,
- Changes in outfall locations,
- Model ordinances,
- BMPs that have demonstrated effectiveness in controlling nutrients,
- Stormwater and septic system management districts (such as those in Provincetown and Chicopee, MA), and
- Innovative on-site wastewater treatment systems.

5. **Encourage** discussions between USEPA, US Forest Service, and NOAA, as well as the equivalent agencies in Canada, regarding impacts from atmospheric deposition of nitrogen and their relationship to forestry practices.

6. **Advocate** the development of strategies designed to reduce local atmospheric nitrogen emissions.

Policy, Regulatory, and Implementation Issues

The Gulf of Maine Council Should:

1. **Advocate** the use of existing regulatory programs (*e.g.*, point source discharge permits) to manage and control nitrogen. Where needed, consider the addition of nutrient limits on point source discharges.

2. **Become involved** in the federal agency development of nutrient criteria. In the US, this may be done through participation in the Regional Technical Advisory Group (RTAG).

3. **Advocate** the use of the embayment classification scheme discussed above in the implementation of existing regulations or development of new regulations. Include permit writers in these discussions.

4. **Promote** emphasis on nutrient control in non-point source pollution programs—particularly as they relate to water bodies found to be sensitive.

5. **Advocate** for regulatory flexibility designed to provide opportunities for development, testing, and implementation of innovative technologies. This flexibility is necessary in many instances to allow the permitting of research activities. In other situations, flexibility is necessary to allow implementation of innovative systems—with appropriate monitoring.

6. **Establish** a “Research Translator” position to synthesize research results and monitoring data into a form useful to managers. Activities may be supported by:
- A fellowship and / or internship program,
- Promoting the funding of student and community-based projects related to nutrient management,
- Workshops, conferences, and other interactions between scientists and managers.

7. **Establish** an Outreach Coordinator position to create and implement an outreach plan for the GOMC to educate stakeholders on issues related to nutrients. This plan should include such things as:
- Workshops, conferences, and other learning experiences for stakeholders,
- The development of a “report card” on nutrient-related conditions in the embayments,
- Encourage multi-stakeholder approaches to the implementation of embayment management strategies,
- Disseminate information through a broad range of media outlets (*e.g.*, local newspapers, Gulf of Maine Times, web sites)

8. **Promote** broad landscape / seascape management techniques as important and cost-effective nitrogen control strategies (*e.g.*, riparian buffer strips, salt marsh restoration, wetlands protection). Emphasize the economic value of these “free management opportunities”.

Recommendations to the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

The workshop resulted in the following recommendations to be forwarded to the co-directors of CICEET for appropriate action.

Recommendations

CICEET Should:

1. **Convene** a meeting of modelers, researchers, and managers to review existing predictive models and refine them for use in the Gulf of Maine watersheds and embayments. This process should help refine the types of data necessary for accurate predictions.

2. **Support** the development of remote sensing methods and technologies for collecting and assessing data over large spatial scales. Particular emphasis was placed on data collection related to macro-algal proliferation.

3. **Develop** better methods for data assimilation, synthesis, and integration.

4. **Develop** improved monitoring capability and efficiency. This would include the development of new sensors, remotely operated vehicles (R.O.V.) and data transmission.

5. **Improve** information dissemination technology.

6. **Evaluate** the effectiveness of integrated aquaculture as a nutrient control strategy.

Actions Taken

by the Gulf of Maine Council Related to Recommendations from the Workshop

Gulf of Maine Council The day after the workshop, a series of preliminary recommendations from the participants was forwarded to the Gulf of Maine Council for its consideration. At its meeting on December 5-6, 2001, the Council voted to take the following actions related to workshop recommendations. (Wording of recommendations listed below is from the preliminary recommendations and may differ slightly from the final recommendations provided earlier in this document.)

Gulf of Maine Council Tasks Applicable to the Nutrients Workshop Funded in 2002-03[*]

Workshop Recommendations & Council Responses

No. 1

Support the development of a suite of indicators of eutrophication impacts appropriate to each class of embayments with particular emphasis on those that may provide an "early warning system". Indicators must clearly demonstrate impairment due to nutrients; and

No. 2

Establish a monitoring coordinator position to facilitate interactions between various monitoring efforts in the Gulf of Maine and nurture citizen monitoring efforts.

Council 2002—2003 Work Plan	Council Next Steps
1. Integrated Monitoring Program This task will analyze, interpret and distribute Gulfwatch data and findings to date; review inventory of monitoring programs and conduct outreach; link with volunteer monitoring programs; identify indicators; identify linkages between databases; and produce new relationships around the Gulf. **Project position ....$45,000** **Printing, communications $5,000**	**1.** The Secretariat, in consultation with the Monitoring Committee, will develop a position description, a recruiting plan and hire a 1-year project position by March 1st. The position will report to the Monitoring Committee. Contact Laura Marron (603) 271-8866.
2. State of the Gulf (SOG) The Council seeks to work in partnership with others to explore the development of indicators of environmental quality. This seed funding will be used to link with other funding partners. **State of Gulf Indicators $15,000**	**2.** The Gulf of Maine Program has an ad hoc group that will identify next steps and potential partners including a pending GPAC initiative. Contact Laura Marron (603) 271-8866

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[*] In early December 2001 the Council met in St. John, New Brunswick and reviewed the recommendations from the November 2001 Nutrients workshop convened in Portsmouth, New Hampshire. The Council approved partial funding for a number of tasks.

Actions Taken

by the Gulf of Maine Council Related to Recommendations from the Workshop

No. 3

Disseminate information on the availability of existing tools and techniques that have been shown to be effective in controlling nutrient inputs. These may include:

- Advanced wastewater treatment
- Changes in outfall locations
- Model ordinances
- BMPs that have demonstrated effectiveness in controlling nutrients.
- Stormwater and septic system management districts (such as those in Provincetown and Chicopee, MA)
- Innovative treatment systems

Council 2002—2003 Work Plan

1. Convene sewage workshop

The Council will organize a workshop in Halifax, Nova Scotia to promote the sharing of information throughout the region on methods to mitigate the adverse effects of sewage on the marine environment.

Workshop seed funding..............................$5,000

Council Next Steps

1. The NS Department of Environment is presently forming a workshop steering committee to design and convene the workshop. Contact Pat Hinch (902) 424-6345.

No. 4

Establish an Outreach Coordinator position to create and implement an outreach plan for the GOMC to educate stakeholders on issues related to nutrients. This plan should include such things as:

- Workshops, conferences, and other learning experiences for stakeholders,
- The development of a “report card” on nutrient-related conditions in the embayments,
- Encourage multi-stakeholder approaches to the implementation of embayment management strategies,
- Disseminate information through a broad range of media outlets (*e.g.*, local newspapers, Gulf of Maine Times, web sites)

Council 2002—2003 Work Plan

1. Public Education and Participation

The Council provided funding to their Education Committee to perform a series of specific tasks including development & implementation of 5-year Committee work plan; partnering with others to convene a Volunteer Monitoring Workshop; increasing GOM Times circulation and the GOM Display, partnering with others to produce new Fact Sheets, etc.

Education tasks seed funding...................$26,000

Council Next Steps

1. The Public Education and Participation Committee will meet in January to elaborate on their work plan and commence activities in February. Contact Verna DeLauer (603) 271-2155.

No. 5
Establish a “Research Translator” position to synthesize research results and monitoring data into a form useful to managers. Activities may be supported by:

- A fellowship and / or internship program,
- Promoting the funding of student and community-based projects related to nutrient management,
- Workshops, conferences, and other interactions between scientists and managers.

Council 2002—2003 Work Plan

1. Science translator demonstration project

This 3-year initiative will increase the pace of marine scientific research that is translated into information that coastal managers need when making management decisions. The funders will use an iterative process to engage managers in identifying selected priority management issues. A full-time contractor with scientific training and superb communication skills will perform the translation work and disseminate the results to the management community. The written results will be technical assistance materials (*e.g.*, papers in lay terms, brochures, manuals, guides, web products, etc.) that are scientifically defensible / supported. The outcome of this effort will be incorporation of the latest scientific research into coastal permitting and policy decisions.

Council & other partners..................$72,500/yr.

Council Next Steps

1. Project funding partners are forming a steering committee, preparing a recruiting strategy and conducting a users needs assessment. Contact David Keeley (207) 287-1491.

In addition to these specific tasks that have received funding commitments from the council, there are other activities that the Council will pursue to implement other recommendations from the workshop. These include:

- Classification system and susceptibility index — Encourage federal agencies to update and expand on current work.
- BMP effectiveness assessment — Request federal agencies to report to Council in summer 2002 on status of effectiveness assessments
- Forestry & atmospheric deposition — Request agencies to coordinate with NEGC / ECP Climate Change initiative.

CICEET

As of January 2002, CICEET has solicited proposals that address a series of topics related to nutrient enrichment and eutrophication. These topics are as follows:

1. Develop and / or apply novel and cost-effective methods for reducing or eliminating nutrients from wastewater and storm water.
2. Develop better waste management technologies and strategies to reduce nutrient impacts from agriculture on coastal and estuarine ecosystems.
3. Develop methods to evaluate the effectiveness of best management practices for reducing nutrient loading from agricultural, residential and commercial sources.
4. Develop and / or apply innovative and transferable methods and technologies to identify sources and / or quantify loadings of nutrients to the coastal and estuarine environment.
5. Develop and / or apply novel techniques to mitigate impacts of nutrient enrichment on estuarine and coastal habitats.

Several of these topics address topics discussed at the workshop and, depending on proposals received, may provide answers to questions that evolved from those discussions.

Further information about this Request for Proposals and projects subsequently funded may be found on the CICEET web site at http://ciceet.unh.edu.

White Papers

Introduction

In order to provide a context for the issues to be discussed, the sponsors commissioned three background, or white, papers for dissemination to participants prior to the workshop. These included the following:

No.1

Nitrogen in the Gulf of Maine: Sources, Susceptibility and Trends

Prepared by:
John Sowles
Maine Department of Marine Resources

John Sowles is presently the Director of Ecology at the Maine Department of Marine Resources. He has worked on water quality issues in both the US and abroad for almost 30 years with his current work involving the evaluation of nutrient discharges to the waters of Maine's coastal zone. His special interest is in placing human impacts into the context of natural variability.

Ecology Division
Dept.of Marine Resources
P.O. Box 8
West Boothbay Harbor, ME 04575-0008
Phone: (207) 633-9518
E-mail: john.sowles@state.me.us

No.2

Assessing, Monitoring and Controlling Nitrogen Pollution in the Gulf of Maine

Prepared by:
Christine Werme
Independent Consultant

Michael S. Connor
New England Aquarium

Dr. Christine Werme is an independent consultant, specializing in marine and environmental science and quality assurance. She has spent more than 25 years in assessment and communication of environmental issues. Since 1998, Dr. Werme has prepared annual overviews of research and monitoring conducted by the Massachusetts Water Resources Authority. She has summarized data on nutrient and other pollutant inputs and effects for several New England estuaries, including Massachusetts, Buzzards, and Narragansett Bays.

Dr. Michael S. Connor is Vice President for Programs and Exhibits at the New England Aquarium, where he manages research, conservation, education, design, husbandry, and other services. Prior to his tenure at the aquarium, Dr. Connor was Director of the Environmental Quality Department at the Massachusetts Water Resources Authority. His experience in assessment and management of excess nutrient inputs to marine waters spans more than 25 years. He has worked along all US coasts and in Korea, Japan, and Hong Kong.

Dr. Christine Werme
E-mail: cewerme@aol.com

Dr. Michael S. Connor
E-mail: mconnor@neaq.org

No.3

Pressing Management Issues Related to Nitrogen in the Gulf of Maine Region

Prepared by:
Steve Bliven
Bliven & Sternack

Steve Bliven is the Principal and Owner of Bliven & Sternack, an independent consulting firm. He also holds the position of Senior Research Fellow at the Urban Harbors Institute, University of Massachusetts Boston. He has spent over 25 years in coastal resource management endeavors, ranging from local Conservation Commissions, to the Massachusetts Coastal Zone Management Office, to private consultancy.

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No.1

Nitrogen in the Gulf of Maine: Sources, Susceptibility & Trends

Prepared by:

John Sowles
Maine Department of Marine Resources

White Paper 1 of 3

for

A Workshop
on Nutrient Management
in the Gulf of Maine

sponsored by:

The Cooperative Institute for Coastal and Estuarine
Environmental Technology (CICEET)
The Gulf of Maine Council on the Marine
Environment
and
The National Oceanic and Atmospheric
Administration's National Ocean Service

November 28-29, 2001
Sheraton Harborside Hotel
Portsmouth, NH

INTRODUCTION

As a result of human activities, the amount of nitrogen globally available to living organisms has approximately doubled (Vitousek *et al*., 1997). Most of the increase has occurred over the past 50 years due to the industrial fixation of nitrogen into commercial fertilizer, emissions from the burning of fossil fuels, and biological fixation from planting nitrogen-fixing legume and rice crops. Coastal waters such as Chesapeake Bay, Tampa Bay, Long Island Sound, and the Gulf of Mexico have responded with harmful algal blooms, oxygen depletions, and loss of seagrasses.

Although global and national characterizations heighten awareness of cultural eutrophication as an environmental issue, neither the distribution of nitrogen emissions nor expressions of eutrophication are uniform over the globe or within regions such as the Gulf of Maine. Eutrophication in the Gulf of Maine is really only now emerging as an environmental issue prompted mostly by recent experiences elsewhere. While hardly complete, this white paper is an attempt to compile some of the most obvious information on major sources and loads and offer some ideas on what attributes of local coastal waters might contribute to how a water might respond to nitrogen enrichment.

A few points to consider while reading:

1. Nitrogen is the assigned topic of this paper. However, nitrogen is by no means the only or always the most important nutrient driving primary production at all locations within the Gulf of Maine. Phosphorus, silica, iron, and other nutrients play key roles in determining what, if any, problems occur. For example, toward the freshwater end of an estuary phosphorus becomes limiting. In offshore waters, sometimes silica becomes selectively limiting to diatoms thus giving rise to less desirable phytoplankton.

2. Even when nitrogen is limiting, a problem associated with excess nitrogen loading may not necessarily result. Other physical factors affect whether or not and how a system responds to nitrogen. The Gulf of Maine is considered to be among the most biologically productive marine systems in the world. Without the large influx of nutrients from offshore, the Gulf of Maine could not support the commercial fisheries it does. Indeed, Boddeke and Hagel (1991) make the case that recent declines in landings from the North Sea can be explained by efforts to control pollution.

3. Compiling quantitative information for this report was difficult and it was impossible to describe a single reliable, coherent picture of the "Gulf of Maine." Methods to describe sources, loadings and physical boundaries were as numerous as authors. Discrepancies were not trivial. Not even the size for the Gulf of Maine was consistent. For example, surface area was reported to be anywhere from 10,300 (Townsend, 1998) to 18,000 km2 (McAdie, 1994) depending on boundaries used. Most oceanographic papers account only for dissolved nitrogen while most coastal assessments omit dissolved nitrogen favoring total nitrogen. Definitions were also a problem. The "catch-all" non-point source category sometimes was a combination of diffuse sources and included unaccounted for point sources in the upper reaches of watersheds. To the extent possible, I have tried to "standardize" sources and units and to resolve definitions.

4. Finally, I continue to observe a disparity in semantics between those involved in local coastal systems and those involved in large offshore systems. For example, around the Gulf of Maine, many water quality managers accustomed to freshwater systems are less familiar with marine systems. Marine systems lack the tight, Vollenwieder-type, predictive models used in lakes or the linear waste assimilation models used in rivers. Marine systems are open with arbitrarily defined boundaries. Offshore oceanographers talk in terms of areal loading while coastal scientists are interested in volumetric loading or concentrations. I believe that it is useful to point out these differences, not that one is right and the other wrong, but merely to avoid assuming that the context of another's work is the same as one's own.

SOURCES AND SINKS

Continental Slope Water

The largest single source of nitrogen to the Gulf of Maine is the ocean itself. Estimates abound but the consensus is that about 2,250,000 MT-TIN (metric ton total inorganic nitrogen) of the Gulf of Maine's "new" nitrogen derives from nutrient-rich deep continental slope water flowing into the Gulf of Maine through the Northeast Channel and across the Scotian Shelf (Schlitz and Cohen,1984; McAdie, 1994; Townsend, 1998).

During summer stratification, primary production in the offshore Gulf of Maine becomes nutrient-limited when primary production depletes the euphotic zone of nitrogen. Below the pycnocline, however, nitrogen is abundant but unavailable to photosynthesis for lack of light. Late summer and fall cooling and storms destratify the water column resulting in nitrogen becoming available for the fall bloom.

Although this large offshore source drives primary production in the Gulf of Maine as a whole, it also has implications for nearshore systems. Localized exceptions to this large scale pattern occur where upwellings from currents, wind, and tidal mixing supply well-lit surface waters with nitrogen during the summer, either on a continual basis or sporadically. For example, at the eastern end of the Gulf of Maine, (Passamaquoddy and Fundy) surface waters are generally nutrient-rich throughout the summer (Martin *et al.*, 1999). The Eastern Maine Coastal Current transports this nitrogen-rich water westward along the coast (Pettigrew *et al.*, 1998). At some point and time east of Penobscot Bay, dissolved nitrogen in surface waters is thought to become limiting. Where that occurs is not well defined. These nitrogen limited areas are the areas and regions where human sources of nitrogen can potentially affect primary production and alter phytoplankton communitiesóand where coastal water quality managers are most in need of information.

Atmospheric Deposition

Until the late 1980s, the contribution of atmospheric nitrogen to coastal waters was thought to be both natural and minimal. Only recently did evidence emerge to show that atmospheric deposition can contribute significant loads comparable to those from sewage and agriculture (Valigura, 2001). Compared to atmospheric carbon, the principal greenhouse gas, human activities have had a far more significant effect on the amount of nitrogen available. Between 1950 and 1997, the amount of nitrogen oxides (NOx) emitted into Earth's atmosphere from fossil fuel production increased from about 8 to 30 million metric tons N (Valigura, 2001).

Atmospheric deposition is a significant source for many waters, sometimes contributing as much as 40% of a water body's total nitrogen budget (Paerl, 2001) and accounts for greater than 25% of the total nitrogen load to 19% of US estuaries (Turner *et al.*, 2001). Areas where coastal eutrophication is most pronounced (*e.g.*, Chesapeake Bay, Long Island Sound, Gulf of Mexico) are generally waters below large airsheds where nitrogen deposition rates are the highest in the country and / or where agricultural fertilizers are applied over large portions of their watershed (Meyers *et al.*, 2001). The Gulf of Maine does not share the same attributes of the above waters, possibly explaining why its response has not been as obvious.

In the Gulf of Maine region, estimates of total nitrogen deposition rates vary from about 5.56 kg N / ha / yr (Meyers *et al.*, 2001) to 12.6 kg N / ha / yr (Townsend, 1998). Estimates of total annual load to the Gulf of Maine range from 57,400 MT-N (Christensen *et al.*, 1992) to 130,200 MT-N (Townsend, 1998). Locally, atmospheric nitrogen deposition can be a significant component of the local nutrient budget as shown in Table 1.

Table 1.

Relative atmospheric nitrogen load to three coastal systems within the Gulf of Maine (from Valigura *et al.*, 2001).

Water Body	% from Atm. Dep.
Maquoit Bay, ME	33
Great Bay, NH	10
Massachusetts Bay, MA	12.5-16%

And although a total nitrogen budget for Casco Bay has not been completed, an initial analysis of data from the Casco Bay region indicates that the atmospheric contribution directly to the surface of Casco Bay (360 MT N / yr) is approximately equal to 50% of all known point sources (Diane Gould, USEPA, Personal Communication, 2001).

Point Sources

Industry and Wastewater

According to the Gulf of Maine Land-Based Pollution Sources Inventory (NOAA, 1994), of the 25,000 MT-TN (metric tons total nitrogen) discharged by facilities to the Gulf of Maine and its watershed, Massachusetts accounts for 58% of total nitrogen load, followed by Maine (22%), New Hampshire (9%), New Brunswick (8%), and Nova Scotia (3%). In terms of nitrogen, 91% of total nitrogen point source discharges in the entire Gulf of Maine region come from wastewater treatment plants while 9% of the point source nitrogen load derives from industry. Almost 80% of all process water to the Gulf of Maine flows through four watersheds: Massachusetts Bay, Sheepscot Bay (Kennebec and Androscoggin Rivers), Merrimack River, and St. John River. Table 2 presents loadings through the four rivers with highest process flows.

Table 2.
Total nitrogen (Metric Tons) estimated to be discharged by industry and wastewater from four watersheds.

Location	Industry	Wastewater
St. John River	205	1,040
Sheepscot Bay	250	1,265
Merrimack	110	3,865
Massachusetts Bay	90	14,300

Of the industrial portion inventoried, pulp and paper manufacturing accounted for 45% of the nitrogen load to the Gulf of Maine. Their large volume flows combined with small concentrations results in this high percentage. There is, however, reason to believe that even this is an overestimate since estimates were based largely on license limits and not actual monitoring data. Pulp and paper mills normally operate well below their license limits and experience in Maine has shown that effluent nitrogen concentrations are typically a fraction of the target concentrations (Maine Department of Environmental Protection data).

Reliable quantitative information on nitrogen discharges to the Gulf of Maine is difficult to find. Monitoring for nitrogen is not routinely required as part of a discharge permit and many industrial discharges flow to municipal wastewater plants where the industrial contribution is combined with and reported as part of the municipal load. The National Research Council (2000) reports that, on the coast, food-processing industries, especially seafood processors, are the most likely sources of nitrogen discharges. In the L'Etang Inlet, NB, for example, seafood processing contributes 61 MT-N annually versus only 3.8 MT-N from sewage (Peter Strain, DFO; Personal Communication).

Finfish Aquaculture

Finfish aquaculture in the Gulf of Maine results in a discharge of nutrients directly to the water. About 80% of the nitrogen is excreted in dissolved form (ammonium) and thus immediately available to phytoplankton. Because the industry is closely monitored, estimates of nutrient loading from this source are probably more accurate than those of other sources. In 2000, over 100 million pounds of finfish were grown in the Gulf of Maine mostly in New Brunswick (66 million pounds) and Maine (36 millions pounds) while Nova Scotia, New Hampshire, and Massachusetts contribute another 1 million pounds (Marcy Lucas, Me. Dept. Marine Resources; Karen Coombs, NB Dept. Fisheries and Aquaculture; and Roland Cusack, NS Dept. Fisheries, all Personal Communications). Various models exist to estimate the amount of nitrogen lost to the environment from finfish culture (Beveridge, 1996). Recent efforts to increase food transfer efficiency and minimize release of nitrogen to the environment have lowered nutrient loss significantly over recent years (Hardy, 2000). Applying rates between 60 and 40 kg N (for older and newer diets respectively) released per metric ton of fish produced results between 2,730 MT and 1,820 MT N introduced directly to the gulf each year by finfish aquaculture or 0.1% of the Continental Slope Water intrusion. On the other hand, in small confined bays such as L'Etang Inlet, New Brunswick or Cobscook Bay, Maine, contribution of nitrogen by finfish aquaculture can be large. For example, in Cobscook Bay, Sowles and Churchill (unpublished) estimate that aquaculture contributes 360 MT-N annually and in L'Etang, aquaculture contributes 480 MT-N annually (Peter Strain, DFO; Personal Communication).

Despite the concern over such large nearshore sources, adverse effects from nitrogen loading have not yet been observed from finfish aquaculture in the Gulf of Maine. This is likely due to the position of finfish aquaculture in relation to the nitrogen-rich continental slope water of Fundy and Passamaquoddy Bays (ME and NB). Since this area of the coast is not nitrogen limited (Martin *et al.*, 1999), effects on primary production are not seen. Finfish aquaculture is expanding westward, however, into water that is nitrogen limited. Several operations are proposed for the eastern edge of Penobscot Bay and the University of New Hampshire operates an ocean aquaculture demonstration project off the Isle of Shoals.

Non-Point Sources

Agriculture

Nitrogen runoff from agriculture derives from fertilizers, manures, and legume crops. Agriculture is a dominant contributor of nitrogen to coastal waters experiencing problems elsewhere in the US (*e.g.*, Chesapeake Bay and Gulf of Mexico). In the Gulf of Maine region, agriculture comprises only about 8% of the watershed and therefore probably plays a minor role overall. On a local level, however, agriculture can be significant, as in the case of Maquoit Bay, Maine (Horsley and Whitten, Inc., 1996) where agriculture was estimated to contribute 30% of the nitrogen to this small, shallow bay.

Urban

As a consequence of atmospheric deposition onto impervious surfaces and urban / residential activities (including soil disturbance, chemical spillage, etc.) urban runoff can be a large source of nitrogen to local coastal waters. In Gulf of Maine waters, Castro *et al.* (2001) estimate that urban non-point source runoff is the dominant source of nitrogen in Great Bay, New Hampshire (21%) and Casco Bay, Maine (17.6%). And while urban runoff may constitute a minor fraction in other watersheds, it is an immediately manageable source for which remedies are available.

Losses and Sinks

Denitrification

The conversion of biologically available ammonium and nitrate to relatively unavailable nitrogen gas through denitrification, is the dominant mechanism for nitrogen loss in the ocean (Codispoti and Christensen 1984). Annual estimates of denitrification for the Gulf of Maine vary from 463,000 MT- N (Christensen *et al.*,1992) to 754,600 MT-N (Townsend, 1998) or about 20%—50% slope water inflow, respectively. Nowicki *et al.* (1997) studied denitrification in Boston Harbor and found that despite relatively high rates, denitrification offsets only a small percentage (7-9%) of the overall nitrogen inputs to heavily loaded Boston Harbor. In other estuaries that are more moderately loaded, denitrification could play a larger role. Although variability is high, even over small scales (Table 3), accurately predicting the importance of denitrification will be difficult.

Table 3.
Denitrification rates (umol N m-2 h-1) for three Gulf of Maine systems (adapted from Nowicki *et al.*, 1997).

Location	umol N m-2 h-1
Boston Harbor	<10-412
Massachusetts Bay	<10-128
North Atlantic Shelf	68

Burial

Christensen *et al.* (1992) estimate that about 62,000 MT-TN per year are lost to burial in the Gulf of Maine. Permanent loss of nitrogen through deep burial is limited to depositional areas, usually in deep basins where storm surge and currents are low. Through remineralization and nitrification, nitrogen that is not permanently buried is released to the surrounding water column. Because near coastal systems are shallow and exposed to periodic resuspension from river flows and storms, it is reasonable to assume that permanent loss due to burial is small in these shallow coastal systems.

Fisheries Harvest

Commercial fisheries harvest is not compiled for the Gulf of Maine, specifically, rather by port landed. With some assumptions, however, a rough estimate may be made based on finfish port landings data. Assuming an average whole body nitrogen content (Vinogradov, 1953) of 3% N, and using landings for Maine, New Hampshire, and Massachusetts of about 195,000 MT (NMFS, 2001) and 184,000 MT for Scotia-Fundy (DFO, 2001), about 11,400 MT-N is removed in fish harvest. In actuality, total removal is slightly higher since shellfish landings have not been included.

Summary Mass Balance

Table 4 below summarizes various nitrogen sources and sinks in the Gulf of Maine from the more recent estimates of Townsend (1998) with additional estimates derived from this paper.

Table 4.
Sources and sinks of nitrogen in the Gulf of Maine.

	Sources	Annual Mass Units
Inputs		
	Offshore (a)	2,511,600 MT-TIN-N
	Precipitation (a)	130,200 MT-TIN-N
	Coastal Point Sources (b)	25,000 MT-Total-N
	River (a)	11,200 MT-TIN-N
	Finfish Aquaculture (c)	2,730 MT-Total-N
	Non-Point Sources	not estimated
Total Input		**2,680,730**

	Sources	Annual Mass Units
Losses		
	Outflow (a)	-1,373,400 MT-TIN-N
	Denitrification (a)	-463,400 MT-Total N
	Burial (a)	-61,600 MT-Total N
	Particulate and DON (d)	-711,200 MT-Total N
	Commercial Harvest (e)	-11,400 MT-Total N
Total Loss/Removal		**-2,621,000**

Residual *	**+59,730**

Footnotes:
(a) as reported in Townsend, 1998
(b) as reported this paper
(c) as reported this paper
(d) from Campbell, 1986.
(e) as reported this paper

***** The residual divided into the incoming slope water results in a concentration less than the precision of the analytical test underscoring the variability and uncertainty associated with Gulf of Maine loading estimates.

FACTORS DETERMINING SUSCEPTIBILITY TO NITROGEN LOADING

The NRC (2000) suggests 12 key characteristics as those important in determining estuarine response to nutrient loading. Most of these are interrelated with each affecting the others. All are relevant to Gulf of Maine estuaries and embayments:

1. **Physiography** describes the local surficial geology, climate, slope, aspect, and predominant biological community of a system. Physiography of the watershed affects important nitrogen processes including nutrient retention and uptake by vegetation and wetlands that ultimately affect delivery to coastal waters. Physiographic features such as orientation and exposure of the water body to wind and sun affect flushing and vertical mixing.
2. **Primary Production Base** is the dominant plant community type responsible for primary production in the water body. A few examples include macroalgae, benthic microalgae, seagrasses, emergent salt marshes, and phytoplankton. Each of these has a unique set of environmental requirements that results in different responses to nutrient enrichment.
3. **Nutrient Load** is simply the mass or quantity of nutrients, in this case nitrogen, delivered to a system. In waters that are nitrogen limited, an increase in nitrogen load is likely to produce some increase in primary production.
4. **Dilution** is the volume, or sometimes area, over which a load is dispersed. The more dilute a nutrient is, the less its capacity to exert an effect. Volumetrically, a municipal discharge can be put into the context of an embayment of known volume and flushing. Using an areal example, the ratio of water surface to watershed size (dilution) is a convenient way to screen relative importance of watershed versus direct atmospheric deposition.
5. **Hydraulic Residence Time** is the time over which the water in a system is retained before being flushed out. Residence time is controlled by tides, winds, freshwater inputs, and system morphometry. If residence time is less than the doubling rate of phytoplankton, then blooms are less likely to occur. Residence time is somewhat arbitrary in that it depends on where a system's boundary is drawn which, in turn, depends on the spatial scale of interest. In addition to affecting phytoplankton populations, residence time also affects rates of nitrogen loss through denitrification.
6. **Stratification** is important in that it isolates masses of water from one another. In the Gulf of Maine, for example, the warmer summer surface layer is depleted of nitrogen while the cooler bottom water has ample quantities. Once stratified, many surface phytoplankton populations are isolated from a supply of nutrients and their populations decline.
7. **Hypsography** is the shape of the system, specifically in relation to elevation. Not only does a deep basin have the potential to stratify, it also is more likely to to have higher rates of denitrification and burial. Conversely, a uniformly shallow system has a larger percentage of its water column in the euphotic zone and is continually well mixed. These uniformly shallow systems also are likely to have wider intertidal and fringing marsh areas.
8. **Grazing** of phytoplankton by benthic filter feeders can be an important mechanism that controls phytoplankton populations. In the Gulf of Maine, shellfish beds such as *Mytilus edulis* are the dominant benthic community of some embayments. Shellfish aquaculture can occupy many acres of bottom or even increase "apparent" bottom area by providing suspended substrates.
9. **Light Extinction Depth** determines the depth to which light is sufficient to allow photosynthesis. The distribution of submerged aquatic vegetation such as kelps, seagrasses and rockweed is, in part, dependent on light. Factors that affect light include suspended particulates (suspended sediment, detritus, and plankton) and color. Together with stratification, light extinction controls whether bottom waters become devoid of oxygen.
10. **Denitrification** is the bacterial process that counteracts the effects of eutrophication by converting nitrate to forms that are not available for photosynthesis. Denitrification rates are determined by many of the same factors that appear to control a system's vulnerability to eutrophication including hydraulic residence time, sediment type, and organic carbon load. Up to a certain point, denitrification is directly related to organic loading. However, as sediments become organically loaded and hypoxic, macrobenthos and microbiological communities shift in response. With reduced bioturbation and microbial processing, denitrification rates decline. This positive feedback loop can drive the effects of eutrophication further.
11. **Timing** and Location of Delivery are also important in that a load delivered to a location or at a time when nitrogen is not limiting may not increase primary production. On the other hand, if delivered when nitrogen is in short supply, it could promote plant growth.

12. **Allochthanous Organic Matter** inputs increase the amount of carbon in a system as well as the amount of dissolved organic nitrogen. Both tend to drive systems toward heterotrophy resulting in the net consumption of oxygen from the water column and hypoxia. Biological community shifts in response to the organic load affect the primary production base, nitrification and denitrification.

Four other characteristics also seem appropriate for consideration:

13. **Sediment Quality**, primarily its textural properties, also affect infauna and microbial communities, which, in turn, affect rates of nitrification and denitrification. For example, denitrification is greater in fine-grained sediments than sands and gravels (Nowicki, *et al.*, 1999). And chemical composition, especially sulfide, iron, and molybdenum, are known to affect microbial nitrogen transformation including fixation and denitrification.
14. **Form of Nitrogen** is sometimes critical. Plants are able to use nitrogen in its dissolved form and then only in a few forms, mostly inorganic. Refractory nitrogen such as organic dissolved and particulate nitrogen require bacterial processing before it is ready for plant uptake although Berg, *et al.* (1997) have shown that dissolved organic nitrogen is assimilated by some nuisance species of phytoplankton. Stolte *et al.* (1994) showed that large diatoms dominate with nitrate while smaller species have a higher preference uptake for ammonia. Kudela and Cochlan (2000) suggest that urea is preferred over dissolved inorganic nitrogen by some red tide organisms. Eventually, much of the particulate nitrogen becomes available and has the potential to cause delayed response in a system.
15. **Availability** of other Nutrients determines the composition of phytoplankton communities. As different species have different half-saturation constants for various nutrients, the availability and relative concentrations of nitrogen, phosphorus, iron, and silica affect interspecific competition and ultimately phytoplankton community composition. “Good” phytoplankton are thought to form the basis of a diverse and productive fishery while “bad” phytoplankton form harmful and nuisance algae blooms.
16. **Latitude** clearly affects temperature but it also affects day-length or, more appropriately, night-length. In stratified situations, temperature and darkness in turn affect duration and strength of stratification as well as net oxygen production (or loss) in lit bottom waters of the near coastal zone.

Susceptibility in the Gulf of Maine

While expressions of eutrophication in the Gulf of Maine are evident (Bricker *et al.*, 1999), problems due to cultural eutrophication are less evident. The distinction between cultural and non-cultural sources of eutrophication is important to management. Red tides in the eastern portion of the Gulf of Maine, for example, are believed to be naturally occurring and generated from offshore (Townsend *et al.*, 2001). As such, they are probably beyond practical management.

Why, despite its long history of cultural development and increased loading of nitrogen due to human activities, are symptoms of eutrophication less obvious than other areas of the continental US where inputs are less and symptoms obvious? And what characteristics of the Gulf of Maine make it apparently less susceptible to the effects of eutrophication?

Roman *et al.* (2001) provide some insight into why the Gulf of Maine might be responding differently to nutrient enrichment. Northeast Atlantic estuaries, including the Gulf of Maine, are unlike most others in North America. Compared to other areas where problems occur, watersheds in the Gulf of Maine are relatively small and the water bodies themselves are generally deep. Northeast coastal systems operate within a macrotidal regime, boreal climate, and complex bedrock geology. Its glacial history has resulted in many drowned river valleys and tidal mud flats. Rocky shorelines are unique to the northeast being virtually absent on the rest of the Atlantic coast and Gulf of Mexico. Riverine sediment loads are low, compared to other eutrophic coastal areas, and the water column is relatively clear. Despite hundreds of years of high population, urban areas are serviced by municipal wastewater treatment. Outside urban areas, agriculture is generally a minor landuse in the coastal zone.

Many of the Gulf of Maine attributes fit nicely into the characteristics that Howarth *et al.* list as important variables determining impacts from nitrogen enrichment. Together, these attributes may mitigate the effects of nitrogen loading in the Gulf of Maine. Certainly, I am not suggesting that the issue is unimportant or that it should not be addressed. To the contrary, now is the time to address it through research, monitoring, and management. At the same time, I suggest that we use caution before concluding a specific effect is inevitable.

TRENDS IN NITROGEN INPUTS

Long time series that provide trends in actual nitrogen inputs to the Gulf of Maine are few. Many trends are inferred from measurement of such things as dollars spent on wastewater treatment, citizen education on best management practices, and legislation. Some of these indirect changes are discussed below.

Population Shift and Land-Use Change

An obvious and important factor forcing change on the Gulf of Maine is human population. Culliton *et al.* (1990) report that the northeast portion of the United States from Maine through Virginia is the fastest-growing area of the country including nine of the 10 counties US-wide projected to have the most rapid growth. In the US portion of the Gulf of Maine, the present coastal population is expected to increase another 6% by 2010. New Hampshire is reported to be one of the 10 fastest-growing states in the nation at a projected 129% increase between 1960 and 2010. Growth is expected to be greatest in the western region of the Gulf of Maine from southern Maine to Greater Boston.

This is important in three regards. First, this region is at the downcurrent end of Gulf of Maine circulation. Second, this portion of the coast is exposed to the Gulf of Maine and relatively well flushed. And third, infrastructure to treat domestic waste and urban runoff is in place or being planned. Together, this set of circumstances may moderate effects of nitrogen enrichment.

To the east and upcurrent, however, the specific implication of increasing coastal population is uncertain. As land is taken out of vegetative cover, presumably nitrogen uptake in the watershed declines and nitrogen exported to the coast increases. On the other hand, as population density increases, at some point engineering solutions such as community wastewater and stormwater management become more affordable, thus reducing the amount of nitrogen delivered to coastal waters. Then, as populations continue to grow, the original technology's capacity becomes outdated and inefficient thus increasing delivery of nutrients to the coast. This growth cycle is one with which water quality managers should be—or become—familiar.

Climate Change Effect on Continental Slope Water

Over the long term, if predictions on climate change and resultant sea level rise hold true, circulation and residence time of the Gulf of Maine could be drastically altered. Based on conditions of the warmer and dryer hypsithermal period that existed 9000—5000 years B.P., Christensen *et al.* (1992) predicted that the total volume of the Gulf will increase, tidal energy will be reduced and stratification will be stronger. With a larger volume, total inflow and thus contribution of nitrogen rich slope water will be reduced by 417,200 MT-N. The subsequent lowered net productivity could have serious economic implications.

Atmospheric Deposition

Although Valigura *et al.* (2000) report a huge increase in atmospheric deposition over the past 50 years, in the Gulf of Maine region deposition during the past decade appears to have leveled off or even slightly declined (*e.g.*, Merrimack River and Massachusetts Bay (Roman *et al*, 2000; USEPA, 2000)). Declines are anticipated elsewhere in response to recent legislation. In 1998, for example, to decrease transport of ozone across state boundaries in the eastern half of the United States, the USEPA required 22 states and the District of Columbia to reduce emissions of nitrogen oxides. Emission reductions are expected to be in place by 2003 and deposition expected to decline by 2010 (USEPA, 2000).

Watershed Discharge

Analysis of river water quality data by Roman *et al.* (2000) illustrates an interesting pattern of nitrogen concentrations in Gulf of Maine rivers. Concentration of nitrogen in rivers of the western Gulf of Maine is generally higher than in rivers to the east. However, the western rivers, that drain already well developed urban watersheds, have either level or declining nitrogen concentrations while eastern rivers, which are undergoing development, are slightly increasing.

Wastewater

In the past 10 years, several municipal outfalls (MWRA, Boston, MA; Ogunquit, ME; and Old Orchard, ME) have been relocated from inshore areas to offshore thereby changing many of the parameters that contribute to susceptibility to nitrogen loading. This trend is likely to continue as populations increase. Even landlocked municipalities located well inland from the coast are expressing interest in moving their discharges directly to coastal waters. Sanford, ME, for example, is 20 miles inland where its present discharge violates state freshwater quality standards. Forced to spend large sums for advanced treatment or find more dilution, Sanford has considered piping its effluent to the ocean. As population growth exceeds the assimilative capacity of small inland rivers, more inland towns are expected to explore the possibility of an ocean outfall (MEDEP, Staff Communication).

Agriculture and Urban Runoff

As noted earlier, agriculture in the Gulf of Maine watershed is relatively minor. In coastal watersheds in general, agriculture is on the decline and being replaced by residential and urban development (Turner *et al.* (1999). As the population is projected to increase in the Gulf of Maine, it is reasonable to expect subsequent declines in coastal agricultural lands to make way for housing. Urban runoff, on the other hand, might be expected to increase. The net effect, of trading agricultural runoff that contains higher concentrations of nutrients for urban runoff that contains lower concentrations of nutrients is a projected reduction in nitrogen runoff. Where urban land use replaces forest, however, the opposite is true. Nationally and regionally, water quality managers are aware of storm water quantity and quality issues and should be expected to implement controls where needed. Indeed in the US, storm water is required to be licensed under the NPDES permit program in large population centers.

Finfish Aquaculture

Several factors have been responsible for the growth of salmon aquaculture in the Gulf of Maine. Ideal environmental conditions such as moderate water temperatures, abundant oxygen, and rapid water exchange, coupled with available labor, shore-side facilities, and transportation have made the eastern Gulf of Maine especially attractive. Although growth of the industry has been rapid (Table 5), in the past several years, growth has slowed due to global market conditions, regulatory confusion surrounding listing of the "wild" Atlantic Salmon under the Endangered Species Act, disease, and public controversy over use of public waters.

Table 5.
Aquaculture finfish produced in the Gulf of Maine (in 1000 Metric Tons).

	1985	1990	1995	2000
Nova Scotia	<0.1	0.7	1.0	1.1
New Brunswick	0.6	7.5	15.0	30.0
Maine	0.4	2.0	10.0	16.0
New Hampshire	<0.1	<0.1	<0.1	<0.1
Massachusetts	<0.1	<0.1	<0.1	<0.1
Total	1.1	10.2	26.0	47.1

Over the long term, growth is expected to resume as demand increases and technologies are developed to overcome constraints. Systems now are available to collect and remove solids from farms enabling farms to occupy low energy sites that formerly were considered unacceptable due to benthic impacts. Feed formulations and feed management technology such as high protein, low fiber diets and acoustic Doppler feed systems have helped increase feed conversion efficiency resulting in less nitrogen released to ambient waters. Interest in open-ocean aquaculture continues with several experimental systems being tested including one off New Hampshire.

Trend Conclusion

Trends in water quality, public education, legislation, climate and landuse change all suggest that overall, nitrogen inputs to the Gulf of Maine will decline. However, within any single water body, loads may increase in response to local trends and conditions. Point and non-point effects of urbanization and finfish aquaculture appear to be the two most obvious activities that have the potential to contribute to increasing nitrogen loading.

POINTS FOR WORKSHOP DISCUSSION

Five topics for further discussion emerge as a result of preparing this paper:

1. Given the differences between Gulf of Maine coastal waters and those of other impacted areas of the country, it seems reasonable that some effort should be afforded development of predictive capacity. The challenge is to identify those characteristics, or surrogates for them, that can be practically measured (*e.g.*, residence time, dilution, and sediment texture) in order to anticipate estuarine response and couple those with attributes that can be managed (*e.g.*, timing / location of discharge, availability of other nutrients, and biomass harvest). Such an exercise could and should be conducted uniformly across the Gulf of Maine, using a standard set of methods.
2. Strong justification exists for establishing a Gulf of Maine Eutrophication Monitoring Network to validate predictive models as well as to monitor trends over time. Included in this should be coastal monitoring as well as deep Gulf of Maine monitoring. As aquaculture expands westward and municipal outfalls are expanded, there is a need to assess system response. Nearshore, key index sites representing heavily loaded and lightly loaded systems undergoing change should be followed. Understanding spatial and seasonal distribution of nutrients is also important as is identifying local influence of the Eastern Maine Coastal Current and other areas of nutrient upwelling. And finally, lessons are to be learned from the Gulf of Mexico and Long Island Sound. Given the uncertainty in estimating a nitrogen mass balance for the Gulf of Maine and consistent surplus estimated by various authors, it seems prudent to monitor deep basins now for oxygen deficits.
3. Sources and methods used to develop information on nitrogen (and other nutrients) in the Gulf of Maine are widely diverse. Estimates of error are generally absent preventing any reasonable assessment of confidence on any single result. Physical boundaries are frequently undefined. For these and other reasons, it is difficult to draw reliable comparisons across studies. Although each researcher follows the most suitable protocol for his or her work, one wonders to what extent the addition of other measurements might, at little cost, produce large differences in value to other researchers around the Gulf. For example, government reports would improve if, in addition to administrative data (*e.g.*, at jurisdictional levels), information was collected and reported at an ecological level (*e.g.*, water body or watershed).
4. The US Environmental Protection Agency is now developing Coastal Nutrient Criteria. The ecological and economic implications of these criteria are huge. In addition, states are required to develop Total Maximum Daily Loads (TMDLs) on all impaired waters that will result in the allocation of nutrient loads from the various sources. Much stands to be gained by participating in these efforts to assure that the outcome is practical, sound, and effective.

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No.2

Assessing, Monitoring, and Controlling Nitrogen Pollution in the Gulf of Maine

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ASSESSING, MONITORING, AND CONTROLLING NITROGEN POLLUTION IN THE GULF OF MAINE

This white paper provides background for discussing actions that can be taken by environmental agencies and private organizations to assess, monitor, and control eutrophication in the Gulf of Maine. The paper draws on the studies funded by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), an assessment of the needs of coastal managers (Frankic, 1999), and the experience of environmental managers working throughout the country, primarily from Chesapeake Bay, Long Island Sound, and Florida. Population density, characteristics of sources, regional flushing, stratification, and water temperatures have made eutrophication a more serious issue in these areas than it has been in the Gulf of Maine.

Monitoring and environmental management plans typically follow sequential approaches, in which existing information is assessed and additional needed information is identified and obtained through surveys and research. Those new and existing data are evaluated in the context of the natural physical, chemical, and biological conditions of the area, and the evaluation is used to set management goals and implement control strategies. This paper recommends a similar, progressive approach.

However, in following sequential approaches, it is important for managers to understand that, in fact, all work is not sequential. Assessments of environmental conditions, assessments of nutrient loads, and implementation of controls should move along simultaneously, driven by a framework or model that begins with simple assessments and actions and progresses with time to more detailed assessments and actions. As an example, consider the Boston Harbor cleanup, which has been underway since the mid 1980s. When the Massachusetts Water Resources Authority (MWRA) was first established, it was clear that environmental conditions were appalling, and that nutrient loads from ongoing sludge dumping into the harbor were unconscionable. Knowing exactly how much nitrogen was entering the harbor due to sludge additions was not necessary before managers could decide that dumping had to end. Sludge dumping did end in 1991, and MWRA has taken additional steps to decrease nutrient inputs to the harbor. Now, after more than a decade of clean up, there are no further simple actions that can be taken that would radically decrease nitrogen inputs or improve environmental conditions. Considerably more detail about nutrient states and individual inputs is necessary for additional control measures to have further benefit to the harbor and the region.

ASSESSMENT

Assessment of nutrient problems requires an understanding of eutrophication in the setting of the water body of interest. Assessments typically are based on reviews of existing data and generation of new information to fill data gaps. Before detailed control strategies can be developed, an assessment process must determine the nutrient loads entering the system from all sources.

UNDERSTANDING THE PROBLEM

The first step that any manager must undertake in assessing nutrient problems is to determine whether the specific water body for which he or she is responsible has a nutrient over-enrichment problem. To make that assessment, the manager must have an understanding of some basic factors:

- The specific nutrients of concern
- The potential sources of those nutrients within the watershed
- The natural physical, chemical, and biological conditions of the water body
- The potential undesirable ecological effects of the over-enrichment

For the Gulf of Maine, managers must develop this understanding on several geographic scales, from small embayments to the region as a whole.

Nutrients of concern

Nitrogen is the focus of this paper, because in coastal and marine systems, nitrogen is the main nutrient that causes eutrophication. In contrast, phosphorus is usually the controlling nutrient in freshwater systems. These differences do not mean that managers of marine waters can simply ignore phosphorus. Human inputs of nitrogen are often correlated with inputs of phosphorus, and control technologies also frequently go hand-in-hand. Other nutrients can also be of concern. For instance, decreased silica or increased iron can change the species composition of phytoplankton blooms and exacerbate the effects of eutrophication. Some researchers hypothesize that dissolved organic carbon is a cause of increasing dinoflagellate blooms (R. York and D. Anderson, personal communications). However, nitrogen is the most important nutrient and the one of greatest concern.

Potential nitrogen sources

Human activity has profoundly increased the flux of nutrients to coastal waters over the past decades. In the Chesapeake Bay, researchers have estimated that human activity has increased the inputs of nitrogen by six to eight times the natural levels. Inputs to the Gulf of Maine are discussed in another white paper in this series. Briefly, sources include the atmosphere, wastewater, storm water runoff, agricultural runoff, silviculture, and aquaculture. Inputs can also come from other marine waters, across the oceanic boundaries of the Gulf of Maine.

Manufacture of fertilizers, combustion of fossil fuels, and production of nitrogen-fixing plants all serve to introduce biologically available forms of nitrogen into the atmosphere where they can be directly deposited onto marine waters or deposited onto land and subject to runoff in storm water. Nitrogen deposition onto marine waters can be a substantial portion of the total nitrogen load.

In heavily populated areas, wastewater inputs can be the major source of nitrogen to coastal waters, either as discharges from sewage treatment plants or as runoff from septic systems. Traditionally, managers have looked first to the point sources of wastewater when they have developed plans for controlling nitrogen inputs. Unfortunately, secondary treatment of sewage effluent removes only about 20 to 25% of the nitrogen. Tertiary treatment is more successful at nitrogen removal, but is rare in the Gulf of Maine.

Over the country as a whole, use of fertilizers in agriculture increased dramatically after World War II (NRC, 2000). Within the Gulf of Maine watershed, the State of Maine contains most of the agricultural land. Silviculture has been important in Maine and New Brunswick for 200 years and when not practiced appropriately can drastically increase runoff.

Only 20 to 30% of the nitrogen and phosphorus added to aquaculture operations is incorporated into fish biomass and removed at harvest; the other 70 to 80% of added nutrients is lost to the environment as metabolic waste, feces, and uneaten food fragments (Chambers *et al.*, 2001). Aquaculture facilities have increased in the Gulf of Maine over the past decade.

Managers often focus on the human inputs within their own regions, forgetting that ocean waters flow across regional boundaries. Water enters and exits the Gulf of Maine primarily through the Northeast Channel, which divides Browns Bank and Georges Bank. Water also flows along the eastern and southern edge of Nova Scotia and into the Gulf of Maine, and water exits through the Great South Channel, south of Georges Bank. The nitrogen budget for the Gulf of Maine is dominated by these cross-boundary exchanges (Townsend, 1997). Even in Massachusetts Bay, where wastewater loads are highest, water quality models show that the majority of nitrogen is advected into the Bay from the Gulf of Maine rather than introduced by local riverine and point source discharges (HydroQual, 2000).

Natural conditions

The natural environment, including physical, chemical, and biological conditions, has a major effect on whether nutrient inputs result in eutrophication. Understanding the natural conditions and how they affect specific areas of the Gulf of Maine is a critical part of understanding the overall problem. While managers can learn from the studies that have been conducted in the Chesapeake Bay and the Gulf of Mexico, it is important to recognize the differences between those areas and the Gulf of Maine. For example, unlike the Chesapeake Bay region, the Gulf of Maine watershed is dominated by highly permeable sand and gravel aquifers. Consequently, groundwater is a more dominant source of nutrients in the Gulf of Maine. Indeed, in some shallow New England estuaries, over 80% of the total inorganic nitrogen inputs come from groundwater discharge (Roman *et al.*, 2000).

NRC (2000) lists the most important factors in determining a water body's susceptibility to nitrogen over-enrichment, ranging from the physiographic setting to the spatial and temporal distribution of nutrient inputs. Various researchers have tried to classify estuaries based on geomorphology, hydrodynamics, or habitat types. NOAA has been developing a classification scheme that would rate the susceptibility of estuaries to nutrient over-enrichment. Classification can be useful in comparing across multiple estuaries or regions. Such schemes are of less value to managers working within a single estuary. For those managers, a thorough understanding of estuary-specific conditions is necessary both for assessing nutrient issues and for developing appropriate controls.

Monitoring potential environmental effects

Briefly, the ecological effects of eutrophication can include increased primary productivity, increased oxygen demand and hypoxia, shifts in community structure of bottom communities as a result of anoxia and hypoxia, changes in plankton community structure caused directly by nutrient enrichment, blooms of undesirable "nuisance" species of microscopic algae, degradation of seagrass and algal beds, and disease and pathogen increases. While estimating nutrient loads is an important part of defining the problem, monitoring the potential effects often provides the first indication that over-enrichment has occurred. Given limited resources, managers may invest more in monitoring effects than in monitoring nutrient loads.

Monitoring chlorophyll levels is a simple and direct way of tracking algal growth as a response to nutrients. Chlorophyll a is the most abundant form of chlorophyll in photosynthetic organisms and, for the most part, gives plants their green color. Light attenuation or turbidity is another measure of biomass response to nutrients, although it is influenced by suspended sediments and other factors to a greater degree than chlorophyll measurements are influenced by the same factors.

Dissolved oxygen is one of the best indicators of estuarine health. Nutrient-fueled algal growth can substantially deplete dissolved oxygen levels when algae and plants die, sink, and decay (EPA, 1999a, Chapter 9). Areal extent of submerged aquatic vegetation, seagrass beds, provides another important indicator and one that is sensitive to nutrient conditions (EPA, 1999a, Chapter 18). Maine and Massachusetts have relatively complete coverage (http://www.csc.noaa.gov/crs/bhm/crs_lcr/n_east.html), which can be used as a basis for tracking change.

Production of seagrasses, such as the eelgrass that is found in the Gulf of Maine, is rarely stimulated by nutrient additions. Instead, nuisance blooms of macroalgae can replace the seagrasses. Loss of seagrass beds can further exacerbate nutrient problems, when resuspension of bottom sediments increases and reintroduces nutrients to the water column.

Algal community studies are generally too expensive and time consuming to be used in large-scale or regional studies, except when they are directed towards assessment of specific nuisance species, such as *Alexandrium tamarense*, the organism responsible for paralytic shellfish poisoning and known as red tide in the Gulf of Maine. Outbreaks of *A. tamarense* have occurred in Canada for more than 100 years, in Maine since the 1950s, and in Massachusetts since the 1970s (Anderson, 1997). The toxic dinoflagellate appears to originate from seed beds in the north from where it is transported to the south in years in which wind patterns are appropriate. In Massachusetts Bay, for example, there is no bloom unless there is also a bloom in southern Maine and steady winds from the northeast. The effect of eutrophication on *A. tamarense* blooms has not been firmly established, however, the occurrence of a bloom in a new location is thought to be a warning sign.

In Massachusetts Bay, MWRA takes advantage of the Massachusetts Department of Marine Fisheries monitoring program to assess whether such new occurrences of red tide have occurred. Rather than sampling phytoplankton, the program monitors the presence of paralytic shellfish poison in shellfish. Shellfish, primarily blue mussels, are sampled from 16 primary stations and, if significant toxin is measured at the primary sites, 47 secondary stations are sampled. Maine has a similar program, in which mussels from about 100 sites are monitored weekly. Sampling expands with the season and based on indications of toxicity (www.state.me.us/dmr/rm/public_health/publichealth.html#3).

GETTING THE NEEDED INFORMATION

Managers use existing data, gather new information, and rely upon models to make the assessment of whether nitrogen over-enrichment is a problem.

Existing information

Enough preliminary information has been collected by NOAA, satellite imagery, and individual scientific cruises to accomplish a preliminary classification of those areas within the Gulf of Maine that are most susceptible to eutrophication problems or are already showing the effects of nutrient enrichment. NOAA has made initial assessments to determine which embayments along the coast of the Gulf of Maine are most susceptible to eutrophication problems through a first order assessment of nutrient inputs and flushing (NOAA, 1997; Bricker *et al.*, 1999) followed by surveys of regional experts. Those assessments specified the St. Croix River and Cobscook Bay, Englishman Bay, Narraguagus Bay, Sheepscot Bay, and Casco Bay as the areas in Maine where symptoms of eutrophication occur periodically and / or over an extensive area. The 1999 report notes that conditions in Boston Harbor and Casco Bay are expected to improve with the attention that has been paid to them, but that, without management action, conditions in Massachusetts Bay, Plum Island Sound, Hampton Harbor Estuary, Great Bay, Damariscotta River, Blue Hill Bay, and Cobscook Bay can be expected to decline. Kelly (1997) has also provided a simple tool for assessing nutrient loading, which he tested with a 1995 survey of 19 estuaries and embayments conducted by the Maine Department of Environmental Protection. Kelly argued that systems with low ratios of freshwater input to tidal input are likely to be of low risk for eutrophication.

For regional managers, the questions remain:

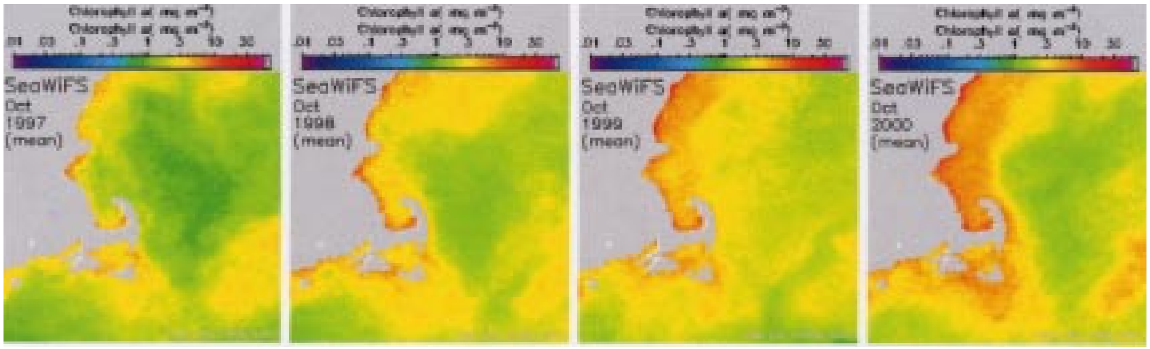
- Are the assessments by NOAA and EPA sufficient to characterize the extent of nitrogen problems in the Gulf of Maine? If so, what is limiting their adoption?
- What institutional factors prevent the progression from assessment to action plans?

New information

Besides conventional sampling methods in which scientists make direct measurements or take samples and analyze them in the field or back at a laboratory, three major tools have been used for rapid assessment of eutrophication: remote sensing, moored arrays, towed sensors.

Figure 1.

Satellite data show an increasing trend in fall chlorophyll levels in Massachusetts Bay, Cape Cod Bay, south of Cape Cod, and in the Gulf of Maine (J. Yoder, URI, J.O'Reilly, NOAA)

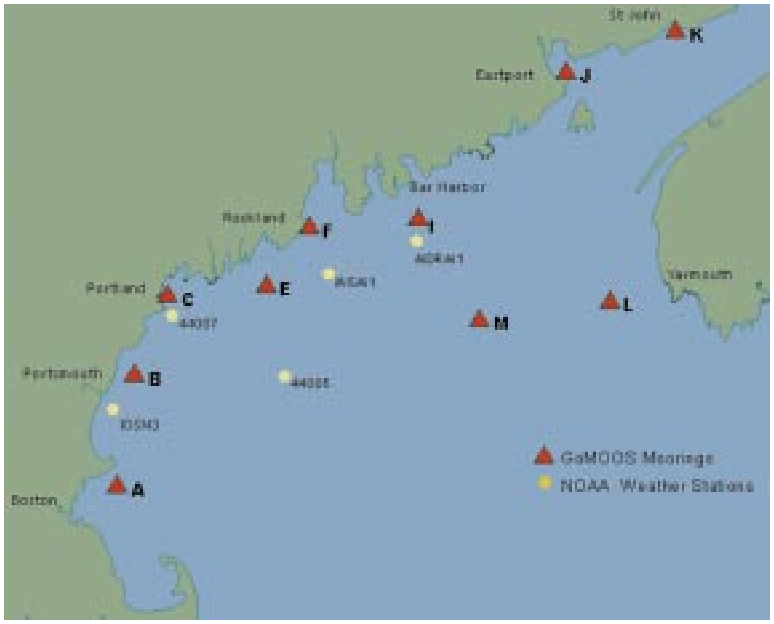


The National Air and Space Administration (NASA) has as part of its mission a goal to view earth from space in order to better understand it as a system. As part of this mission, NASA operates the Sea-viewing Wide Field-of-view Sensor (SeaWIFS) Project. The project has included the launch of a SeaStar satellite, equipped with sensors that use ocean color data to detect magnitude and variability of chlorophyll and primary production. The purpose of the SeaWIFS data is to examine oceanic factors that affect global change and to access the oceans' role in the global carbon cycle. The data are also valuable for wide-scale regional assessments, although their value is limited for the smaller estuaries within the Gulf of Maine (Figure 1). On the smaller scale, aerial photography can provide more appropriate coverage.

Moored arrays—GOMOOS has now developed permanent mooring stations that could continuously monitor water transparency, color, and potentially nitrogen concentrations (Figure 2). At the present time, only two stations in the Gulf of Maine are monitored. Consequently, GOMOOS provides few data that can be linked specifically to data from the small estuaries that ring the area. However, GOMOOS data can be valuable when used to validate or extend the use of models.

Several towed sensor systems are now available. MWRA has recently used one such system, the Battelle Ocean Sampling System (BOSS), for plume-tracking exercises. The BOSS *in situ* sensor package can include instrumentation to measure, for example, conductivity, temperature, depth, transmissometry, and altitude above seafloor. A winch controls the depth of the towed sensor package. Depending on the vessel's speed and winch operation, the system can operate in three different modes: vertical profile, constant-depth towing, or "towyo." In vertical profiling mode, data are captured as a function of depth while the vessel remains stationary. In constant-depth mode, the BOSS is towed through the water continuously at a single depth. During towyo mode the BOSS is operated in a vertically undulating (ascent and descent) pattern to obtain data continuously at different depths while underway. Such systems are usually used to focus on specific point source inputs, such as an outfall plume.

Figure 2.
GoMOOS moorings
in the Gulf of Maine



Most assessments of technology needs for new monitoring systems focus on the importance of sensor technology. Indeed, funding from CICEET has addressed flow cytometers for monitoring phytoplankton (Sieracki, 2001), nutrient sensors (Caffrey, 2001 and Charrette, 2001), improved sensors for aerial video imagery (Crawford, 2001), and fluorescence sensors (Anderson, 2001). The major issue for coastal managers is:

- How can these new monitoring tools be integrated into Gulf of Maine monitoring systems?
- Should the Gulf of Maine Council develop a gulf-wide nutrients monitoring plan?

Modeling

Managers typically use models to synthesize and interpret measurement data. A good model can help managers understand the nature of the problems and predict the success of possible management options. There are two basic categories of models useful in assessing problems of eutrophication in coastal waters: watershed models and coastal models. NRC (2000) separates watershed management models into three categories:

- Models that simulate watershed processes.
- Models that use land-use categories and data on chemical concentrations to estimate nutrient loads.
- Models that use regression or other statistical techniques to relate water quality measurements to characteristics in the watershed.

Most of the detailed models that simulate watershed processes are limited to the research community in the Gulf of Maine (*e.g.*, Valiela, 2001). However, CICEET has funded a number of studies that would improve loading estimates into the Gulf of Maine (Loder, 2001; Lathrop, 2001; Vorosmarty, 2001), in some instances by developing Geographic Information System (GIS) layers for use by town planners. Most large municipalities (Boston, Detroit, Atlanta, Columbus, GA, etc.) are using a version of SWIM, an EPA-approved land-use / runoff coefficient model for their planning for Combined Sewer Overflows or storm water treatment. Regression models are mostly part of a rapid assessment exercise.

Estuarine and coastal models are increasingly important to managers. The models typically combine hydrodynamics and water quality data. Off-the-shelf models are available, but competent technical personnel are necessary to ensure that the models are used appropriately. EPA supports the use of a suite of models including the WASP and QUAL families. Managers must ensure that the parameters being modeled and the degrees of accuracy and precision of the information being generated will provide useful results.

More sophisticated water quality models that incorporate food-chain information, sediment remineralization, and other ecological processes are becoming more common. Because these modeling efforts require extensive amounts of data to set, calibrate, and validate model parameters, they can be quite expensive ($500,000—$5,000,000) to develop. Thus, their use is usually limited to projects with high enough projected capital costs to warrant their expense (*e.g.*, Chesapeake Bay, Long Island Sound, New York Harbor, Massachusetts Bay).

The choice of models will require that two issues that are particularly important in the Gulf of Maine, nitrogen transformations in the sediments and advective transport of nitrogen between offshore and estuarine waters, be adequately captured. These important processes are quite expensive to represent by modeling. The development of some extensive circulation models for the Gulf of Maine by Lynch and others may allow for some simple estimations of the advective transport problem. Even the most sophisticated models have limited goals—it would not be possible to predict algal community succession nor further stages of the food chain on the basis of changing nutrient inputs.

At a first level, simple models (box models, regressions) can provide a quick assessment of the problem and the magnitude of the reductions necessary. NOAA / EPA (1989) screening approach uses average salinity and freshwater input to roughly assess flushing in each of the region's estuaries. By combining flushing with a qualitative assessment of nutrient loading, estuarine susceptibility is rated. Eric Adams and others (1992) were able to capture much of the Boston Harbor problem with a two-box, mass-transfer model containing very little biology. Nixon (1992) has been able to describe much of the susceptibility to eutrophication by simple regressions of loading to chlorophyll. Dettman (2001) has refined the Nixon and Klein approaches to provide a tool that would allow a good first-order classification of the status of Gulf of Maine nearshore waters.

Important questions regarding modeling include:

- What level of sophistication is necessary in the watershed models? Are the land-use category models sufficient?
- How will CICEET-funded studies change estimated loadings to the Gulf of Maine?
- Can these loading models be combined into a GIS layer with Dettman's methodology to develop some "rules of thumb" for different coastal towns to use to regulate development (*e.g.*, the way some Cape Cod towns are trying to protect salt ponds)?

- Would a screening evaluation using Dettman's methodology help Gulf of Maine managers?
- Is there any benefit to take a Gulf of Maine-wide approach, or is the use of smaller estuarine models more appropriate?
- Without the capability of easily handling sediment processes and advective transfers between the Gulf of Maine offshore waters, is there any benefit to using the EPA WASP or QUAL-family models? Can these issues be handled in some other manner?

USING THE DATA TO ASSESS NUTRIENT LOADS

Managers then use their understanding of the problem and the existing and new data to assess nutrient loads to the waterbody of concern. A very preliminary evaluation of loads to the US portion of the Gulf of Maine was conducted by NOAA in the 1980s. The National Coastal Pollutant Discharge Inventory used data gathered by the National Urban Runoff Program to estimate point and nonpoint pollutant loads to geographic units. These units were defined by US Geological Survey (USGS) cataloging units, counties, and unique areas made by overlaying county lines on the USGS cataloging units. Unfortunately, the efforts focused on the only United States, limiting the value for the Gulf of Maine.

A more detailed assessment was conducted for the Massachusetts Bay system by Menzie-Curie & Associates (1991). Loads were calculated from several sources and on several scales: (1) individual major point sources throughout the entire drainage basin, (2) point sources that discharged directly into coastal embayments or the open bay, (3) inputs summed for each of 27 rivers in the system, (4) point sources, runoff, and in a few cases groundwater discharges for 5 drainage basins, (5) coastal runoff from the zone located within 0.5 miles from the coast, (6) in-place sediments and hazardous waste sites within 500 feet of a surface water body, (7) ocean disposal of dredged materials, and (8) inputs from atmospheric deposition.

Using 1991 data, Pait (1994) estimated that more than 300 MGD (million gallons per day) of effluent flowed into the Gulf of Maine from at least 378 wastewater treatment plants each day. A decade later, those estimates need updating—MWRA alone discharges 360 MGD into Massachusetts Bay. Point source treatment has dramatically changed since these earlier assessments were completed, and there is a better understanding of non-point source loading assessments through the extensive work conducted in the Chesapeake Bay. The preliminary assessments should be quickly updated to determine the most important and uncertain areas requiring an improved assessment.

CONTROL

Control of nutrient discharges includes setting goals, taking actions, and evaluating the success of actions in meeting the goals.

SETTING GOALS

For effective control of nitrogen over-enrichment, managers must have meaningful and realistic goals for preservation or remediation of an area. The goals may address two issues, source reduction and environmental conditions.

Currently, most states have simple narratives as nutrient standards. EPA has developed draft criteria (http://www.epa.gov/waterscience/standards/nutrients/marine). With review and adoption of these criteria, there will be increasing pressure for states and provinces to develop standards. The question that managers have is: What technical information is needed for states and provinces to develop water quality standards for nutrients?

When the goals relate to environmental conditions, managers must select target indicators and target levels for those indicators. For example, NRC (2000) lists several primary indicators: variations in algal composition, elevated concentrations of chlorophyll a, and increase in the extinction coefficient for given water bodies. As secondary indicators, NRC lists changes in the dissolved oxygen regime, changes in the areal extent of seagrass beds, and changes in the frequency, duration, or areal extent of nuisance algal blooms.

TAKING ACTIONS

Control strategies depend on the source of nutrient loads to the system. Given that managers already have some knowledge about the important sources of nutrients to the Gulf of Maine, it is important to make progress on controls even while assessments are ongoing. A first level of control could simply be an assessment of extent of compliance with existing laws and regulations. Managers may be surprised to learn that they are not always already doing what they'd already planned. Coming into compliance with existing regulations can be an effective first step at controlling eutrophication.

A second step may be to prioritize watersheds that have the largest or most difficult problems. The largest freshwater discharge is the Saint Johns River, and consequently it is an important source of nitrogen to the Gulf of Maine as a whole. Another priority watershed, the St. Croix Estuary is already using the watershed-wide approach to address effluent limits, septic system loads, and storm water runoff (www.scep.org). Depending on the extent of the problem, simple or complex waste-load allocations could be developed for the highest priority watersheds, followed by implementation planning. Since waste-load allocations have the potential to be time and resource-intensive, an alternative approach would be to develop a hierarchy of regulatory and non-regulatory actions for watershed priority classes.

As an alternative or supplement to a watershed approach, implementation can focus on the specific sources of nutrients, such as point sources, septic systems, storm water runoff, atmospheric sources, agriculture, silviculture, and aquaculture.

Point sources

Loading from point sources can be reduced by treatment. Conventional primary treatment reduces total nitrogen loading by 2-28% (NRC, 1997). Conventional secondary preceded by conventional primary treatment reduces total nitrogen by 0-63%. Tertiary or biological nutrient removal treatment preceded by conventional primary and secondary treatment removes 80-88% of the nitrogen. Among Canadian municipalities discharging to Atlantic coastal waters and the St. Lawrence estuary, about 18% of the population is served by sewers that received primary treatment, about 34% received secondary treatment, while 48% had no treatment (EC, 2001). In the US almost all sewered systems receive primary and secondary treatment. Costs of tertiary treatment are being reduced through innovative variations to the basic activated sludge process (Kerr, 1999; Mitsch *et al.*, 1999; Doering *et al.*, 1999). Variations in operating procedures and low-cost retrofits may increase nutrient removal in secondary treatment (Kerr, 1999; WERF, 2000). This approach has been particularly successful in Long Island Sound.

Because sewage treatment plants provide a centralized location where nitrogen discharges are concentrated, the cost-effectiveness of nitrogen removal can be better than other management alternatives. Trading schemes may provide incentives to achieve economically efficient nutrient reduction. In the Gulf of Maine, MWRA is required to maintain a comprehensive technical survey of nitrogen removal technology. In its most recent review (CDM, 2001), MWRA evaluated suspended growth, fixed film, and hybrid systems to provide habitat for nitrifying and denitrifying microorganisms. Capital costs of $460—480 million and operating costs of $35 million would be required to reduce nitrogen loads by 30-40 tons per day. To some extent, these costs are high due to the land constraints caused by the plant's location—constraints faced by many coastal treatment plants. The costs are also a function of the aggressiveness of the effluent goal. Long Island Sound managers have had a great deal of success in making inexpensive modifications to plant operations that have yielded incremental reductions in nitrogen releases.

A large part of the operating expense of tertiary treatment is the addition of methanol to provide a carbon source for nitrate reduction (CDM, 2001). Combining nitrogen removal with primary treatment may be a preferable point source control strategy for the remaining Canadian discharges.

The cost-effectiveness of point source control strategies makes this a favorite strategy by nutrient managers, but in the Gulf of Maine:

- Are there cases where point source control of nitrogen will be effective in solving existing problems?

Septic systems

Most of the growth in the coastal community is occurring in suburban and rural communities where centralized sewage treatment is sparse—for instance, the fastest growing county in Massachusetts is Barnstable County, approximately synonymous with Cape Cod. As part of the National Estuary Program, the Buzzards Bay Project has developed field tests to evaluate the effectiveness of different septic system technologies for nitrogen removal (http://www.buzzardsbay.org).

Many coastal managers, though, are not confident that this problem is best approached by technology solutions—they wonder where regulatory control of regular inspection and maintenance of septic systems would lie (DeMoss and Stacy, personal communications). It is important to realize that eutrophication problems co-occur with a large subset of related problems. Many of the control strategies are encompassed by different planning strategies for controlling urban sprawl. Nearly everyone who has worked on these issues agrees that the only long-term solution is a massive planning approach that includes cluster communities mixed with open space.

There are several remaining questions:

- Can septic system loads be cost-effectively reduced by new technologies?
- How would this control technology be monitored and maintained?
- Are cluster development or small-scale waste pumping and treatment systems more cost-effective solutions?

Storm water runoff

With the implementation of storm water discharge regulation through the NPDES program there is an increasing database available evaluating the contribution of storm water discharges to coastal nutrient loads. Storm water loading estimates associated with land types are available from a variety of sources, as are Best Management Practices (BMP) for urban and suburban storm water control. For instance, CICEET is funding studies to evaluate storm water control systems to protect Great Bay (Ballestero, 2001; Davis, 2001). A major remaining question is to determine the most cost-effective elements of storm water control.

Atmospheric sources

Atmospheric source control is important to the regional nitrogen budget but is largely out of the hands of regional managers. The sensitivity of the Gulf of Maine to distant transport is demonstrated by the large number of exceedances of ozone standards at Acadia National Park, far from any local sources. Atmospheric source control is an important part of the nitrogen control strategy in both Chesapeake Bay and Long Island Sound. In Long Island Sound, implementation of the Clean Air Act will reduce atmospheric nitrogen loads by almost 20% (NYSDEC and CTDEP, 2000). Larger reductions depend on national strategies. These reductions would not only reduce eutrophication issues, but also address other significant issues in the Gulf of Maine including ozone non-compliance and the acidification of lakes and forests.

One potential regional action is a regional assessment of the status of catalytic converters (Howarth, personal communication). Contaminated converters can be over-reducing, converting nitrogen oxides into ammonia rather than nitrogen gas. Ammonia is more immediately available to plankton and clearly more of a problem.

Agriculture and silviculture

Most of the agricultural watershed draining into the Gulf of Maine is in the state of Maine, which has recently evaluated the impact of agriculture on nutrient and sediment loads (ME DAFRR and ME DEP, 2001). While the impact of agricultural loads to the Gulf of Maine has not been examined in depth, significant deterioration to many of Maine’s streams and lakes has been caused by agricultural sources of sediments, nutrients, and pathogens. As a result, Maine has actively developed Best Management Practices (BMPs), and a significant number of farmers have implemented BMPs (Jemison *et al.*, 1997). The survey found high adoption rates for some BMPs such as planting across the slope, using buffer strips, stabilizing eroding ditches, using reduced tillage, and better manure management. The adoption of other BMPs, including using winter cover crops and controlling livestock access to streams, remained low. In addition, there has been very little assessment of the loads associated with these BMPs and whether additional regulatory or voluntary programs are necessary or more complete implementation of the existing programs would be sufficient.

New Brunswick has addressed silvicultural and agricultural loads through the BMPs, developed by governmental agencies and the provincial federations of agriculture. In addition, farmers have been taught how to prepare environmental farm plans that include audits of farm practices to minimize nutrient loading problems. One interesting outreach project is the Fundy Model Forest, which has developed sustainable forestry practices for 420,000 hectares of Acadian forest, including a video on BMPs to protect water quality (www.modelforest.net).

Several questions remain:
- Do agriculture loads have a significant impact on Gulf of Maine eutrophication, and if so, where?
- Are existing BMPs sufficient to control these problems or are new methods necessary?
- Do BMPs work?

Habitat Remediation

Habitat remediation and other ecological restoration strategies have become increasingly important as part of nutrient management strategies. The restoration of wetlands to intercept nutrient loads has been proposed as an important component of the Gulf of Mexico hypoxia control strategy and has been used in a handful of situations in New England. Two other ecological restoration strategies have been funded by CICEET in New England, the development of a mechanical planter for the restoration of eelgrass beds (Nixon, 2001) and the restoration of oyster beds in Great Bay to improve water clarity (Grizzle, 2001).

At present, the use of habitat remediation needs an overall strategy, including:
- Can a management plan for habitat remediation be developed?
- Can remediation techniques be matched to particular habitat locations in the Gulf of Maine?
- How can habitat remediation and nutrient control strategies be matched in the Gulf of Maine?

EVALUATING SUCCESS

Ongoing monitoring of the nutrient loads and environmental effects of nutrient additions is a necessary part of any program to assess and control eutrophication. Managers should evaluate monitoring results in context with the goals and targets. Results should be interpreted in a context of the desired uses of the water body and should provide a basis for a feedback loop. If goals are not being met, then control strategies should be re-evaluated. When goals are met, then managers must be prepared to shift from a philosophy of remediation to one of preservation.

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No.3

Pressing Management Issues Related to Nitrogen in the Gulf of Maine Region

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INTRODUCTION

Other papers in this series (Werme / Connor, Sowles,) discuss sources and amounts of nitrogen entering the Gulf of Maine and its surrounding estuarine systems. Generally, the principal source of nitrogen for North Atlantic estuarine waters is from offshore coastal waters (Bricker, 1999). Moderate or higher levels of eutrophication occur in many of the estuarine systems and tend to be localized there. Information on loadings, sources, and impacts to estuaries, however, is limited and uneven. Bricker *et al.* (1999) note six estuarine systems in the US portion of the Gulf of Maine where symptoms of eutrophication "occur periodically and / or over extensive areas":

- St.Croix River / Cobscook Bay (ME)
- Englishman Bay (ME)
- Narraguagus Bay (ME)
- Sheepscott Bay (ME)
- Casco Bay (ME)
- Boston Harbor (MA)

In two of these—Boston Harbor and Casco Bay—symptoms of eutrophication are projected to decline over the coming 20-year period. Only in St. Croix River / Cobscook Bay are conditions expected to worsen. Bricker *et al.* further note that only one of these, Boston Harbor, has high human-related sources.

Five other estuaries or embayments show moderate symptoms ("generally less periodic and / or occur over medium or smaller area") with three (Damariscotta River (ME), Great Bay (NH) and Massachusetts Bay (MA)) expected to worsen.

Unlike other water bodies (*e.g.*, Long Island Sound), anthropogenic nitrogen loadings in the Gulf of Maine do not appear to have had system-wide impacts. Consequently, watershed and regional managers must focus on individual estuarine and embayment systems rather than the Gulf as a whole. Estuarine and embayment management programs in the Gulf of Maine may be complicated when the principal sources of nitrogen—waters from the Gulf or atmospheric deposition—are external to the system and consequently beyond the control of a localized management program (although some sources of atmospheric deposition may be addressed at the state or provincial level).

For a watershed or regional manager, a significant issue becomes determining whether the particular embayment 1) already exhibits symptoms of a nitrogen-related problem, 2) is approaching a stressed condition and threatened with worsening conditions, or 3) has both the current and anticipated capability to process the levels of nitrogen being input to the system. If nutrient loading is an issue of concern in a particular embayment, the regional manager will have to decide whether there are local sources (*e.g.*, development, agriculture, or aquaculture) that can be successfully controlled to prevent eutrophic conditions.

Management Issues

Because nitrogen can travel into and through an estuarine or embayment system in a variety of ways, management issues will take many forms. Those most commonly seen sources / management issues in the Gulf of Maine region include:

- Point source loading

  Pait (1994) in a 1991 point source inventory for the Gulf of Maine, noted that approximately 90% of the nitrogen inputs from point sources were from wastewater treatment plants and approximately 9% from industry (about half of that from the pulp and paper industry). Although Pait did not separate discharge sites and volumes between estuaries / embayments and the open waters of the Gulf, many of the point discharges are into enclosed waters. The management issues associated with point sources are typically related to establishing appropriate discharge limits and subsequent enforcement of those limits. From the time of Pait's report, treatment at several of the larger wastewater treatment plants has been significantly modified, particularly at the Massachusetts Water Resources Authority where secondary treatment was installed and the outfall extended from its former location near Boston Harbor to a point 12 miles out into Massachusetts Bay. Combined sewer overflows (CSOs) also exist in some areas of the Gulf of Maine and may discharge significant amounts of nitrogen during storm events.

- Atmospheric deposition

  The airshed for the Gulf of Maine extends over many states and provinces. This suggests that a significant amount of the nitrogen deposited from the atmosphere into the Gulf of Maine comes from outside the watershed—although the exact fraction is unknown. This means that management of this source must be done at a multi-state/province or national level. Both Canada and the US have air quality emission programs in place and both are working to adjust them to reduce levels of nitrogenous compounds.

- Urban/suburban runoff

  Management of runoff and the pollutants it carries is a complex issue. In many, if not most locations, storm water is discharged directly into estuaries or their tributaries with no opportunity for any sort of treatment. Another complicating issue is the myriad of sources supplying nitrogen to the storm water—fertilizers, atmospheric deposition onto land, pet waste, etc. Management schemes have to address engineering, maintenance, and land use issues to minimize this source. A project in Jordan Cove watershed, Waterford, Connecticut has been testing the effectiveness of various best management practices related to a residential development. Designers feel that nitrogen export through runoff can be reduced by 65% through these means (Coastlines, Autumn 1996, www.epa.gov/ordntrnt/ORD/webpubs/netuw/cote.pdf).

- Septic systems

  A significant portion of the watersheds draining into the Gulf of Maine is not served by centralized treatment facilities but rather with on-site septic systems or package treatment plants serving limited areas. When operating according to design, these discharge into the ground—and ultimately groundwater. Depending on the nature of the geology of the area, nutrients may move fairly rapidly to estuarine waters (*e.g.*, through fractured granite bedrock) or take decades to travel through sandy soils. While most conventional on-site septic systems provide very little treatment for nitrogen (effluent containing on the order of 50 mg/l nitrogen is not uncommon (Horsley & Witten, 1999)), "alternative" systems designed for nitrogen removal may dramatically reduce the concentrations discharged into groundwater.

- Agricultural inputs

  The Gulf of Maine lacks the extent of intense farm practices noted in other parts of the US and Canada. Potato, blueberry, and dairy farming are the most significant agricultural practices in the region. Forestry also occurs widely in the watersheds draining to the Gulf of Maine and improper practices may dramatically change runoff characteristics or the ability of the forest system to take up nitrogen. Best management practices are available and, in many cases, technical and financial assistance are available to help put them into place. The USDA offers Environmental Quality Incentive Grants and Forestry Incentive Grants to help fund best management practices related to issues such as water quality related to livestock agriculture, nonpoint source issues in Atlantic Salmon watersheds, grazing land management, and erosion control associated with forestry practices.

- Aquaculture

  Finfish aquaculture is a developing industry in the Gulf of Maine and concerns have been raised about the concentration of nitrogenous materials from feeding and excretion. Sowles (2001, this series) cites Hardy (2000) noting that there have been significant efforts by the industry to increase food transfer efficiency and minimize release into the environment that have had the result of lowering "nutrient loss significantly over just the past five years." Nevertheless, there remains public concern about the impacts of aquaculture when conducted in or near the confined waters of coastal embayments.

- Marinas and boating

  Mooring and marina areas are often considered sources of nutrients during the boating season. Programs to address this concern have been established at all levels of government. The USEPA has begun a "clean marinas" effort providing technical assistance in the operation of marinas in an environmentally sound manner. In the US, federal funding is provided to marinas and municipalities to establish pump-out facilities in harbors, and federally designated "no discharge zones" prohibit any discharge of waste from boats. However, enforcement of no discharge conditions remains uneven.

- Denitrification

  In instances where source reduction is ineffective or where appropriate levels cannot be met, "treating" the sources or the system to remove nitrogen is often considered. This may take the form of advanced treatment levels for wastewater treatment plants (see Werme & Connor this series), denitrifying septic systems, or other engineering approaches. Other methods include diverting storm water, industrial, or wastewater treatment plant discharges through natural or created wetlands to provide "polishing" of the effluent. In this case, nitrogen is taken up in vegetation—in some instances harvesting and removal is necessary. The wetland vegetation may be either submerged or emergent. Other natural "filtration" may take place in vegetated corridors along stream banks.

Public awareness of the issues

Nitrogen loading and its impacts are not typically high visibility environmental issues for the general public. They lack the visceral reaction caused by sewage contamination and generally do not affect economics or recreational activities in the immediate and apparent way that a shellfish bed closure does—although there is a growing awareness of the links between excess nutrients, harmful algal blooms, and human health and recreation in some geographic areas or segments of the population. Non-point source pollution, particularly when it is related to the invisible movement of groundwater or atmospheric deposition, is a particularly difficult concept for the non-technical person to grasp. Consequently, without considerable public outreach/education, there is not apt to be sufficient broad public support for the implementation of management actions that might either require a change in human behavior (voluntary or otherwise) or the expenditure of public funds.

A key aspect of most watershed management efforts is public outreach. Each of the three US National Estuary Programs (NEPs) in the Gulf of Maine (Casco Bay, New Hampshire Estuaries, and Massachusetts Bays) and the four Atlantic Coastal Action Plans (ACAP) in Canada (St. Croix Estuary Project, ACAP St. John, Clean Annapolis River Project, and the Eastern Charlotte Waterways, Inc.) have either a regular newsletter or a web site through which the issues important to that program are discussed. Most of these programs sponsor workshops or have technical and outreach staff attend public meetings to promote awareness of environmental issues and possible solutions. At the national level, environmental agencies have web sites and the USEPA produces a bi-monthly newsletter, "Coastlines", providing "Information about Estuaries and Near Coastal Waters". (This publication may also be found on the Internet at www.epa.gov/owow/estuaries/coastlines .)

Virtually all management mechanisms require broad public acceptance to be effective. Whether it be funding engineering solutions to wastewater treatment, rezoning an area so that density matches the capacity of the system, or implementing best management practices for agriculture or forestry, those regulated or taxed need to understand why these mechanisms have been put into place and what the benefits will be as a result of the expenditures or modifications in behavior. Otherwise, there will not be support for funding or there will simply be a lack of consistent compliance.

Watershed groups, whether part of the NEP or the ACAP system or independent watershed associations, quite often act as a forcing mechanism to bring together technical expertise, stakeholders, and managers to focus on a problem and a solution. An example of this comes from Buttermilk Bay, MA—part of the Buzzards Bay National Estuary Program. Buttermilk Bay is threatened with eutrophication, in large part due to nutrients from on-site septic systems moving through groundwater into the bay. Its watershed extends into three municipalities, one of which does not front on the bay. When a nitrogen loading model indicated that a full build-out of the watershed would increase nutrient discharges to a level that would tip the system into a eutrophic state, managers assessed possible options and decided that the most economic and effective solution would be rezoning of the land in the watershed to limit the density of septic systems. To effect the changes in zoning, each town, through its annual meeting of the citizens, had to formally vote in favor. In this instance the public outreach effort was sufficiently effective that the public recognized the issues and the need for a solution—and passed the zoning changes almost unanimously, even in the town that doesn't front on the bay (Horsley & Witten, 1991; Coastlines, Spring 1996).

National Estuarine Research Reserves in the Gulf of Maine (Great Bay, NH; and Wells, ME), as well as Waquoit Bay, on the south side of Cape Cod, have been active in promoting understanding of nutrient loading through workshops, publications, and will, in the near future, be expanding a Coastal Training Initiative designed to "translate" the latest scientific findings for managers. The Waquoit Bay National Estuarine Research Reserve has been particularly active in the area of nutrient loading from the watershed to an embayment and has produced a number of publications related to its management. This information is available through their web site at http://www.waquoitbayreserve.org/ .

Another example of an effective program bringing science to managers is the Nonpoint Education for Municipal Officials (NEMO) program through the Cooperative Extension System at the University of Connecticut. Their program entitled "Linking Land Use to Water Quality" provides ways to quantify the predicted impacts on water quality from various land use scenarios. Additional information is available on their web site http://nemo.ucon.edu/ .

Management Mechanisms

Regional and watershed managers initially attempt to establish goals for nutrient levels and loadings for specific embayments. This process entails setting target goals (defining "how clean is clean") for the embayment and what levels of input the waterbody can tolerate before it becomes "unclean". From there, the mechanics of the estuary need to be understood—total loadings, flushing rates, uptake within the estuary and watershed, etc.

Last year the Washington, DC Environmental Law Institute (ELI) issued a report entitled "Putting the Pieces Together" (ELI, 2000) that assessed several state nonpoint source control mechanisms. The report found that when states link all of their nonpoint source efforts to watershed assessment and planning it "improves accountability for outcomes, while it enhances delivery of cost share and technical assistance. It also ties enforcement more closely to water quality objectives." Many federal agencies have organized around a watershed management basis; examples include the USEPA §319 nonpoint source grant program which requires watershed assessments for some funding, the USEPA-state National Estuary Programs, the NOAA-funded §6217 programs which foster state coastal nonpoint source management programs, and the ACAP programs in Canada. Many state and provincial programs are also managed on a watershed framework.

In the US, a prime management mechanism for this process is through the Total Maximum Daily Load (TMDL) program under the Clean Water Act. Section 303(d) of that Act requires that states and tribes develop lists of waters that do not meet established water quality standards, prioritize them, and prepare TMDLs that will allow the water bodies to meet those standards.

While the TMDL program provides a mechanism for nutrient management, it requires significant development time. As of the most recent state surveys of impaired waters (1998), few in the Gulf of Maine are listed as being impaired specifically due to nutrient problems. Maine lists 5 impaired estuaries with none related to nutrients; New Hampshire lists 9 with again none related to nutrients, while Massachusetts lists 50 in the Gulf of Maine with six embayments in the Charles River watershed listed as being impaired by nutrients (2001, www.epa.gov/owow/tmdl/). According to the USEPA Region 1 Office, the number of estuaries in these states impaired by nutrients is "probably significantly undercounted" (Bruce Rosinoff, USEPA Region 1, Personal Communication). A major part of the difficulty with listing nutrient-impaired waters is the lack of consistent water quality standards for nutrients in estuaries. Massachusetts is currently beginning a long-term project to identify such standards, assess estuaries from Duxbury south to the Rhode Island border for nutrient problems, and develop TMDLs for the corresponding watersheds.

Once the maximum loadings are identified, management techniques to meet the established standards may take several forms. Initially they may be divided into regulatory and non-regulatory forms.

Regulatory techniques find their basis in the “police powers” granted to various levels of government in order to protect the health, welfare, and safety of the citizens. Point sources in the US are controlled through the National Pollution Discharge Elimination System (NPDES). However, nitrogen is not a routinely managed pollutant for many discharges. Some sources, traditionally considered as nonpoint sources are beginning to be regulated in the US as point sources. This includes Concentrated Animal Feeding Operations (CAFO) and some aquaculture operations. Discharge permits with mandated maximum levels of pollutants may be required for these activities. Unfortunately, in many instances the information needed to write effective permits in these areas is lacking.

The ELI report referenced above found that almost all states utilize an array of management tools to address nonpoint pollution, including some form of enforceable regulatory program. These mechanisms may take the form of defining ways specified operations must be conducted (*e.g.*, “stay a specified distance from the waterway”) or they may take the form of a defined “punishment” for causing the violation of a resource-based standard (*e.g.*, “the discharge from your site (even if it is not from a point source) caused pollutant levels to go above specified standards”). The report further suggested that mechanisms of the latter type were less effective than the former primarily because they take effect only after the violation has occurred (although it may be argued that the incentive of avoiding “punishment” leads to voluntary compliance). A lack of effective monitoring and timely enforcement may also be an issue.

The ELI analysis found that all of their test states (Maine was the only one of the Gulf of Maine states that was addressed, although the suggestion was that most other states have some form of regulatory management capabilities) either have, or can establish within an existing legal construct, measurable standards for practices ranging from “land clearing and grading” to “timber harvesting” to “concentrated animal feeding operations. ” While the report found that regulatory / enforceable methods are generally not the initial option in the management of nonpoint source pollution, they are necessary as “an essential back-up to other strategies” and may be critical in instances of non-compliance with voluntary programs.

While all of the test states in the ELI study had established programs enforceable throughout their jurisdictions, many have special “overlay” programs that provided special emphasis on particularly sensitive areas. Maine’s Mandatory Shoreland Zoning Act is an example of this whereby municipalities are required to adopt a local ordinance consistent with state standards and offers a mechanism to protect “nutrient sensitive waters.”

Enforcement procedures related to instances of nonpoint source pollution generally are utilized only after all other approaches have failed. Consequently, to be effective, the enforceable mechanisms must be straightforward, and effective in a rapid and efficient manner. There is, however, a suite of other *a priori* enforcement procedures utilized in most communities that directly affect nutrient loadings. These include such things as health codes, zoning, building codes, wetlands protection, etc. While many of these are not developed specifically to manage estuarine water quality, they may be quite effective—if the ordinances and regulations incorporate measures to address pollution issues. Some of the available options include:

- Zoning

  As noted in the Buttermilk Bay example above, zoning may be used to limit density of development to a level compatible with established standards of water quality. This can limit the number of on-site septic systems in un-sewered areas and thereby limit the nitrogen input from these sources. Cost to the community is generally minimal—the argument that reduction of the number of structures will lessen the tax base depends greatly on the demographics of the community as to its validity. Zoning has its limits in that many areas are already zoned into small lot sizes that are “grand-fathered” and thereby not subject to change. If not used carefully, increased lot size zoning may also lead to sprawl. (Cluster zoning may avoid this concern.) Finally, large lot sizes may lead to challenges based on the concern for “snob zoning” (*i.e.*, large lots purposely keeping prices out of the reach of some portions of the population). This may generally be overcome by a clear definition of the reasons for the zoning and technical backing for the decisions reached.

- Building, construction and subdivision codes

  Building and construction codes typically establish standard procedures for such aspects of development as land clearing, storm water control, impervious surface, etc. They generally have little direct cost to the community; additional costs are absorbed by the developer or, more commonly, passed on to the purchaser. Requirements typically call for the use of best management practices.

- Health regulations

  Health regulations may be applied to the design, construction, use, and maintenance of systems used for human waste disposal—wastewater treatment facilities, on-site septic systems, boat pump-out facilities, etc. As with building and construction codes, the cost to the municipality is generally not great, with costs being passed on to the purchaser. A difficulty with this approach is that the mechanism is typically designed to protect human health, not environmental health. Consequently, environmental benefits are often incidental. Post-construction enforcement is often a problem.

- Wetland Ordinances

  Because wetlands have been shown to be a critical component affecting water quality, both at the surface and in groundwater, protective ordinances can be an effective means of maintaining these vital interests. Because there are a significant number of technical issues associated with boundary definitions and impacts from proposed projects on wetlands, this may be a time-consuming and/or expensive option. The benefits however, may be great over the long run.

- Water quality standards

  Standards for levels of pollutants allowable in any given water body may be related to a specific discharge or to a maximum allowable level, often in the form of a Total Maximum Daily Load (TMDL) as discussed above.

Social, economic, and ecological costs and benefits of reduction of nitrogen input

There are measurable ecological, economic, and social costs associated with the impacts of excessive nitrogen loading to estuaries and embayments including declines in water quality, changes in vegetative species and associated habitat, loss of fisheries with fish kills in the most extreme situations, and a change in the “aesthetic nature” of the area resulting in less recreational use and potential for declining property values for land and houses (although as noted above, the public may not see these connections). There also may be significant costs to reducing nitrogen in the system.

A recent study in Falmouth, MA (Coastlines, August 2001) assessed the costs of various options to reduce nitrogen input into a series of coastal ponds in the town. The ponds, fed predominantly by groundwater and small surface water streams, have experienced “algal blooms, low oxygen events, and shellfish bed closures due to declining water quality.” A nitrogen-loading model was developed and used to provide estimates of current loadings and those projected for various development scenarios. In this case, the model determined that on-site septic systems were the leading source of nitrogen for the system. A number of potential management options were considered including regulatory programs, “natural solutions”, engineering solutions, and public education.

The cost-benefit assessment found that centralized wastewater treatment facilities are the most efficient method of reducing nitrogen in dense development areas. (In more rural areas, the cost of the sewer collection system pushes the equation to the cost side.) Clustered “alternative” systems (i.e., systems designed not only to treat pathogens but also to remove nutrients from the effluent) are more efficient (and more apt to be maintained) than individual on-site “alternative” systems.

In the end, the proposed plan called for

- “construction of centralized wastewater treatment facilities and collection systems to serve the densely-populated, nitrogen sensitive” portions of the watershed,
- “construction of small denitrifying cluster units and individual denitrifying systems elsewhere in the watersheds,”
- “educating the public on landscaping practices that minimize the amount of fertilizers” applied to the watershed system, and
- “construction of wetland treatment systems on rivers feeding the coastal ponds.”

Another analysis of costs and benefits related to nutrient management practices is contained in a recent publication from the Casco Bay Estuary Project—"BMPs: Cost-Effective Solutions to Protect Maine's Water Quality" (Casco Bay, 2001). This document compares the cost of BMPs to the cost of conventional construction practices. The report finds that BMP costs are low compared to the costs of conventional practices, are a small portion of overall project costs, and generally provide aesthetic benefits over and above the benefits that can easily be assigned a dollar value.

Points for Discussion

- Are programs to properly manage nutrients in the Gulf of Maine currently in place at the local, state / province, or federal level?
    - If so, are they being implemented?
    - If not, what programs are needed?

- Do we know whether the existing programs work?
    - If not, what information is needed to perform a meaningful evaluation?

- Is the scientific information available to develop new programs or defend existing programs and decisions related to management of nutrients in the Gulf of Maine?
    - If not, what additional information is needed?
    - If not, what sources are available to develop this information? On a local level? On a state or province level?

- Are affordable approaches to implement nutrient management programs for point and non-point sources available?
    - If so, are they being properly utilized?
    - If not, what approaches need to be developed?
    - Do BMPs work?
    - Do storm water treatment systems work?

- Are there new or impending nutrient management issues that will require new management techniques?
    - What are these issues?
    - What techniques do you predict will be needed?
    - What scientific information is needed to develop these techniques?

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Agenda

2001: Managing Nitrogen Impacts in the Gulf of Maine

November 27, 2001

5:00–7:00	**Registration and Reception** Lear Room

November 28, 2001

7:30–12:00	**Registration**
7:30–8:30	**Breakfast Provided**
8:30–9:30	**Plenary Session—Amphitheater** • **Welcome** • **Workshop organization, planning and goals (Steve Bliven)** • **Introductions**
9:30–12:00	**Setting the Stage**
9:30–9:50	**What does the Gulf of Maine Council need from this Workshop?** David Keeley, Maine Office of State Planning
9:50–10:30	**Overview of Nutrients in the Gulf of Maine** David Townsend, University of Maine
10:30–10:45	**Break**
10:45–11:15	**Nutrient Management Case Study** Joseph Costa, Buzzards Bay Project
11:15–11:45	**Nutrient Control Strategy Case Study (Long Island Sound)** Mark Tedesco, Long Island Sound National Estuary Program
12:00–1:00	**Lunch**
1:00–3:00	**Breakout Session 1** **Topic: Nutrient Assessment, Monitoring & Prediction**
3:00–3:30	**Break**
3:30–5:30	**Breakout Session 2** **Topic: Nutrient Control Strategies**

November 29, 2001

8:30–9:30	**Plenary Session—Amphitheater** **Breakout Group Reports (Sessions 1 & 2)**
9:30–10:30	**Breakout Session 3** **Policy & Implementation**
10:30–11:00	**Break**
11:00–12:00	**Breakout Session 3 (Continued)**
12:30–1:30	**Lunch**
1:30–2:00	**Plenary Session—Amphitheater** **Breakout Group Reports (Session 3)**
2:00–4:00	**Workshop Summary and Recommendations**
4:00	**Adjourn Workshop**

Discussion Points

for Workshop Break-out Groups

Assessment and Prediction Issues

Assessment Issues

- Do we know current status of eutrophication in the Gulf of Maine (and New England)?
- Are we confident that we are in agreement about the status?
- Are the assessments by NOAA and EPA sufficient to characterize the extent of nitrogen problems in the Gulf of Maine?
- For the Gulf of Maine (and New England), what are the relationships between increased nutrient loadings and harmful algal blooms, changes in aquatic and wetland vegetation, hypoxia, food webs, and community structure?
- Do agriculture loads have a significant impact on Gulf of Maine eutrophication, and if so, where?
- Can nutrient stresses be quantitatively connected with (or disentangled from) other stresses affecting marine ecosystems in this area?
- What is an adequate descriptor or set of indicators to describe the impacts of nitrogen on Gulf on Maine areas?
- What is the appropriate scale for which such descriptors can be expected to work?
- Does consistency in describing conditions throughout the Gulf of Maine offer advantages in advancing understanding or are ecological differences across the region too large for uniform descriptions to be adequate?
- What are the early warning signs of nutrient over-enrichment?
- Is there strong justification exists for establishing a Gulf of Maine Eutrophication Monitoring Network to validate predictive models as well as monitor trends over time.

Prediction Issues

- What predictive capability do we need for the Gulf of Maine (and its estuaries)?
- What predictive capabilities do we need?
- What predictions can be made about nutrient loading eutrophication impacts in the Gulf of Maine (and New England)?
- What approaches can or should be taken to develop predictive capability? Are new approaches needed?
- Is there any benefit to take a Gulf of Maine-wide approach, or is the use of smaller estuarine models more appropriate?
- What characteristics, or surrogates for them, that can be practically measured (*e.g.*, residence time, dilution and sediment texture) in order to anticipate estuarine response and couple those with attributes that can be managed (*e.g.*, timing/location of discharge, availability of other nutrients, and biomass harvest). ?
- What level of sophistication is necessary in the watershed models? Are the land-use category models sufficient?
- How will CICEET-funded studies change estimated loadings to the Gulf of Maine?
- Is there benefit to linking watershed loading models with hydrodynamic, biogeochemical and biological response models? Is it technically feasible?
- Without the capability of easily handling sediment processes and advective transfers between the Gulf of Maine offshore waters, is there any benefit to using the EPA WASP or QUAL-family models? Can these issues be handled in some other manner?

Nutrient Control Strategies

- Are there cases where point source control of nitrogen will be effective in solving existing problems? Are they affordable?
- Can septic system loads be cost-effectively reduced by new technologies?
- How would this control technology be monitored and maintained?
- Are cluster development or small-scale waste pumping and treatment systems more cost-effective solutions?
- Are existing BMPs sufficient to control nonpoint source problems or are new methods necessary?
- Do BMPs work?
- Do storm water treatment systems work?
- What is the relationship between habitat remediation and nutrient management?
- Can habitat remediation efforts and nutrient control strategies be matched in the Gulf of Maine?
- Can remediation techniques be matched to particular habitat locations in the Gulf of Maine?
- Is there a need to develop more effective and / or cost-effective technologies to control nutrients from point and nonpoint sources? If so what are the priorities?

Policy, Regulatory and Implementation Issues

- If the assessments of nutrient conditions and trends in the Gulf of Maine by NOAA and EPA considered reliable? If so, what is limiting the development of action plans to address the problems identified?
- What institutional factors prevent the progression from assessment to action plans?
- How do we deal with trans-boundary (municipalities, counties, states, and countries) issues when jurisdictional units don't match ecological units?
- Are programs to properly manage nutrients in the Gulf of Maine currently in place at the local, state / province, or federal level?
    - If so, are they being implemented?
    - If not, what programs are needed?
- Do we know whether the existing programs work?
    - If not, what information is needed to perform a meaningful evaluation?
- Is the scientific information available to develop new nutrient management programs or defend existing programs and decisions in the Gulf of Maine?
    - If not, what additional information is needed?
    - If not, what sources are available to develop this information? On a local level? On a state or province level?
- Can science and predictive models be used to drive regulation, land use and zoning?
- How can local / regional jurisdictions become engaged in the planned development of nutrient criteria and TMDLs.
- What technical information is needed for states and provinces to develop water quality standards for nutrients?
- Is there anything we can do about atmospheric sources of nutrients to the Gulf and its estuaries?
- Are there new or impending nutrient management issues that will require new management techniques?

Sponsors

Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

CICEET was established in 1997 as a national center for the development of innovative environmental technologies for the monitoring, management, and prevention of contamination and degradation in estuaries and coastal waters. The Institute is a unique partnership between the University of New Hampshire (UNH) and the National Oceanic and Atmospheric Administration, promoting collaboration among academia, government, and the private sector. Located on the UNH campus and jointly managed by UNH and NOAA Co-Directors, CICEET uses the capabilities of the University and those of the Great Bay National Estuarine Research Reserve, as well as the other 24 reserves in the National Estuarine Research Reserve System to develop and apply new environmental technologies and techniques. Further information may be found on the CICEET web site at **http://ciceet.unh.edu**.

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The Gulf of Maine Council

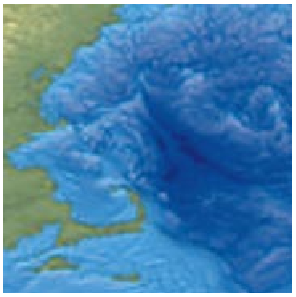
The Gulf of Maine Council on the Marine Environment (the Council) is a collaborative that works to protect Gulf habitats, promote sustainable development of marine and coastal resources, raise awareness of the Gulf, and foster local stewardship. The Council accomplishes this work by convening policy-makers, educating citizens, marshaling resources, and administering local grants. The Governors of Maine, Massachusetts, and New Hampshire and the Premiers of New Brunswick and Nova Scotia created the Council in December of 1989.

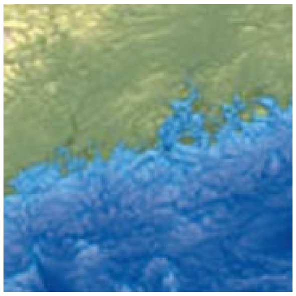
The Council's mission is "to maintain and enhance marine environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations."

The Council consists of two state or provincial agency members and one nongovernmental representative from each jurisdiction that borders the Gulf. There are also federal agency Council members (four from the US and two from Canada). The Council has two funding sources: annual contributions from Council member agencies (all state and provincial member agencies and some federal agencies), and allocations through the US Congress and federal agencies.

The Council pursues a number of "core" activities: the Gulfwatch mussel monitoring program; publication of its quarterly newspaper, the "Gulf of Maine Times"; maintenance of a web site and other information exchange; support of local programs through small grants; and habitat restoration efforts.

For further information about the Council, visit **http://gulfofmaine.org** or contact the Council's coordinator at **info@gulfofmaine.org** or (603) 225-5544.





National Ocean Service, NOAA

As the principal advocate for coastal and ocean stewardship in the US, the National Ocean Service develops the national foundation for coastal and ocean science, management, response, restoration, and navigation. The National Ocean Service maintains its leadership role in coastal stewardship by bridging the gap between science, management, and public policy in the following areas:

Healthy Coasts

The National Ocean Service, through research, response to coastal threats, restoration of damaged areas, and management of coastal resources works to achieve balance in the coastal zone for this and future generations.

Navigation

The National Ocean Service provides the nation with the basic set of information needed for accurate positioning. This includes nautical charts, coastal surveys, and the National Spatial Reference System, a set of standard reference points that establish the latitude, longitude, and elevation framework for the nation's land surveying, navigation, positioning, and mapping activities.

Coastal and Ocean Science

The National Ocean Service is a leader in ocean and Great Lakes coastal science. Some of the National Ocean Service's science activities include understanding and predicting impacts on sensitive habitats, studies of natural disasters, how climate change may affect our lives, and the investigation of the causes of harmful algal blooms and microbes, such as red tides and toxic *Pfiesteria piscicida.*

Coastal Hazards

The National Ocean Service provides communities with information about coastal hazards so they can better reduce or eliminate the destructive effects of natural events.

For further information about the National Ocean Service, visit its web site at **www.nos.noaa.gov** .

Speakers

2001: Managing Nitrogen Impacts in the Gulf of Maine

Joseph E. Costa, Ph.D.
Executive Director
Buzzards Bay Project National Estuary Program

Dr. Joseph Costa is the Executive Director of the Buzzards Bay Project National Estuary Program, a planning and technical assistance unit of Massachusetts Coastal Zone Management. He received his Bachelor of Science degree from University of California at Berkeley, and a Ph.D. from the Boston University Marine Program in Woods Hole. His graduate and postdoctoral research focused on the impacts of coastal development on water quality and coastal habitat, especially those impacts caused by nitrogen inputs. As Executive Director of the Buzzards Bay Project, he has been promoting the adoption of nitrogen management strategies by state and local regulators and planners, as well as the use of alternative and innovative technologies to treat storm water, wastewater, and hydrocarbons from boats. He also helped establish the Massachusetts Septic System Test Center to promote the use of innovative and alternative septic systems, especially for use in nitrogen sensitive areas.

David Keeley
State Planner
Maine State Planning Office

David Keeley has 22 years of experience in environmental management, policy development, and planning with an emphasis on coastal and estuarine issues. He has worked at the local, county and state level in a variety of land use planning and environmental management capacities. Mr. Keeley was instrumental in forming the Gulf of Maine Program, an international state-provincial environment and economy initiative. He has written and managed in excess of $40 million in grants and supervises a staff of planners, lawyers, and scientists at the Maine State Planning Office. He is active at the national level and has served as chairman of the Coastal States Organization. He currently serves on numerous state, national, and international advisory panels and boards. He is active at the community level.

Mark A. Tedesco
Director, LIS Office
US EPA

Mark Tedesco has worked for the US Environmental Protection Agency for 15 years. In 1989 he began working on the Long Island Sound Study, administered by USEPA as part of the National Estuary Program under the Clean Water Act. In 1992 he became Director of the newly established EPA Long Island Sound Office, responsible for completing the $16 million, multi-year program to identify and address remaining water quality impairments in the Sound. The study culminated in the 1994 approval of a Comprehensive Conservation and Management Plan for the Sound by the Governors of New York and Connecticut and the EPA Administrator. Mr. Tedesco is now responsible for continued oversight of the program with a focus on implementation of the management plan in cooperation with government and private agencies and organizations. Mr. Tedesco received his M.S. in marine environmental science in 1986 from the State University of New York at Stony Brook.

Dave Townsend, Ph.D.
Professor of Oceanography
University of Maine

Dr. David Townsend specializes in: Biological oceanography of estuaries and shelf seas; Fisheries oceanography; Ecology and population dynamics of larval fishes and zooplankton; Plankton ecology and trophodynamics; Coupling of physical and biological processes. He received his B.A. in Zoology from the University of Maine, his M.S. in Marine Science from Long Island University and his Ph.D. in Oceanography from the University of Maine. Dr. Townsend's research is broadly focused on the biological oceanography of coastal seas, especially the Gulf of Maine. More specifically, he is interested in physical-biological coupling of phytoplankton, zooplankton, and larval fishes. In the past, these interests have lead him into detailed studies of larval herring dynamics in the Gulf of Maine, larval cod dynamics on Georges Bank, phytoplankton bloom dynamics, the spring bloom and nutrient dynamics on Georges Bank, and biological production (in the broadest sense) of Maine's estuaries. His current research projects are focused on phytoplankton, nutrients and larval cod on Georges Bank, and red tides in the Gulf of Maine. Most of his work is heavily dependent on shipboard oceanographic surveys, as opposed to land-based laboratory experiments. Dr. Townsend prefers to approach specific research problems in an interdisciplinary manner and to propose solutions to those problems that require the formation of teams of researchers that include physical, chemical and biological oceanographers.

Facilitators

2001: Managing Nitrogen Impacts in the Gulf of Maine

Steve Bliven

Steve Bliven has spent over 25 years in the coastal management field, working at the local and state level and in the private and academic sectors. Presently he is the Principal and Owner of Bliven and Sternack, a small environmental consulting company doing policy and outreach work. Prior to starting his firm, he was the Director of Coastal and Wetlands Programs for Horsley & Witten, Inc. of Sandwich MA. He spent almost 15 years with the Massachusetts Coastal Zone Management Office beginning as a coastal biologist, for more than 10 years as the Assistant Director for the program. Currently, he is a Senior Research Fellow at the Urban Harbors Institute at the University of Massachusetts, Boston.

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Fara Courtney is Principal of Good Harbor Consulting, working with governments and organizations on strategic environmental planning and policy initiatives, organizational development and communications. She served for 10 years as a Regional Coordinator for the Massachusetts Coastal Zone Management Office, working with local governments on waterfront planning, water quality programs, regulatory interpretation and inter-governmental relations. With a particular interest in connecting environmental, economic and social priorities, Ms. Courtney was a founding member and primary facilitator in establishing Salem Sound 2000, a successful public/private urban watershed association North of Boston, managed the development and regulatory approval of a comprehensive harbor plan for the City of Salem, MA, and developed programs promoting high environmental performance and energy efficiency in the manufacturing sector in Massachusetts while working with the state's economic development agency. She is a Senior Research Fellow at the Urban Harbors Institute at the University of Massachusetts Boston and a member of the City of Gloucester Waterways Board.

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Marilyn L. Hotch, Esq.

Marilyn L. Hotch, Esq., sole proprietor of MLH Dispute Resolution & Facilitation, has practiced process facilitation and mediation for over a decade. She works with individuals, private corporations, not-for-profit organizations, state and federal agencies, and municipalities engaged in conducting collaborative decision-making and she assists with planning and project assistance, public outreach, and involvement. She also serves as faculty and trainer for conferences and workshops related to conflict management topics. She is on the National Roster of Environmental Dispute Resolution & Consensus Building Professionals for the US Institute for Environmental Conflict Resolution. Ms. Hotch's background includes 19 years as a past practicing attorney with significant experience in environmental, land use, and public policy matters, including 7 years with the MWRA serving in a number of capacities including Director of the Environmental Law Department, Deputy General Counsel, and Special Assistant on Environmental Issues.

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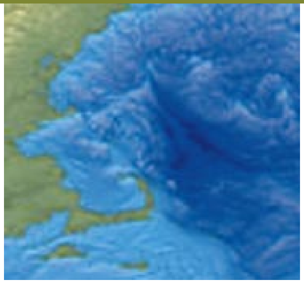

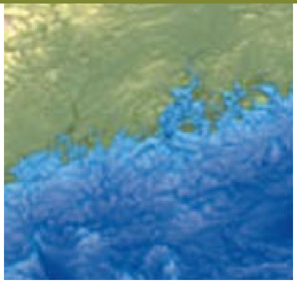

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