Peer Review (Independent Technical Review) of the Massachusetts Estuaries Project Report on the Pleasant Bay System

DRAFT REPORT

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Prepared for:
George Meservey, Director of Planning and Community Development
Town of Orleans
19 School Road
Orleans, MA 02653

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EXECUTIVE SUMMARY

This report presents the Draft results of an independent technical review (peer review) conducted on the Massachusetts Estuaries Project Report for the Pleasant Bay System in the Town of Orleans. This work was conducted under a contract to the Town of Orleans, which was awarded to the Woods Hole Group after a competitive Request for Proposal (RFP) process. The contracted scope of work included three (3) tasks, each with a separate Task Manager. The Task Managers were selected to offer the Town the highest level of expertise and objectivity.

- **Task 1. Benthic Flux Measurements and Analysis of Mechanisms**; Task Manager - Dr. Jeffrey C. Cornwell, Chesapeake Biogeochemical Associates, Inc. and the University of Maryland CES
- **Task 2. Hydrodynamic and Water Quality Models**; Task Manager – Kirk F. Bosma, P.E., M.C.E., Woods Hole Group, Inc.
- **Task 3. Health of Eelgrass and Benthic Community** – Dr. John M. Teal, Teal Partners, Ltd.

Additional technical support for the independent technical review was provided by Dr. John Trowbridge (Senior Physical Oceanographer/Ocean Engineer, Woods Hole Group and Woods Hole Oceanographic Institution) and Dr. Heidi Clark (Environmental Scientist, Woods Hole Group). Bob Hamilton (V.P. and Coastal Engineer, Woods Hole Group) was the overall Project Manager for the contract. Brief biographical sketches on each Task Manager and the technical team are presented in Appendix A. Full resumes for the team are provided in Appendix B.

In addition to this Executive Summary, the report contains an individual section on each Task area. Each Task Manager prepared an overall review in accordance with the scope of work. The scope of work is reiterated in the report for each Task, and the ensuing comments and findings were prepared by the Task Manager to independently address the key issues outlined in the scope. In addition to the independent technical review, each Task Manager prepared a response to certain comments/questions prepared by the Wastewater Management Validation and Design Committee. Although these questions did not provide the basis for the independent review, the peer review team felt it was important to address relevant questions to ensure the stakeholder interests were addressed. Only comments within the scope of the review and the expertise of the reviewers were addressed.

This peer review generally assumes the reader is familiar with the MEP document and process for the Orleans portion for Pleasant Bay. Although a summary of the document and general scientific processes is not within the scope of services for the review team under this contract, this review includes some discussions to clarify some of the key issues. For instance, Section 1.3 summarizes biogeochemical processes, Section E.4 summarizes some of the components of the MEP linked modeling approach, and Section 3.1 summarizes the influence of bottom oxygen on benthic populations, including eelgrass.

E.1 PURPOSE/EXPECTATIONS FOR THIS DRAFT REPORT

As stated clearly in the RFP, the Town is seeking to understand the degree of accuracy and certainty that may be derived from the MEP report, the importance of individual components, and the efficacy of utilizing the report for watershed-based planning. Before committing to a large wastewater infrastructure project, the Town is seeking:

- A peer review of the School for Marine Science and Technology at University of Massachusetts Dartmouth (SMAST) work to validate that the calculated reductions in nitrogen are required to significantly improve water quality and habitat.

- To determine whether the methodology is sufficiently flexible to accommodate refinements and adjustments for unpredictable, naturally-occurring changes in nitrogen concentrations (e.g., effects of the breach that occurred after the MEP report was published).

It is essential to recognize this is a Draft Report. Just as independent technical reviews or "peer reviews" are part of the standard scientific process, so is the process of Draft and Final reporting. This Draft Report summarizes the objective findings and opinions of the experts who reviewed the MEP reports. The information presented herein is intended for review and consideration by the Town, including the Town Staff, the Wastewater Management Validation and Design Committee, other stakeholders, and the public. The Woods Hole Group review team has been working on this for three (3) months. Other stakeholders, including the MEP team, have been at this for many years. The Woods Hole Group review team also had limited access to data, and no access to the models and analysis methods employed by the MEP team when preparing the reports. The stakes are high, the interest is high, and there is a tremendous volume of related work. Not having access to this information, particularly the data and models used by the MEP team, introduces challenges to the peer review process, which more traditionally would involve open sharing of information and data. Therefore, the findings presented herein are based solely on a review of the MEP document, supporting published documents, the scientific literature, and the wealth of collective experience shared by the review team. The review team has extensive relevant knowledge and has formed objective ideas and recommendations, but it is not possible for the team to be expert with all facets of Pleasant Bay, nor can the team address all questions and concerns shared by the stakeholders. Instead, we present opinions to the best of our ability based on experience and the information available for review.

The findings presented in this report also were developed independently and objectively without influence or input from other stakeholders. We focused on the areas where we have the most expertise. It is anticipated that meaningful discussions will result through sharing and discussing the Draft Report. We look forward to learning more from the stakeholders now that the Draft Report is published, some of whom will have substantive input and perhaps more information on certain areas. We anticipate that comments on this Draft Report, as well as ensuing discussions and meetings will be productive. Most certainly, information will evolve between the Draft and Final Reports; some elements may change.

We also anticipate that the level of conclusions and recommendations will evolve in the Final Report. Ultimately, the goal of the Final Peer Review is to be as closed ended as possible. Certain recommendations will encourage more in-depth analysis and data collection; however, the peer review is not intended to recommend more studies. Action is required, and the design process is underway. Our findings are considerate of this ongoing design process, which we've been advised may take 2 years or so. The final recommendations will be geared toward action that can be completed in parallel and to optimize the ongoing design process.

Based on the work conducted by the independent technical review team, there are a number of key issues we intend for the peer review to help the Town address:

- **Federal requirement for action**: The US EPA has mandated establishment of Total Maximum Daily Loadings (TMDL) for stressed Massachusetts estuaries. The Orleans portion of Pleasant Bay is one of many estuaries (89 have been identified) in the Commonwealth that have suffered serious environmental degradation as a result of excessive nutrient loading. Water quality is degraded and sensitive habitats have been lost, resulting in adverse environmental, recreational, and economic impacts. The US EPA has charged the Massachusetts Department of Environmental Protection (MA DEP) with the responsibility to develop and enforce the TMDLs. There is no choice but to take action to reduce the nutrient loadings. The Federal government requires action, and failure to comply will result in consequences. <u>It is our intent that the results from the peer review can improve the approach the Town will take to comply with its mandatory charge.</u>

- **So much at stake**: The solutions to meeting the TMDLs and reducing nutrient loadings are substantial. Though various measures will contribute to the overall solution, the primary method is the reduction of direct inputs of nutrients from wastewater, which ultimately requires some level of sewering. Town or regional wastewater treatment facilities and infrastructure are extremely costly. In the case of Orleans, budgets reportedly approaching $170M, which represents a public works project an order of magnitude higher than previous Town endeavors. Financial impacts to the Town and its citizens are significant. <u>It is our intent that this independent technical review will help the Town optimize its approach to complying with the EPA requirement, potentially saving substantial resources in the future.</u>

- **Multiple Key Hypotheses are Required**: There is not a simple and direct solution for achieving the results intended from implementing the TMDLs required by EPA. The desired effect is improvement of water quality and re-establishment of productive benthic communities and habitats (e.g., eelgrass). However, there is not a direct one-to-one correlation between reducing nutrient loadings and growth of eelgrass, for instance. There are a number of key hypotheses, or leaps of faith, involved, which require intermediate and linked factors to occur, including:

- *Reducing nutrient loading from septic systems will result in a reduction in the nutrient levels in the estuary* – There are a variety of nutrient sources to Pleasant Bay, including septic systems, atmospheric, fertilizer, sediments at the bottom of the Bay, and others. There needs to be certainty that septic systems are a primary source of nutrients, and that reducing septic sources will produce a meaningful reduction in the source of nutrients to the Bay as compared to other sources. There also needs to be confidence in the understanding of groundwater flow patterns, such that reduction of septic loads is achieved in areas that truly affect the quality of the groundwater flow to the estuary (i.e., not areas where the groundwater flows to other water bodies or directly into the ocean).

- *Reducing nutrient levels in the estuary will improve water quality, including increasing dissolved oxygen levels in the water* – High nutrient levels affect water quality in multiple ways. Algal production is increased, which shades the bottom, thereby decreasing photosynthetic activity among benthic plants including eelgrass, and decreasing dissolved oxygen in the water. The excessive algal blooms also produce increased biomass loading to the sediments, which can produce hypoxic or anoxic conditions when the dead algal matter decomposes. There must be confidence that the decrease in nutrient loading is sufficient to minimize algal blooms and the associated adverse eutrophic conditions.

- *Reducing nutrients and raising dissolved oxygen levels in the water will result in healthier benthic communities, including re-establishment of eelgrass beds that existed more than fifty (50) years ago* – Benthic communities, including invertebrate organism diversity and abundance and eelgrass, are affected by numerous factors, including excess nutrient loading, boat/mooring impacts, sediment transport, disease, and other factors. There must be confidence that the increased water quality resulting from the nutrient TMDLs will be sufficient to allow the benthic community to recover in spite of the other stresses. There also must be confidence that the substrate, system hydraulics, use patterns, and other factors are suitable for recolonization.

- *The anticipated benefits will be realized within a reasonable timeframe* – The results will not be immediate. Reducing septic nutrient sources today would start to improve the groundwater quality, but, depending upon the location of the septic source and precipitation trends, it could be many years before the existing nutrient load from septic systems reaching the Bay is actually reduced. Groundwater flowing into the Bay today is derived from many years of loading under current conditions. It will also take many years to actually implement the wastewater infrastructure.

Furthermore, decades of septic nutrient load also resides within the bottom sediments, which results in a benthic flux of nutrients to the water column. The sediments can be cleaned up over time as well, but this will be an indirect result that occurs after the groundwater source is reduced. Consequently, there must be clarity and patience regarding the timeframe of expected improvements, and the public expectations must be realistic.

For the desired effect of the TMDL project to be realized, all of these leaps of faith must come true. <u>We trust that the results from the peer review will help address these leaps of faith, and add confidence regarding the long-term anticipated benefits. The review also helps clarify the uncertainty regarding the extent and rate of recovery of the Pleasant Bay ecosystem following nutrient load reductions.</u>

- **Complex technical matters/lack of transparency**: The MEP work was conducted by qualified, experienced scientists and engineers, who exercised careful professional discretion when performing the work. The work also was completed according to an established protocol and quality assurance plan. For these reasons, there is a certain level of confidence in the MEP work. However, the work is complex, many assumptions are required, and there is potential for significant interpretation and uncertainty. There also remains an unfortunately contentious matter regarding the public availability of the SMAST data and models, which results in a lack of transparency. Furthermore, the MEP reports, while extensive, do not detail all the assumptions, analysis techniques, and implications/sensitivity of the analysis to the input parameters. Even for the trained expert, some elements of the analysis remain unclear. <u>The independent review presented herein is intended to help clarify some of the complex technical matters that are confounding the Town when interpreting and acting on the MEP report.</u>

- **Public opinion**: As a result of the high stakes, investment required to comply with the TMDLs, complexity of the technical issues, and lack of transparency there is some inherent level of skepticism in the process. There also exists the natural tendency to avoid major public expenditures. Given the complexity of the matters, there also is opportunity for various stakeholders to develop conclusions that may be inconsistent or at odds. The information presented within this peer review in some ways helps confirm and boost confidence in the findings of the MEP report, but also identifies, in some cases, significant potential sources of uncertainty, error, and bias in the results. We understand that some stakeholders will place more emphasis on different parts of our review. While this peer review might ideally help resolve all stakeholder concerns/differences that exist, this is not a reasonable expectation. This peer review merely reflects the educated opinions and findings on the three scope areas identified in the RFP. <u>This peer review is focused on objective science, and it not intended to respond to or resolve public opinions. The peer review is also not intended in any way to offer</u>

a critique on the MEP as a whole. Information presented herein should be considered only in the context of Pleasant Bay.

E.2 OVERALL SUMMARY OF THE INDEPENDENT TECHNICAL REVIEW

Overall, the team's findings can be summarized as follows:

- MEP is a high quality and necessary endeavor, and is conducted by highly qualified and experienced scientists, engineers, and planners. There are serious issues facing the Orleans portion of Pleasant Bay that threaten the environment, property values, fishing livelihoods, and general enjoyment of this valuable natural resources. There is a need for action, both to address local concerns and to comply with Federal and State TMDL mandates.

- The MEP reports for the Orleans portions Pleasant Bay represent a strong foundation for developing a course of action to develop and comply with site-specific TMDL requirements.

- Sewering is the primary solution for Pleasant Bay, which is a costly course of action. Defensible science and efficient engineering solutions are required to optimize the level of action required. Small uncertainties and variability in the MEP findings can result in large financial implications for the solution.

- The MEP technical approach is generally sound and reflects valid work conducted by qualified people; however, some of the methods are dated and not considered state of science. Given what's at stake, the peer review team would perform certain aspects of the analysis using different methods, which may better address the complexities of Pleasant Bay.

- In spite of the voluminous nature of the reports, the contents fail to characterize the overall estuary processes (e.g., circulation processes, meaningful model/data comparisons, and layman's overview of the data and model results). The reports also overly complicate certain matters, while failing to document basic analysis techniques, assumptions, and associated implications and uncertainty.

- The peer review team identified a number of technical limitations associated with the analysis that introduce uncertainty, and in some cases may bias the results. Although there are biases in both directions, the biases likely produce a conservative representation of the system. It is possible that a positive environmental response could exceed expectations if the TMDL is met (subject to more sophisticated analysis necessary to resolve remaining uncertainties).

As a final overall comment, one must recognize there are inherent limitations to the MEP process for Pleasant Bay. At present, there is a relatively small qualified team headed by SMAST responsible for evaluating Pleasant Bay along with every other stressed estuary in MA. There are 89 estuaries, which results in a significant effort given the level of detail and number of technical steps required to complete a study for each estuary. From a scientific perspective, it is unreasonable to expect one small group to have great familiarity with all estuaries. From a management perspective, it also may be unreasonable to expect one small team to place the priority level on each estuary that the local stakeholders demand. To achieve overall scheduled state requirements for the MEP, certain protocols and a standardized process needed to be established to have any chance of meeting schedule and budgetary constraints. The protocols may not be ideal for all estuaries, and Pleasant Bay is a particularly complex estuary, with large public infrastructure implications, that may warrant more detailed consideration. The MEP work represents a substantial basis, but may not represent the optimal solution for Pleasant Bay depending upon stakeholder tolerance for uncertainty. With the high stakes involved, local stakeholders may demand more attention, more scenarios, and in some cases more rigor than the SMAST team can possibly offer. The Town may demand a "no stone left unturned approach" and have expectations that are unreasonable for SMAST to achieve within its contracted scope and available resources. In this regard, although there are certain areas where the work could have been approached or presented differently, many of the findings of this peer review should not be interpreted as flaws in the MEP or SMAST work. Rather, the findings represent site-specific recommendations for Pleasant Bay to supplement the scope of work provided by MEP.

As a possible solution, the Town could proceed on its own with more detailed supplemental analysis where warranted. This peer review offers suggestions in this regard for consideration. However, the lack of public access to the data and models prohibits this level of diligence on behalf of the Towns. Decisions on complying with EPA mandates, then, either will be postponed, proceed in the absence of sufficient information, or fail to be made due to lack of public support and consensus. For this reason, we feel strongly that the data and models should be made available to the Towns and public. The information was compiled with public funds by a public university using commercially available products and models that can be applied by other qualified groups in addition to the SMAST team.

Summaries of each of the three (3) Task areas follow.

E.3 TASK 1 BENTHIC FLUX REVIEW

The Task 1 independent technical review of benthic flux measurements and analysis of mechanisms revealed both strengths of and concerns with the MEP report. Notable strengths include the spatial resolution of the measurements, explanation of the cause/effect of nitrogen loading on the retention and remineralization/recycling pathways, and the quality of the experiments and measurements.

The fundamental over-arching concern is the general absence of data presented in the report, and the lack of public access to this information. Having access to the data would allow for better assessment of the overall utility of the work. In spite of the wealth of information collected, the report reveals remarkably little about the benthic biogeochemistry of Pleasant Bay. Perhaps it was not within the SMAST scope to explain the processes, or it was not anticipated that the stakeholders would have the interest and technical background to benefit from this information.

From a technical perspective, the primary limitations are

- All of the cores were incubated in the dark, resulting in the absence of consideration of benthic microalgal effects on sediment nitrogen fluxes. It is well documented that photosynthesis on the sediment surface alters nitrogen fluxes. Daytime fluxes are likely to be much lower than those in the dark in areas where light reaches the bottom (i.e., much of the shallow Pleasant Bay system). On a whole system basis, it is possible that the overall rates could decrease 1/4 to 1/3, but it must be emphasized that we have insufficient access to data to make a defensible prediction.

- The information presented in the MEP report for benthic flux is not directly comparable to similar studies at other sites. The information includes a modeled nitrogen depositional term, does not break the sediment-water exchange into distinct species, and presents no accompanying data on fluxes of soluble reactive phosphorous and nitrogen.

- The estimation of non-summer flux rate was not made; this does not mean that the predicted rates in other seasons are unreasonable, but rather that they are likely poorly constrained. The model relationship with a mid-summer nitrogen flux peak is similar to observations in other systems, but adds uncertainty to the flux numbers. It is not certain whether the hypothesized seasonal change in net nitrogen retention in these shallow water estuarine sediments is correct, and such coverage does not appear to be available regionally except in wetlands.

- The water quality model includes a relatively simplistic model of benthic flux that may underestimate the improvement in sediment nitrogen efflux with decreasing external loading. The model assumes a linear relationship between reduced benthic flux and reduced septic load. However, the response is likely to be non-linear and multiplicative. For instance, the No Septic Loading Scenario (no anthropogenic loading) results in a decrease of watershed loading of 50% and a benthic flux decrease of 35%. Due to a variety of factors discussed in the Task 1 peer review, the system may respond more effectively to reductions in the nutrient load than described by the MEP model. Supplemental measurements and modeling would afford better predictions.

Another key finding is related to the "memory" of the sediments. From a biogeochemical perspective, most of the nitrogen remineralization in sediments comes from recent inputs of organic nitrogen (algae, sea grasses). Under summer conditions, this nitrogen is rapidly depleted, and, although there is some long-term residual, it should not fuel substantial fluxes in future years. Changes in loading will rapidly be reflected in changed fluxes from the sediments, suggesting the recovery time will be shorter once the nitrogen load that reaches the estuary is reduced.

E.4 TASK 2 HYDRODYNAMIC AND WATER QUALITY MODELING REVIEW

The Task 2 peer review focused on the hydrodynamic and water quality models as applied to the Pleasant Bay Estuary. The hydrodynamic model (RMA-2) simulates the flow of water within the estuary as caused primarily by the rise and fall of the tide. The water quality model (RMA-4) is coupled to the hydrodynamic model, and simulates the transport of waterborne constituents (i.e., nitrogen and salinity) within the estuary. Through a process called model calibration, the hydrodynamic model was compared against tide measurements collected within the system to ensure the model simulated natural processes, and subsequently verified to current observations at a couple of locations in the estuary. The water quality model was compared against measurements of nitrogen for calibration, then was verified against measurements of salinity. The models applied for the Pleasant Bay system are the same models applied for other Massachusetts Estuaries Project sites. The computer programs required to run the models are commercially available, and can be installed and run on a personal computer (PC).

The first fundamental purpose of the modeling is to simulate the nitrogen distribution within the estuary for present-day, existing conditions. Models allow for development of a more detailed picture of existing conditions than can reasonably be afforded to measure. The second fundamental purpose of the modeling is to simulate future scenarios, including future build-out scenarios, and alternatives for improving upon existing conditions, such as nutrient reduction alternatives (e.g., sewering scenarios) and changes in flushing dynamics (e.g., inlets or breaches). It is important to recognize that the RMA-2 and RMA-4 models do not simulate regional groundwater or surface water hydrology. Instead, assumptions are input to the model to account for these processes and others. Therefore, if a certain sewering alternative is modeled, the effect on the models is to change an input parameter. The model does not directly simulate the process of removing a septic system. Various other spreadsheet models, calculations, and assumptions are required as an interim steps in the MEP linked-modeling approach. These other steps in the MEP process were not considered as part of this peer review.

The overall modeling approach is well conducted and the hydrodynamic model appears to be reasonably calibrated and verified. As with the benthic flux sections of the report, an overall comment is that the information and data presented in the MEP report are relatively sparse. Although the overall modeling approach is well-described, there is little transparency regarding the interim analyses and assumptions that are required to develop model inputs/boundary conditions and to interpret model results. Lacking the majority of the data, analysis, and any access to the models, it was not possible to conduct a true scientific peer review. Nonetheless, informed opinions were formed based on the material in the report, related documents, some supplemental analysis, and experience with similar models and estuarine systems.

Another overall comment on the modeling is based on a review of supplemental MEP documents. There was apparently an in-depth review and sensitivity analysis of the linked modeling approach as a whole (of which RMA-2 and RMA-4 represent steps in the process). There was no consideration, however, of any other models that might be supplemented into the linked modeling approach instead of RMA-2 and RMA-4. In the experience of the review team, it has been shown that one model is not suitable for all sites. It is possible for Pleasant Bay that an alternative hydrodynamic and/or water quality model might be more appropriate to address either more complex physics or to address more detailed local questions. If the MEP process requires a standardized model, than perhaps a more rigorous supplemental approach could be pursued by the local stakeholders. This would be much expedited and more cost-effective with access to the SMAST data.

The independent technical review of the modeling focused on three (3) major areas: 1) the hydrodynamic model; 2) the water quality model; and 3) the breach. Overall, it is believed that the hydrodynamic model does a good job of simulating depth-averaged, typical tidal flows within the estuary. RMA-2 is a useful model for this purpose, and has proven to calibrate well to tidal hydrodynamics in many estuaries. There are certain limitations of the hydrodynamic modeling, however:

- There is a noticeable lack of explanation of overall system circulation dynamics that could be prepared based on RMA-2 output, such as screen shots or animations of currents. An overall description of the physical oceanography of the system should be possible based upon the available measurements and model results, and would help the public understand the key issues, limitations, and possible solutions.

- The modeling also is two-dimensional and averages all processes over depth. This is a standard practice for MEP, which may not be applicable to Pleasant Bay in certain locations. There were no data observations taken to either verify or discount the importance of potential 3-D processes within the system. Analysis is presented herein exhibiting meaningful stratification in Areys Pond, for instance. Failure to consider 3-D processes may bias the results, and significantly impact the nutrient concentration levels.

- There is an absence of tidal measurements available for calibration in some of the upper embayments (e.g., Areys Pond, Paw Wah Pond, and Kescayo Gansett Pond). Relying on the model to simulate tides in restricted areas adds uncertainty, and supplemental measurements would help resolve this uncertainty.

- There are culverts within the estuary that are simulated in the model, but it is not clear how these were represented in the model. RMA-2 is not ideally suited for simulating flow through constricted structures; better models and calculation methods exist.

- The tidal residual is relatively large. At the fish pier for instance, the tidal residual is more than 1 ft. This accounts for a significant fraction of energy that can influence circulation. It is unclear if this residual was completely generated from short-period, non-deterministic processes. Since the model is run for tidal constituents, not including this level of energy may underestimate flushing potential in certain locations.

The peer review of the water quality model resulted in the most critical aspect of the MEP report for Pleasant Bay. Although the RMA-4 model was applied by qualified personnel according to an accepted quality assurance program, the RMA-4 model does not represent the state-of-science for nutrient modeling, particularly for complex systems such as Pleasant Bay. Basically, the currents from RMA-2 are derived separately and input to RMA-4; there is no dynamic interaction between the hydrodynamic and water quality models. The input terms for septic, watershed, and atmospheric loadings of nitrogen are constants, not accounting for any of the inherent dynamics in the nutrient cycle. Specifying the constant inputs to RMA-4, particularly for benthic flux, is simplistic and requires many assumptions. The assumptions generally result in added uncertainty and may introduce conservatisms inherent to the analysis. Specifically, for simulation of future sewering scenarios, the benthic flux term is scaled linearly with the reduction in nutrient loading. Nutrient dynamics would suggest the reduction in benthic flux may be more substantial. Combined with the 2-D nature of the model, the basic theory behind RMA-4 is perhaps overly simplified for a complex system like Pleasant Bay. More sophisticated models exist that are more routinely applied for TMDL studies.

Other key findings regarding the water quality model are:

- There is a unique approach to simulate bioactive nitrogen for Pleasant Bay. To the review team's knowledge, no other estuaries have been addressed this way (other than for Chatham's Bassing Harbor), making the Pleasant Bay work unique. There is no explanation of how boundary conditions (e.g., sources from septic, watershed, atmospheric, benthic flux) may have been altered or background nitrogen levels may have been modified to simulate bioactive nitrogen instead of total nitrogen, which is the subject of other MEP sites. Analysis of more recent nitrogen data in the system from 2006 and 2007 also suggests the average background nitrogen levels may be lower (~20%) than the values used in the modeling. The RMA-4 water quality model for Pleasant Bay also was calibrated to nitrogen and validated against salinity, which is the opposite approach from many other MEP sites. That this analysis is so unique for Pleasant Bay warrants a more comprehensive consideration of implications to the overall TMDL process in the opinion of the review team. There also is some research suggesting that organic nitrogen (dissolved and/or particulate) may contribute to eutrophication in estuaries. A more rigorous review of this literature, and potential influence on the use of bioactive nitrogen for Pleasant Bay was ongoing at the time this Draft Report was published.

- Based on the information presented in the Pleasant Bay report, as well as information presented in other MEP documents, the RMA-4 model is strongly sensitive to the dispersion coefficients. These coefficients represent the primary calibration parameter that can be adjusted to ensure the model results match measured data. There is certainly more than one unique set of coefficients that would constitute a calibrated model. Other MEP reports suggest that a 50% reduction in dispersion coefficients can result in more than a 90% change to model nitrogen concentrations. Some of the coefficients in the Pleasant Bay model are nearly an order of magnitude (factor of 10) different than values typically recommended for use in RMA-4 users manual.

- The calibration of the RMA-4 model is relatively simplistic, and involves extensive time and other averaging. Although the averages compare reasonably well, it would be helpful to understand how well a time series of the model output compares with measured data (even for the spot measurements on the outgoing tide). This would indicate how well the model described the dynamic physics of the system. Careful examinations of the graphs that compare model results against data also reveal some inconsistencies with how the model and data results were compared. A more comprehensive sensitivity analysis for the water quality model would improve the overall confidence in the nitrogen concentration results, and reveal if there are parameters or input conditions that significantly influence the outcome of the modeling.

- RMA-4 is a finite element model, which by definition can have limitations with conserving the mass of water quality constituents depending upon how the model grid is developed. The report should acknowledge this limitation of RMA-4, and present results to demonstrate that the mass of nitrogen is conserved within reasonable margins.

The peer review of the MEP analysis of the breach in the barrier island suggests the RMA hydrodynamic model is sufficiently flexible to evaluate the impact of natural changes, such as the breach. There are substantial changes in circulation patterns as a result of the breach that result in improved flushing and commensurate improvements to water quality. Based upon the review team's familiarity with the coastal geomorphology in the region, and given the relatively long design life for the contemplated wastewater infrastructure, it would be overly optimistic to plan the wastewater infrastructure with a dependence upon the additional flushing introduced by the new breach. Unless an active inlet management plan is implemented to maintain the inlet, it will continue to evolve and migrate.

E.5 TASK 3 EELGRASS AND BENTHIC COMMUNITY REVIEW

The Task 3 peer review of eelgrass and the benthic community included a detailed review of the MEP documents, the published literature, and data and information from other locations. The peer review generally supports the findings of MEP with regard to eelgrass and benthic communities, and adds confidence to the notion that benthic communities can recolonize and eelgrass beds can recover when nutrient loadings are reduced. The review confirmed that eelgrass and the benthic community respond negatively to high nutrients, including nitrogen and bioactive nitrogen, in particular. High nitrogen reduces dissolved oxygen in the water column via algal production, shading, die-off, decomposition, and increased benthic flux of nitrogen into the water column. Low dissolved oxygen levels are well-documented to adversely impact the benthic community, including loss of submerged aquatic vegetation. Although there are other factors affecting the eelgrass habitat, including wasting disease, sand transport, and boating activity, decreased oxygen levels caused by excessive nutrient loading, and particularly anoxic conditions caused by eutrophication, have the primary adverse impacts on eelgrass in Pleasant Bay. Lower salinity also seems to be an indicator of stressed conditions in Pleasant Bay. Areas with lower salinity are generally have less flushing, higher nutrient loading, and lower oxygen conditions. Benthic communities, including submerged aquatic vegetation, respond well to higher dissolved oxygen, and reducing nitrogen will increase dissolved oxygen, leading to improved conditions for benthic community diversity and eelgrass. Although it will take time for the source of nitrogen to be removed from Pleasant Bay (e.g., even if septic sources are eliminated it will take time for the groundwater to flush), the community should generally should have confidence assuming the nutrient reduction measures will be effective, and that a TMDL on nitrogen is a reasonable approach to achieve the objectives.

E.6 RECOMMENDED NEXT STEPS

As discussed above, action is ongoing and required by the Town of Orleans to comply with federal mandates for TMDLs. This peer review should, in no way, imply that progress should be slowed, or that more study is required to proceed. In fact, the peer review team would encourage the Town to move forward strongly. The MEP work provides a valid basis to proceed, and there should be confidence in the overall solution path. In fact, the response of the system to reduced nutrient loading might be better than anticipated. Since it will take time to realize the benefits, delays will only postpone the desired improvements.

On a parallel path, there is opportunity to quantify and reduce uncertainty, thereby building confidence in the results, optimizing the engineering design, and potentially saving public funds. This can be achieved through implementing the recommendations offered below. It should be emphasized this is a Draft Report, and the recommendations are preliminary. It is fully anticipated that the recommendations will evolve in the Final Report. Key preliminary recommendations for consideration include:

- Town pursuit of an avenue through which the data and models become part of the public record.

- Preliminary assessment to evaluate the relevance of benthic microalgae on benthic flux. This would help resolve the potential bias associated with all cores having been incubated in the dark. A limited scope of work could be implemented at first to determine the extent to which photosynthesis on the bottom sediment is an important process in Pleasant Bay. If so, then a more substantial data collection program, including possible modification of the model boundary conditions, may be recommended. There are qualified local organizations that can perform this work, such as at the Marine Biological Laboratory. It is possible the daily benthic flux terms are overestimated in the MEP report, although insufficient data are available to quantify this.

- Selection of a subset of stations for seasonal benthic flux analysis. There are basic assumptions about the seasonality of benthic flux that are inherent to the MEP report, which should be tested with field data. Although the highest benthic flux is certainly expected in summer, a limited seasonal analysis would add confidence to the analysis and help reduce/understand uncertainty.

- Collect supplemental tidal measurements in upper embayments, such as Areys Pond, Paw Wah Pond, and Kescayo Gansett Pond. This information is essential to ensure the hydrodynamic model accurately represents flushing of these critical Ponds that affect the level of sewering required to meet the TMDLs.

- Conduct a RMA-4 water quality model sensitivity analysis. In particular, the dependence of modeled nitrogen concentrations on model input parameters (e.g. dispersion coefficients) and boundary conditions (e.g., benthic flux rates, atmospheric inputs, background nitrogen) should be quantified. Other MEP reports (e.g., for Bassing Harbor) show the model is highly sensitive to certain inputs. This level of uncertainty should be determined for the Pleasant Bay model as a basis for understanding the level of confidence in the efficacy of future alternatives.

- Depending upon the outcome of the model sensitivity analysis, consideration should be given to a site-specific application of a more sophisticated model for Pleasant Bay to supplement the MEP work. Such a model may incorporate more advanced nutrient cycling, influence of 3-D processes, and more sophisticated treatment of flow control structures.

- Although the current configuration of the Pleasant Bay inlets to the Atlantic Ocean improves tidal flushing and water quality, it would be overly optimistic to plan long-term wastewater facilities under the assumption that the enhanced flushing will remain (in the absence of coastal engineering initiatives to maintain the inlet (e.g., structures, dredging, sand bypassing, etc.). We understand the design process and design life for the wastewater infrastructure will exceed 50-years, which is a time scale within which the inlet has proven to evolve substantially in the past. The worst-case scenario in the MEP report (pre-1987 breach) may also be overly pessimistic. Instead the post-1987 breach conditions may represent a more reasonable design condition. Ultimately, the Town should select a suitable design condition.

- Regardless of whether any additional technical work is completed to supplement the MEP report, the Town should be prepared for an incremental, adaptive management approach for complying with the TMDL requirements. Working cooperatively with the DEP, the Town should seek to establish incremental compliance milestones, perhaps related to preparation of plans, engineering designs, and documents, as well as initiation of wastewater facility upgrades/milestones according to an agreed schedule. This essentially amounts to source control. We also strongly support the Town's commitment to a phased approach for its wastewater facilities planning process. Certain upfront aspects (e.g., land acquisition for facilities, trunk lines, etc.) will have to be designed in anticipation of future phases. The MEP report provides a sound basis to plan this upfront investment, and the uncertainty can be reduced through implementing some of the recommendations presented in this peer review. A long-term commitment to ongoing, water quality, benthic community, and eelgrass monitoring also should be made. Depending upon how the estuarine system responds, future phases may be modified. This is the essence of an adaptive management approach, which we recommend the Town pursue as part of its overall long-term compliance strategy.

1.0 BENTHIC FLUX MEASUREMENTS AND ANALYSIS OF MECHANISMS

1.1 INTRODUCTION

The charge for this analysis is described in the italicized paragraph:

The consultant will a) evaluate the information in the Pleasant Bay Report that describes the methodology and protocol for measuring the benthic nitrogen flux and critically review the data table; b) The consultant will also evaluate the nitrogen criteria used in the Pleasant Bay Report to determine the health of the benthic community and compare it with other published information. In its analysis, SMAST conducted its measurements of oxygen concentrations at the deepest parts of the salt water ponds; c) In addition, the consultant should consider whether, in the absence of septic system nitrogen loading, oxygen would be depleted by other benthic activity.

The approach to evaluating the information can be outlined:

<u>Evaluation of benthic flux information (task a)</u>

- <u>Sampling design.</u> Are cores taken from the middle of these embayments representative of processes throughout the whole ecosystem? Are there coarser sediments with lower rates of metabolism, or are shallow water sediments covered with sea grasses?
- <u>Experimental approach.</u> SMAST uses standard methodologies for the assessment of sediment-water nutrient exchange; chambers are stirred and temperatures matched to the local environment. Core replication appears to be excellent. One key issue is with regard to illumination; if even a small amount of light reaches the sediment-water interface, benthic microalgae can grow. In general, such benthic microalgae can: 1) inhibit denitrification by taking up ammonium otherwise used for nitrification; and 2) inhibit rates of ammonium and/or nitrate efflux. Dark core incubations are insufficient to estimate daily fluxes of nitrogen when benthic microalgal production is moderate or high. Data on light penetration will be examined to determine whether such microalgal production might be important.

<u>Evaluation of the nitrogen criteria used in the Pleasant Bay Report to determine the health of the benthic community and compare it with other published information (task b)</u>

- The approach to estimate changing sediment nitrogen recycling as a function of loading will be examined.
- The modeling approach using this data, particularly the extrapolation used to induce seasonality in the flux data, will be evaluated.

<u>Oxygen depletion – scenarios under lower loading task (c)</u>

- The multiplicative effects of lower loading on both nutrient recycling and upon the net sediment oxygen balance will be discussed.

1.2 OVERALL COMMENT

The key (and only) data set for this analysis is Table IV-11 in the Pleasant Bay MEP final report. That table presents net nitrogen return to the overlying water and does not break the sediment-water exchange into distinct species (i.e., ammonium, nitrate plus nitrite, dinitrogen gas). Moreover there is no accompanying data on fluxes of soluble reactive phosphorus and oxygen. The lack of oxygen flux data makes characterization of these sites difficult, and eliminates the use of elemental stoichiometry (i.e., O_2:N flux ratios) as a means of evaluating the nitrogen fluxes. The net flux number also includes a modeled nitrogen deposition term, making this table one more step removed from the experimental sediment-water exchange data. This modeled term is a source of uncertainty in these benthic flux numbers, and the true net thus becomes a non-empirical flux rate. The benthic flux data are a snapshot of summer conditions, with no measured seasonality. The basic benthic flux data set generation followed standard procedures used in all non-illuminated incubations, and given the qualifications of the investigators, is likely to be first rate.

The strengths of this data set are:

- A large number of sediment-water exchange sites. The spatial coverage was excellent and appeared to reasonably cover small embayments and both shallow and deep environments in the main bay. For this kind of evaluation, this is a strong spatial data set.
- The report very clearly explains cause/effect of nitrogen loading on the retention and remineralization/recycling pathways.
- Based on our reading of their published literature and other reports by these investigators, we have absolutely no concern with the quality of the experimentation and measurements.

The chief limitations of the data set and report are:

- Limited seasonality. The key period for the benthic flux of nitrogen to create water quality problems is summer, mainly because of warmer temperatures, remineralization of organic N deposited during cooler temperatures, higher sediment-water flux rates, and reduced efficiency of denitrification as a nitrogen pathway. However, we don't really know if the hypothesized seasonal change in net N retention in these shallow water estuarine sediments is correct and such coverage does not appear to be available regionally except in wetlands (Hammersly and Howes 2003).
- Lack of consideration of the effects of benthic microalgae on benthic processes. It is well documented that photosynthesis on the surface of the sediments alters nitrogen fluxes (e.g., Sundback et al. 1999; 2000; Risgaard-Petersen 2003), it is mainly a matter of the degree of attenuation of such fluxes. Benthic microalgal

photosynthesis both intercepts nitrogen produced within the sediment and under high rates of photosynthesis, can remove nitrogen from the water column.

- Minimal data presentation. From this report, we know remarkably little about the benthic biogeochemistry of Pleasant Bay; the data useful for comparison to other systems and for examination of internal consistency is not available. In particular, a complete data set on nitrate, ammonium, phosphate and oxygen fluxes would be helpful; denitrification would also be very useful, but harder to obtain since it is much harder to measure.

1.3 SEDIMENT NITROGEN CYCLING: BIOGEOCHEMICAL BASICS

Nitrogen is essential for plant growth, and a key component of such species as amino acids, DNA/RNA and proteins. In aquatic photosynthetic systems, nitrogen and phosphorus are generally the two key micronutrients of interest. In general, the ratio of nitrogen to phosphorus for algal growth has a central tendency around 16:1, the "Redfield" ratio. In freshwater, there is usually an excess of nitrogen relative to phosphorus and the addition of phosphorus produces more algal biomass. In estuarine and marine waters, there is generally an excess of phosphorus relative to nitrogen, and addition of more nitrogen stimulates the production of more algal biomass. In some estuaries there can be seasonal differences in which element limits primary production.

The dominant nitrogen species of interest are ammonium (NH_4^+), nitrate (NO_3^-), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), and dinitrogen gas (N_2, the dominant gas in the atmosphere). The dissolved inorganic species are generally the most useful to algae, with DON important for some cyanobacteria. Inputs to estuaries from groundwater are often in the form of inorganic fixed nitrogen (DIN, generally NO_3^- + NH_4^+). Watershed inputs can be in many different forms, but groundwater inputs from aerobic groundwater is generally nitrate. Nitrate is especially mobile because it adsorbs very little to soils, especially when compared to ammonium. Organic nitrogen (DON, PON) from the watershed can have a range of reactivities within the aquatic system, with a substantial part of such nitrogen having only a moderate liability. In the water column, uptake of nitrogen leads to algal growth; the senescence of such phytoplankton by the collapse of algal blooms or by zooplankton grazing results in the conversion of algal nitrogen back into inorganic nitrogen (remineralization). This can occur in both the water column and in sediment.

The sediment nitrogen cycle starts with the deposition of organic matter to the sediment-water interface (Figure 1). The organic matter can be very labile, such as from phytoplankton and benthic microalgae, of intermediate reactivity such as sea grass organic matter, or be relatively recalcitrant, such as some terrestrial organic matter. Fermentative processes release nitrogen as dissolved organic nitrogen, which is rapidly remineralized to ammonium in conjunction with oxidants such as dissolved oxygen, iron oxides, or sulfate. Under reducing conditions, the ammonium can diffuse out of the sediment or adsorb to particles. Under oxidizing conditions, ammonium can be nitrified, with a conversion to nitrate or nitrite. That nitrate can be released to the water column or utilized by denitrifying bacteria to convert fixed nitrogen to N_2 gas; denitrification results in nitrogen losses to the ecosystem.

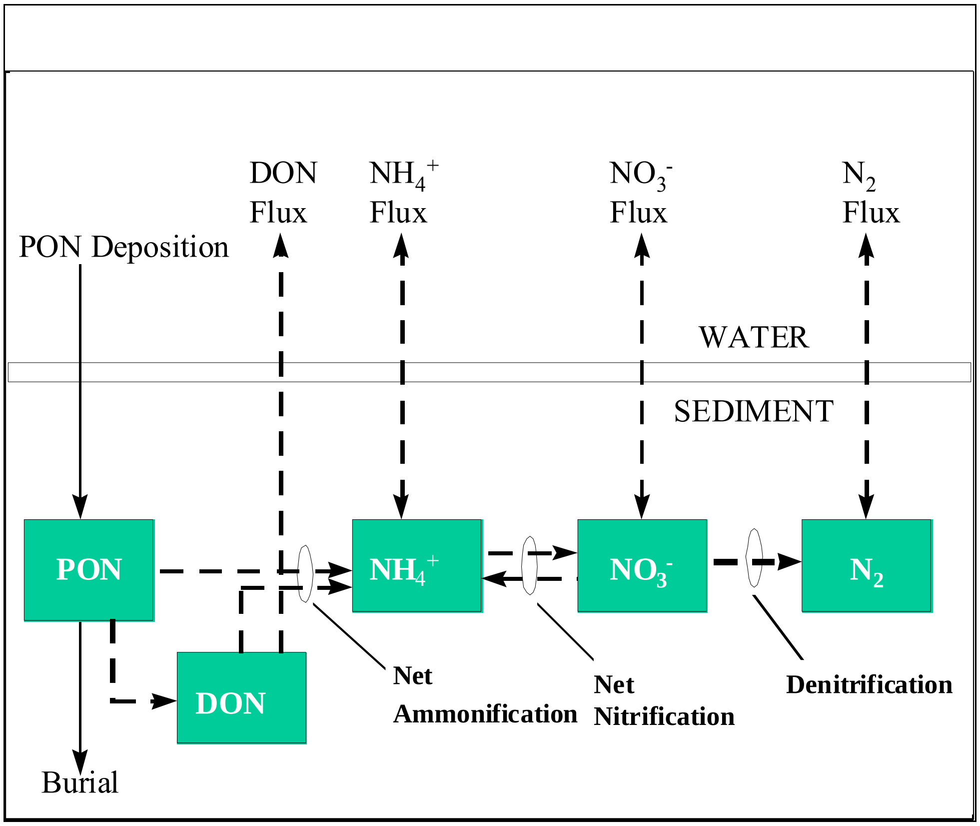

Figure 1. Simplified sediment nitrogen cycle (Cornwell et al. 1999). The conversion of PON to DON and finally to NH4+ is variously called remineralization or ammification. Fluxes across the sediment-water interface are driven by concentration differences across that boundary; sediment NH_4^+ concentrations can be orders of magnitude higher than water column concentrations. The backwards arrow from nitrate to ammonium is referred to dissimilatory nitrate reduction to ammonium (DNRA) and often occurs in sulfidic sediments.

In environments with minimal oxygen at the sediment-water interface, nitrification can be limited by the anaerobic conditions. In systems with high nitrate in the overlying water, diffusion of nitrate into the sediment can be an important supply of nitrogen for denitrification. Finally, in extremely reducing, often sulfidic sediments, nitrate can be reduced back to ammonium, a process called dissimilatory nitrate reduction to ammonium (DNRA).

Not shown in this diagram is the considerable effect that algae growing on the sediment surface can have on the net fluxes of nitrogen and phosphorus. Benthic microalgae take up remineralized ammonium and water column nitrate, effectively resulting in the minimization of dissolved inorganic nitrogen releases from the sediment. In addition, denitrification is often minimized because benthic microalgae effectively compete with nitrifiers for remineralized nitrogen (Risgaard-Petersen 2003). Benthic microalgae affect the overall nitrogen balance by being an important sink for nitrogen in the sediments. Rather than allowing a simple reflux of nitrogen back to the water column, they effectively intercept fixed nitrogen. The loss of benthic microalgae results in the loss of this sink, and possibly a non-linear enhancement of nitrogen inputs to the water column. Sea grasses also sequester considerable amounts of nitrogen, with storage in above and below-ground biomass. The turnover of sea grass organic matter generally proceeds slower than for algal organic matter, resulting from a lower nitrogen content that results in slower microbial utilization. Regardless of whether the sediments have algae or macrophytes, their exchange of nitrogen with the water column is very different than in non-vegetated sediments. One semantic issue is whether the nitrogen released from sediment is a **new** nitrogen load to the ecosystem. Such nitrogen is more effectively thought of as nitrogen from internal cycling; its source is organic nitrogen from autocthonous sources (algae/sea grasses) or allocthonous sources (e.g., terrestrial organic matter). Experience in other systems indicates that the remineralization of organic matter, and thus organic nitrogen, occurs rapidly after deposition. In temperate estuaries, most nitrogen remineralization comes from organic matter deposited within the last year. Within seagrass beds, where carbon:nitrogen ratios are higher, organic matter is longer lasting.

Oxygen has a central role in the sediment nitrogen cycle. With minimal oxygen in the water column, nitrification does not occur and when water column nitrate is not excessively high, denitrification is limited. The result is a high flux of ammonium out of the sediment (e.g., Kemp et al. 2005). Under aerobic water column conditions, nitrification rates are high and denitrification is enhanced. Denitrification is a positive attribute in aquatic systems represent a loss of fixed nitrogen that could otherwise grow more algae.

1.4 EVALUATION OF TECHNICAL APPROACH

The SMAST sediment-water flux approach is similar to that used by many groups. Cores (15 cm inside diameter) were collected without disturbing the sediment-water interface and transported to a shore laboratory for incubation. Field temperatures were maintained and the cores were incubated in the dark. A time series of chemical measurements were then taken, with samples taken for 24 hours. The report presents no information on the depletion of oxygen during the incubations, either from the perspective of perturbation of existing redox gradients by changing oxygen concentrations or by presentation of sediment oxygen demand rates. This limits this evaluation of processes affecting the balance of nitrogen in these sediments. Based on other well described recent SMAST studies (e.g., Howes et al. 2008 a,b), all technical phases of the measurement program are likely more than adequate.

1.4.1 Sampling Design

Sediment biogeochemical studies are relatively expensive and investigators are challenged to capture both temporal and spatial variability within a reasonable budget.

The study design necessarily requires compromise; each investigator and modeling team is likely to have a different mix of time and space.

The SMAST study design had an emphasis on the spatial scale, with a large number of sites examined for sediment-water exchange of nitrogen. An impressive total of 62 sites were sampled for the benthic study. These sites were divided into 28 sub-embayments in Table IV-11. In all but three of the sub-embayments, at least two cores were incubated. Replicate cores (i.e., from the same coring location) were taken at 3 sites. Each basin's N fluxes appeared to be relatively similar at the different coring locations; the standard deviations for the sediment regeneration numbers was relatively low for this kind of study. The relatively tight grouping of rates suggests there has been a good characterization of each basin for the time sampled.

The lack of seasonal sampling of benthic fluxes is often compensated for by using relationships temperature. Overall sediment respiration and nitrogen recycling are often a function of temperature, with more remineralization under warmer conditions. In cooler conditions, organic nitrogen sedimented to the sediment-water interface may degrade more slowly and persist until warmer conditions. SMAST present a hypothetical pattern of net nitrogen flux (Figure IV-20); similar patterns have been observed in other estuaries (e.g., Chesapeake Bay - Cowan and Boynton 1996; tidal marsh creeks – Hammersly and Howes 2003). With little regional guidance for the seasonal pattern of dark fluxes in shallow water estuaries, it is quite possible that this predicted seasonal pattern may not be a good representation of fluxes in fall, winter and spring.

In recent decades, benthic microalgal production has been shown to be important to benthic biogeochemistry, influencing both the balance of nutrients and decreasing the resuspension of inorganic particulates. In Figure V-9, the bathymetric contours suggest that the dominant water depths in the extended ecosystem are usually < 2 m. Site-average secchi depths from Pleasant Bay in 2007 ranged from 0.63±0.25 m at Pochet-Upper (WMO-3) to 2.53±0.81 at Namequoit Pt.-N (PBA-13). Average of all 17 monitoring sites was 1.62±0.6 m. Typically, secchi depths represent ~10-15% of incident light (Wetzel and Likens 1991), well within the range in which benthic microalgae can grow. Given these water depths and secchi depths, it would be surprising if benthic microalgae were not an important part of this ecosystem. The sampling design did not include illumination of the sediment water interface during incubation, so this component was not assessed.

The 1) modeled nitrogen inputs to sediment, 2) lack of seasonal data for fluxes, and 3) dark incubation of sediments that are likely photosynthetic are all potential limitations to this data set. It is difficult to evaluate the inputs of nitrogen to the sediment because, as in many systems, there is no straightforward way to determine these rates empirically. Simple concentration changes in solid phase nitrogen are too insensitive to develop loading estimates, and sediment traps in shallow systems mainly measure resuspended sediment. The lack of seasonal data is a concern, but the hypothetical seasonality almost certainly has the obvious summer maxima and winter minima predicted by SMAST. Certainly the off-season data are likely to be within a factor of two; if summer conditions are the main issue in the TMDL, then this may not be a key issue. From our perspective, the major issue is with regard to dark illuminations. In many cases, there is a major decrease in sediment ammonium or nitrate efflux from such sediments when they are illuminated during incubation (e.g., Risgaard-Petersen 2003; Kemp and Cornwell 2001; Howes et al. 2008a,b). In areas with benthic microalgae, one might expect a 50-100% decrease of fluxes in the light; this would translate into a 25-50% decrease in the daily efflux.

1.4.2 Evaluation of Flux Data

The data from SMAST Table IV-11 are shown in Table 1. We have converted the mass units to µmol units in adjacent columns, using hourly rates instead of daily (mainly for our own convenience and to make stoichiometric conversions easier to understand). Our interpretation of the sediment N regeneration numbers is that this is not a benthic flux rate. Rather than being the benthic flux experimental data, it also includes a PON input number modeled from water column data. Thus, each flux consists of actual measurements, plus model output for nitrogen deposition. Net deposition is difficult to measure in shallow water sediments and modeling may be the most appropriate approach. There is no data to test the deposition model. The net long-term balance of N in sediments is:

PON deposition to sediments = N return to the water column (sum of nitrate, ammonium and N2 fluxes) + N burial

There is no requirement that this equation balance on an hourly or daily basis. Indeed, net labile PON storage during cool months results in a buildup of N in the sediments that is remineralized by bacteria during warmer summer months. This storage effect would be especially evident in sea grass environments. This is represented by the net cool season deposition shown in SMAST Figure IV-20. However, this equation should balance on an annual or multi-year basis; when there is any burial of nitrogen, the result should always be a net influx of nitrogen. If unmeasured denitrification N fluxes are moderate to high, this will also hinder a full N balance calculation in the sediments. Characterization of high N effluxes (> 100 □mol m-2 h-1) as a new loading to the water column is inappropriate. The organic N responsible for the fluxes has already been counted as: 1) a flux of external organic N into the ecosystem from groundwater, the atmosphere or streams; or 2) as a net flux of organic N from the algae or macrophytes derived its nitrogen nutrition from groundwater or atmospheric nitrate or ammonium.

Comparisons to other flux data sets are not feasible since there is a component of modeled net deposition of N to the sediment surface embedded in the available data. It is interesting to consider how/why there are such dramatic differences between the small embayments and the main bay areas. The report effectively explains these differences as a result of hydrography/residence time, proximity to loading, differences in water column productivity, and redox-related shifts in N-cycling pathways. Additional differences may occur because of the presence/absence of benthic microalgae and sea grasses.

Table 1. Rates of sediment N regeneration in Pleasant Bay.

Location	Sub Unit	Sediment N Regeneration mg N m^{-2} d^{-1}		µmol m^{-2} h^{-1}	
		Mean	S.D.	Mean	S.D.
Meetinghouse Pond	Pond Basin	79.5	12.7	221	35
Lonnies Pond	Pond Basin	22.7	3.9	63	11
Areys Pond	Pond Basin	107.3	13.9	298	39
	Namequoit River	107.3	2.1	298	6
The River	Mtghouse Channel	113.0	13.5	314	38
	Upper River	14.3	5.6	40	16
	Mid River	12.0	1.8	33	5
	Lower River	34.2	6.4	95	18
	Mouth River	**-10.9**	**11.3**	**-30**	**31**
PawWah Pond	Pond Basin	120.7	13.9	335	39
Quanset Pond	Pond Basin	98.0	5.9	272	16
Round Cove	Cove Basin	138.9	10.4	386	29
Muddy Creek	Upper	81.8	1.7	227	5
	Lower	**-16.0**	**5.0**	**-44**	**14**
Bassing Harbor Sub System	Ryders Cove	19.7	1.6	55	4
	Frost Fish Creek Upper	**-5.1**	**0.0**	**-14**	**0**
	Crows Pond	12.3	1.3	34	4
	Bassing Harbor Basin	**-8.9**	**1.8**	**-25**	**5**
Pochet	Uper-Mid	**-1.2**	**1.5**	**-3**	**4**
	Lower Basin	**-1.7**	**2.5**	**-5**	**7**
Little Pleasant Bay	Upper	16.0	1.1	44	3
	Mid	0.2	1.3	1	4
	Broad Creek	4.1	2.3	11	6
	Lower	**-1.1**	**1.9**	**-3**	**5**
Pleasant Bay	Main Basin	24.1	2.2	67	6
	Little PB-ChatHbr	**-7.0**	**1.4**	**-19**	**4**
	Strong Isl-Bassing Hbr	**-18.1**	**1.1**	**-50**	**3**
Chatham Harbor	Basin	**-8.8**	**0.7**	**-24**	**2**

1.4.3 Benthic Flux Modeling

The changes in benthic fluxes based on different loading scenarios (Table 2) were (page 144) calculated as:

(Projected N flux) = (Present N flux) * [$PON_{projected}$]/[$PON_{present}$]

The No Septic Loading Scenario (no anthropogenic loading) results in a decrease of watershed loading of 50% and a benthic flux decrease of 35%. The approach to determining changes in sediment-water N balance does not appear to reflect any changes in proportions of N burial/efflux/denitrification and driven mainly by PON sedimentation changes. Changes in water column oxygen associated with decreased N loading may result in the increased importance of coupled nitrification-denitrification. Any increases in light penetration associated with decreased N inputs may result in an increased biomass and productivity of benthic microalgae and sea grasses. On average, benthic microalgae modulate ammonium and nitrate fluxes from sediments and decrease the importance of denitrification. Sea grasses also often stimulate denitrification. The modeling in the MEP report may underestimate the improvement in sediment N efflux with decreasing external loading.

Table 2. Loading and benthic flux rates: whole system from report tables VI-2, VI-6, and VI.2.6.2.

	Present kg d^{-1}	Build Out	No Anthropogenic Loading
Watershed Load	127	165	20
Direct Atmospheric Load	86	86	86
Total Loading	213	251	106
Benthic Flux	185	213	120
Benthic Flux:Loading Ratio	0.87	0.85	1.14

1.4.4 Effects on Bottom Water Oxygen

It is reasonable to project increases in bottom water oxygen as overall rates of sediment metabolism decrease and rates of benthic photosynthesis increase. The current data set does not include rates of benthic respiration (as sediment oxygen demand) and/or benthic photosynthesis. Since oxygen concentrations are a function of: 1) biochemical demand in the water and sediment, 2) rate of exchange with the atmosphere, 3) water residence time; and 4) photosynthesis, making quantitative estimates of changes in bottom water oxygen is not possible without a modeling exercise. Other changes in the system as nutrient loading changes could include changes in the abundance of macroalgae and/or phytoplankton, also affecting net oxygen balance of the sediments.

1.5 COMPARATIVE DATA

Initially, we had hoped to directly compare benthic flux data sets from other Cape Cod or regional studies to the Pleasant Bay data. Given the absence of *bona fide* benthic flux data in the report, we are unable to make a meaningful comparison. Several studies would be of moderate relevance if the flux data was made available:

- Hopkinson et al. 1999. Benthic fluxes along the Parker River estuarine gradient
- Nowicki et al. 1999. Denitrification in the Nauset Marsh Estuary
- LaMontagne et al. 2002. Nutrient fluxes and denitrification in the Childs River.
- Hammersly and Howes 2003. Nutrient fluxes and denitrification in the Mashapaquit Marsh tidal creeks.

1.6 IMPLICATIONS

To summarize the analysis of the benthic flux data, the implications of this report from our perspective may be summarized:

- What are the chief limitations of the benthic flux work? The foremost and most difficult part of this analysis is the lack of access to information already generated by SMAST and paid for by the State of Massachusetts. Embedded in that data set are better answers to the questions being asked by the Town of Orleans. The second limitation is the absence of consideration of benthic microalgal effects on sediment nitrogen fluxes. Daytime fluxes are likely to much lower than those in the dark in areas where light reaches the bottom (i.e., much of the bay). Finally, the estimation of non-summer flux rate was not made; this does not mean that the predicted rates in other seasons are unreasonable, but rather that they are likely poorly constrained. The model relationship with a mid-summer nitrogen flux peak is similar to observations in other systems, but adds uncertainty to the flux numbers.
- Are sediment N fluxes likely to be under or overestimated? In general, because of the attenuation of nitrogen fluxes by benthic microalgae, I would suggest that these rates are on the high side. In sub-embayments and tidal rivers with either higher turbidity or greater water depths, these data should be an excellent representation of summer conditions. On a whole system basis, it is possible that the overall rates could decrease 1/4 to 1/3, but it must be emphasized that we have insufficient access to data to make this a defensible prediction.
- Is the N sedimentation model appropriate? The estimation of N inputs to the sediment is difficult in any aquatic environment, especially difficult in shallow water systems. These estimates were made on particulate nitrogen concentrations and residence time, and are likely the only way to make this estimate. If a seasonal nitrogen balance had been done (annual fluxes out of sediment plus sediment N burial = N inputs), an annual N sedimentation budget could be made. For the shorter-term estimates, a model is likely the only approach.

- Would one expect a simple relationship between decreased loading and benthic fluxes? In this model, the benthic flux to total N loading ratio increases about 20% with lower anthropogenic inputs. This suggests that relative to loading estimate, increased sediment nitrogen fluxes of ammonium and nitrate would occur, an unexpected result. One might expect that nitrogen fluxes would decrease because of increased bottom water oxygen in upstream parts of the system, leading to an increased proportion of remineralized nitrogen going to denitrification, a nitrogen loss. Furthermore, if decreased loading results in more habitat for benthic microalgae and sea grasses, the flux to loading ratio would decrease even more.
- What are the implications for oxygen concentrations from the benthic fluxes? That calculation requires running the flux information through the whole model. Clearly, sediment respiration can deplete overlying water oxygen; without oxygen flux data, the direct effect cannot be estimated. The whole ecosystem effect of producing less algae via decreased nitrogen loads will necessarily lead to improved bottom water oxygen concentrations.
- Is sediment "memory" an issue? From a biogeochemical perspective, most of the nitrogen remineralization in sediments comes from recent inputs of organic nitrogen (algae, sea grasses). Under summer conditions, this labile organic nitrogen is rapidly depleted. Although there is some residual over the long-term, it should not fuel substantial fluxes in future years. Changes in loading will thus rapidly be reflected in changed fluxes from the sediments; this is reflected in the Table 2 information from SMAST.
- Are there simple ways to resolve some of these benthic issues? Benthic flux studies are expensive and will always be limited in either or both temporal or spatial coverage. SMAST has done an exemplary job on the spatial aspect of sampling, this is an unusually large number of sites for this kind of work. Perhaps the key missing element is whether our hypothesized benthic microalgal influence is truly important. A few simple measurements could be used to see if this is the case. More temporal coverage would be very useful, but costly. A typical approach might be to select a small subset of the stations for seasonal or multi-year analysis.

1.7 RESPONSE TO SELECT COMMITTEE COMMENTS

The following two sub-sections offer responses from Dr. Jeff Cornwell to a selection of the validation committee's independent comments on the MEP reports. Not all comments are addressed, since many are not within the contracted scope of work, there is insufficient information in the MEP report to address the matter, or the question was not considered germane to Task 1.

1.7.1 Chapter IV Comments

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS p 25 ¶ 1

Seems important to understand what mechanisms are involved, how this impacts the nitrogen mass balance and the 'seasonal' aspect. Mass of Nitrogen from decay of plant matter? kg/acre/year? Where does it go? When? How? What is the specific (step by step *detail) analytical procedure used? Is there a standard analysis procedure in Standard Methods for Water and Wastewater Analysis (includes sediment analysis?) Is there a copy of Standard Methods available in town? (none in library although it is available in the reference section of CC Community College). Should we have a copy?*

IV.3.3Rates of Summer Nitrogen Regeneration from Sediments p 79 ¶ 2

It seems that the relative magnitude of N loading to the sub-embayments is important. lf septic nitrogen loading is eliminated or reduced, does it make the sub-embayment healthy again? Or, is the nitrogen accumulation in plants and animals and the impact of their life cycles on the nitrogen mass balance the problem? This is not a prejudgment of the facts; it is simply a question at this time.

- Removal on nitrogen inputs will have a relatively rapid impact on the system. The organic matter in plants, animals and sediments does not persist for long periods of time. In the case of sediment, most of the nitrogen fluxing back to the water column is of recent origin (<< 1 year). If less nitrogen is put into the embayment, there will indeed be an attenuation of algal growth, sediment nitrogen deposition, and return flux of nitrogen to the water column.

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS p 29 ¶ 1

Wording seems vague as to how much detailed data on land use was available or employed vs. broad categorization of land use and estimates. How detailed (e.g. lot by lot) was the land use information and what is meant by pre-determined nitrogen loading rates? Do we want to do a detailed analysis and nitrogen mass balance for a specific sub-embayment and compare to the model results?

- Not in task, I have the same questions. Clearly having access to the spatial/temporal input data would be valuable.

IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS p 29 ¶ 3

Why was data collected only during summer months? Does this properly account for nitrogen transport and mass balance on year round basis?

- Not in task. In non-summer months, it's a watershed model.

IV.1.2 Nitrogen Loading Input Factors Wastewater/Water Use p 32 ¶ 3

Discusses "..MEP has derived a combined term the effective N Loading Coefficient (consumptive use times the nitrogen concentration) of 23.63 to convert water (per cubic meter) to nitrogen load (N grams)." Do we understand how this compensates for changes in occupancy rates? Where are the water use data and calculations that would help to understand this? How do we go about testing/verifying the occupancy/water use/ N loading assumptions? Check specific embayments/sub-embayments?

- Not in task.

Orleans Future:
We are looking at a project with a ~30 year horizon. What does the future population structure of Orleans look like? Knowing the current nitrogen loading and mass balance is important. How do we think it will change over 20-30 years? Is the trend to more 'second' homes that are occupied for only 3-5 months per year? Or, will the second homes of today be occupied year around as the baby boomers retire? lf the babyboomers retire here, what does that mean with regard to occupancy? Year around? Summer, with winter residence elsewhere? What infrastructure is needed to support that population in terms of public and, importantly, retail shops and services? How does this impact the nitrogen loading of the embayments in 20 years?

1.7.2 Chapter VIII Comments

Subject: Summary Chapter VIII

Reviewer Questions:

p. 200, ¶ 4:
Dissolved Oxygen. SMAST describes the high level of oxygen stress in the sub-embayments. "These small enclosed basins tend to have higher nitrogen levels and high rates of sediment metabolism associated with their circulation and focus of watershed nitrogen loads." Consequently, SMAST relates bio-activity stress due to low oxygen to elevated nitrogen levels. It is correct that septic nitrogen in the form of ammonia or urea consumes oxygen in their oxidation to nitrates, but is the oxygen stress totally related to increased septic nitrogen concentrations?

- The embayment processes do not distinguish the different sources of N. Oxidation of ammonium can occur in the groundwater, with oxygen consumption there; direct inputs of ammonium could lead to oxygen consumption, but it is likely not a major oxygen sink. *Oxygen stress in the embayments is mainly due to the oxidation of algae and terrestrial organic matter*. The algae clearly depend on bioavailable N (mostly nitrate and ammonium) from groundwater, surface water and atmospheric sources.

p. 201, ¶ 1:
"Salt marsh creeks (that do not empty at low tide) frequently become hypoxic in summer as a result of high organic matter loading associated with marshes. Even pristine salt marshes can exhibit this behavior." Don't the sub-embayments, such as Meetinghouse and Arey's Ponds collect organic matter? Is it possible that the hypoxia in these "A ponds" is caused by similar mechanisms to those in the marshes?

- I have little direct familiarity with these sites, but oxygen sags often occur in marshes. Inputs of marsh or terrestrial organic matter into the ponds clearly could lead to hypoxia in the ponds, depending on residence time and vertical mixing.

p.202, ¶ 1:
"As for the oxygen and chlorophyll indicators and the distribution of sediment metabolism, the enclosed basins (Group A, above) are generally significantly to severely impaired relative to the benthic infaunal habitat quality." It appears that to accept this

premise that the impairment is related to low oxygen and chlorophyll, one must accept the fact that septic nitrogen is the primary cause of deplete oxygen. Is it possible that the same mechanisms that occur in marshes occur in the Group A subembayments?

- Yes. Distinguishing algal sources and external (i.e., marsh) detrital sources of sediment oxygen uptake is difficult, but not impossible. However, the current data set would mainly have to use chlorophyll settling as a way to examine algal organic matter inputs; to do this would require some modeling.

p. 204, ¶ 1 and 2:
"the restoration target should reflect both recent pre-degradation habitat quality and be reasonably achievable." "The threshold nitrogen level for an embayment represents the tidally averaged water column concentration of nitrogen that will support the habitat quality being sought."

- This is the general wording used in other estuarine restoration efforts. The loading is likely a purer reflection of how to control algal biomass, concentration is affected both by inputs, uptake, and physics.

p. 204 , ¶ 5 :
"After the sentinel sub-system (or systems) is selected, the nitrogen level associated with high and stable habitat quality typically derived from a lower reach of the same system or an adjacent embayment is used as the nitrogen concentration target." Is this a reasonable approach?

- Not in task, beyond my expertise.

p. 205, ¶ 1:
What is the support for the notion that dissolved organic nitrogen is nonreactive in the marine environment? What are the sources of dissolved organic nitrogen?

- Non-reactive is an unfortunate term. A considerable proportion of DON may be bioavailable on longer time frames. In the context of this study, it's a matter of how fast it degrades versus how quickly it is washed out of the system. DON comes from terrestrial inputs and the decomposition of organic matter produced in the estuary.

p. 205, ¶ 2:
The nitrogen threshold of 0.16 mg bioactive nitrogen/liter was set based on a Dec. 2003 MEP Report for Bassing Harbor. What if it were 0.17? Or 0.18? How is the determination made? Note that the data in Chapter VII, Table VII-7, eelgrass areas declined from 246 to 114 acres between 1951 and 2000. Was the concentration of bioactive nitrogen less than 0.16 mg/liter during this 50 year period? Especially from 1951 to the early 1980s when the building boom occurred? Again, is bioactive nitrogen the only real culprit?

- Not in task.

p. 205, ¶ 3:

"Ryder Cove represents a system capable of fully supporting eelgrass beds and stable high quality habitat based upon the 1951 – 2000 surveys. At present, this basin is transitioning from high to low habitat quality in response to increased nitrogen loading." So… if Bassing Harbor has had high quality water column in terms of bioactive nitrogen until recently, why did the eelgrass population decline between 1951 and 1995? Are there other potential causes of eelgrass decline that are not included in the SMAST assessment?

- Not in task, there clearly are other reasons for eelgrass loss at the regional scale, but others are more expert on this.

p. 206, ¶ 1:

"Unfortunately, total nitrogen within this system appears to be very high. In fact, the whole of lower Pleasant Bay appears to contain very high levels of total nitrogen.

Analysis of the composition of the watercolumn nitrogen pool within these embayments revealed that the concentrations of dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON) were the same as for the Stage Harbor System. In fact, the level of these combined pools (DIN+PON) was lower in Bassing Harbor (0.133 mg N L-1) than in the Stage Harbor (0.158 mg N L-1) and the mouth of Oyster River (0.160 mg N L-1). Note that the mouth of the Oyster River exhibits a documented stable healthy eelgrass habitat (MEP 2003). It appears that the reason for the higher total nitrogen levels in the Pleasant Bay waters results from the accumulation of dissolved organic nitrogen. The bulk of dissolved organic nitrogen (DON) is relatively non-supportive of phytoplankton production in shallow estuaries, although some fraction is actively cycling. It is likely that the high background DON results from the relatively long residence time of Pleasant Bay waters relative to the smaller systems. This allows the accumulation of the less biologically active nitrogen forms, hence the higher background.

Decomposition of phytoplankton, macroalgae and eelgrass release DON to estuarine waters as do salt marshes and surface freshwater inflows." (underlines added) The quotation indicates that the very high total nitrogen levels in Pleasant Bay are not expected or well understood. The text "explains" the phenomenon using the phrases "It is likely" and "It appears" throughout. It seems that the explanation is a pure conjecture without any facts to back it up. Since the crux of this matter is about how much nitrogen is in Pleasant Bay, how it moves in and out of the bay and how it impacts the flora and fauna in the bay, it would seem important to have and understand the facts about the nitrogen levels in the bay.

- I agree. Certainly residence time is part of this, but not the whole explanation.

p. 206, last ¶:

"moving into the mouth of The River (PBA-13) and the lowermost basin of Pochet (WMO-03) eelgrass coverage appears to have declined since 1951, although eelgrass is still present. This loss of beds indicates that the habitat quality has become impaired, but since eelgrass remains, the impairment is judged to be "moderate."

(see p.182, para. 2: "….smaller eelgrass areas in Pochet and fringing shallow areas in The River and Meetinghouse Pond. …..However, it is clear from the 1951, 1995 and 2001 temporal sequence that the eelgrass areas in each basin, except Chatham Harbor, are declining in coverage. In The River and Pochet the eelgrass areas were always patchy and in the shallows. By the 2001 survey this pattern continues, but the beds appear to be declining, although they persist.")

Given the inferiority of the 1951 photos and the lack of any field verification, the thesis that eelgrass has been declining from 1951 to 2001 corresponding to an increasing rate of nitrogen introduction to the bay is lacking in credibility. Furthermore, the report does not present convincing evidence that 0.16 mg/L is a critical nitrogen level. Where is the body of scientific research showing the relationship between nitrogen concentration and eelgrass success?

- Not on task.

p. 208, ¶ 2:
"While these systems [drowned kettle ponds] may not be supportive of eelgrass habitat, they are generally capable of supporting healthy benthic animal habitat. Infaunal animals are sensitive to the organic matter loading and resultant periodic oxygen depletions associated nitrogen overloading. Since these conditions typically occur at higher nitrogen loads than does the shading of the bottom by increased phytoplankton production (principal cause of eelgrass loss), the nitrogen threshold level for healthy benthic animal habitat is higher than for healthy eelgrass habitat." How important, in relative terms, are "organic matter" and the "nitrogen concentrations" in supporting a healthy benthic habitat? SMAST appears to consider the loss of eelgrass to be solely attributed to bioactive nitrogen in the water column, and ignores other mechanisms that contribute to eelgrass loss!

- Not on task.

p. 208, last ¶:
After describing successful amphipod communities in the Orleans ponds where the bioactive nitrogen concentration varies apparently varies from 0.2 to 0.4 mg/l, the report concludes that 0.21mg/l should be established as the threshold concentration for benthic infauna. Why 0.21? Why not 0.28 or .030?

- Presumably the model suggests that higher levels promote more oxygen stress.

p. 209, final 2 sentences:
"Therefore restoration success will be gauged by reaching the target at the sentinel station and at the secondary stations for eelgrass (Ryders Cove) and infauna. Overall there are three primary (PBA-12, PBA-03 and CM-13.) and 8 secondary target stations within this System, the largest embayment on Cape Cod."

This states that both the sentinel station and the secondary station must meet targets. The targets are shown in Table VIII-2 which contains both Bioactive Nitrogen thresholds and

Total Nitrogen Thresholds for all 8 secondary stations, 6 of which are in Orleans. Thisseems inconsistent with the statement on p. 204 i.e.,

"……to first identify a sentinel station within the embayment …….is selected such the restoration of the one site will necessarily bring the other regions of the system to acceptable habitat quality levels."

These multiplicity of requirements and seemingly conflicting statements need to be resolved.

- Agreed. It is not clear that the SMAST document is detailed enough to be of help on this question.

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2.0 HYDRODYNAMIC AND WATER QUALITY MODELING

2.1 INTRODUCTION

This chapter presents the technical peer review of the numerical hydrodynamic and water quality modeling performed as part of the MEP work for Pleasant Bay in Orleans, MA. Specifically, a review was conducted on the information presented in the Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster, and Harwich, Massachusetts report (Howes, et al., 2006). Various other reports were compiled and reviewed in the context of this report as well. Although the scope of work in the RFP specifically asks for a review of the hydrodynamic modeling, it was essential to review the water quality model as well. The RFP requested evaluation of three specific items within the hydrodynamic model topic area:

a. The consultant will consider all aspects of the model, including but not limited to whether the boundary conditions are sufficiently defined, whether the assumption of uniform vertical concentrations in each cell in the grid [is reasonable], and whether the dispersion coefficients are reasonable.
b. In addition, the consultant should consider whether the model should be modified to include a counterclockwise circulation pattern through a tidal cycle in Pleasant Bay and estimate whether such a modification would have a significant impact on the calculated results.
c. Also, the consultant should review SMAST's calculation and use of system residence time for flushing rates in the semi-enclosed northern sub-embayments.

This chapter is divided into four specific sections, including:

- 2.2 Hydrodynamic Modeling Comments – this section focuses on the hydrodynamic modeling performed in the MEP report (chapter V), and the data collected to complete the hydrodynamic modeling effort
- 2.3 Water Quality Modeling Comments – this section focuses on the water quality modeling performed in the MEP report (chapter VI)
- 2.4 Impacts to Water Quality due to Inlet Migration and Breaches – this section evaluates the potential impacts to water quality based on inlet migration as presented in the MEP report (chapter IX)
- 2.5 Additional Overall Comments – this section provides additional overall comments related to the hydrodynamic and water quality modeling.

Within these subsections, the specific concerns raised within the RFP, as well as a more comprehensive technical review, is provided. Each section includes primary comments, less significant minor comments, and direct responses to commentary and questions raised by the Wastewater Management Validation and Design Committee (WMVDC). In some cases, analytical calculations were conducted to supplement the results in the MEP report in an attempt to address the limited data available for this review. The review is focused solely on the numerical hydrodynamic and water quality modeling of the embayment, and not the watershed delineation or groundwater modeling presented in chapter III and IV of the MEP report.

2.2 HYDRODYNAMIC MODELING

Overall, the 2-D hydrodynamic model is well formulated, accurately calibrated, and performs well in determining water surface fluctuations and tidally driven depth-averaged circulation in the Pleasant Bay system. The 2-D simulations seem to have been conducted well and seem to capture the main features of the tidal fluctuations and the tidally driven depth-averaged circulation.

Key comments related to the hydrodynamic modeling are provided below.

2.2.1 Key Comments

2.2.1.1 Influence of Potential Stratification Effects

It is likely that three-dimensional effects are important in some locations within the system, particularly in the smaller embayments where tides are weak, freshwater inflows occur, and computed nutrient concentrations are large. Three-dimensional effects that potentially may influence the circulation and subsequently the nitrogen dispersion include:

1) stratification that creates a constraint between bottom waters and the surface, which slows renewal of dissolved oxygen,

2) development of a two-layer estuarine circulation with a relatively fresh outflow near the surface and a denser inflow near the bottom, which increases the effective longitudinal diffusivity of the system, and

3) 3-D effects produced by solar heating during summer, particularly in those parts of the system that are relatively deep (~ 5 m) with relatively weak currents.

Ability to quantify these potential 3-D effects is absent in both the model simulations (which are 2-D depth-averaged) and the measurements. Based on the data presented in the MEP report, neither temperature nor salinity has been measured as a function of depth, which is a potential shortcoming in the data set. If observations throughout the water column had shown stratification in the upper embayments, the use of a 3-D model may have been warranted. Additionally, if observations indicated a lack of stratification, then the selection of a depth-average numerical model may have been adequate. Due to the importance of the MEP work to the Town, it may be reasonable to argue that 3-D measurements and 3-D modeling are more representative of state-of-the-art, especially if data observations revealed potential stratification within the system.

Some depth-resolved observations of salinity, temperature, and dissolved oxygen were collected by Horne and Horne (2001) in Arey's Pond, a subembayment in the upper portions of the Pleasant Bay system. These historical data, observed prior to the MEP, contain measurements of temperature, salinity, and concentration of dissolved oxygen at several depths at the deepest part of Arey's Pond. In order to determine if stratification effects may be important in the upper estuaries in the Pleasant Bay system, the Horne and Horne (2001) data were used to evaluate potential density stratification in Arey's Pond.

The depth-averaged temperature increases from spring to summer (Figure 2), presumably as a result of solar heating in both Arey's Pond and the adjacent bodies of water. The salinity also increases slightly from spring to summer (Figure 2), possibly as a result of reduced freshwater discharge from streams and groundwater as the summer progresses.

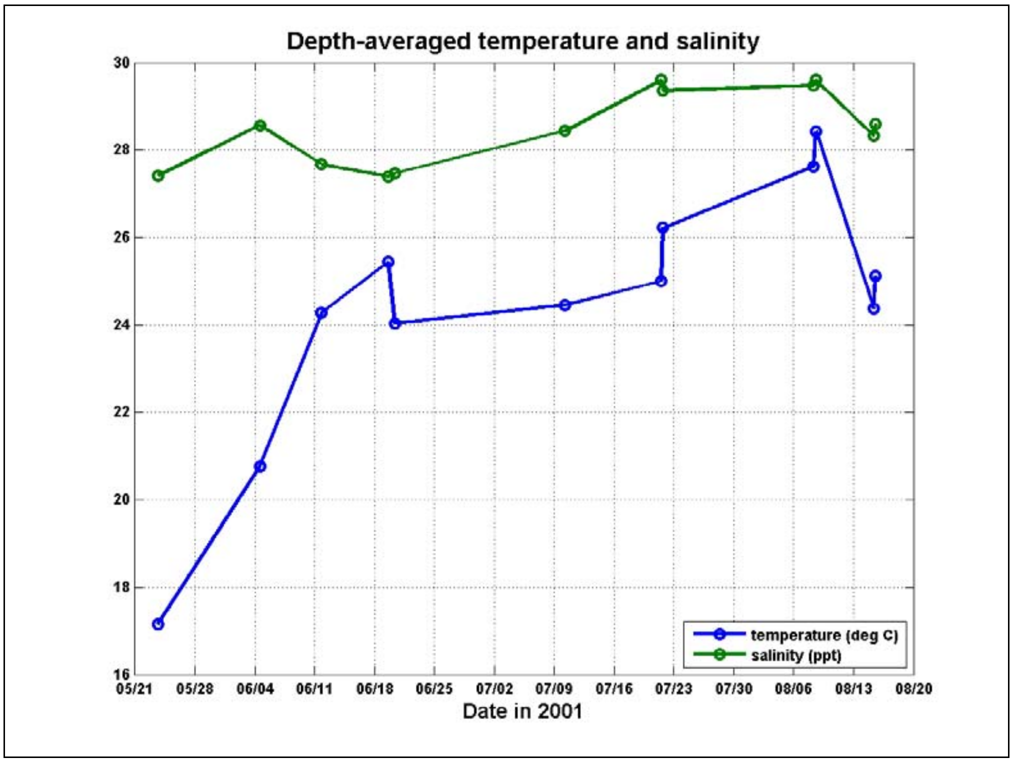

Figure 2. Depth-averaged temperature and salinity at the deepest part of Arey's Pond in 2001. Observations from Horne and Horne (2001).

To assess potential vertical variations in the observed water column, vertical gradients of temperature and salinity (i.e., changes in temperature and salinity with depth) were computed using the depth varying data of Horne and Horne (2001). Figure 3 shows the vertical gradients (rate of change of temperature and salinity with depth) for all measurement times for both salinity (green line) and temperature (blue line). In addition to the gradients, the 95% confidence levels are also presented as the bars extending vertically. Most of the gradient values are statistically significant since even the 95% confidence intervals are greater to or less than zero and are nearly always stabilizing. The gradients indicate that the temperature in Arey's Pond decreases with depth, while the salinity increases with depth, such that relatively warm, fresh water overlies colder, saltier water in Arey's Pond.

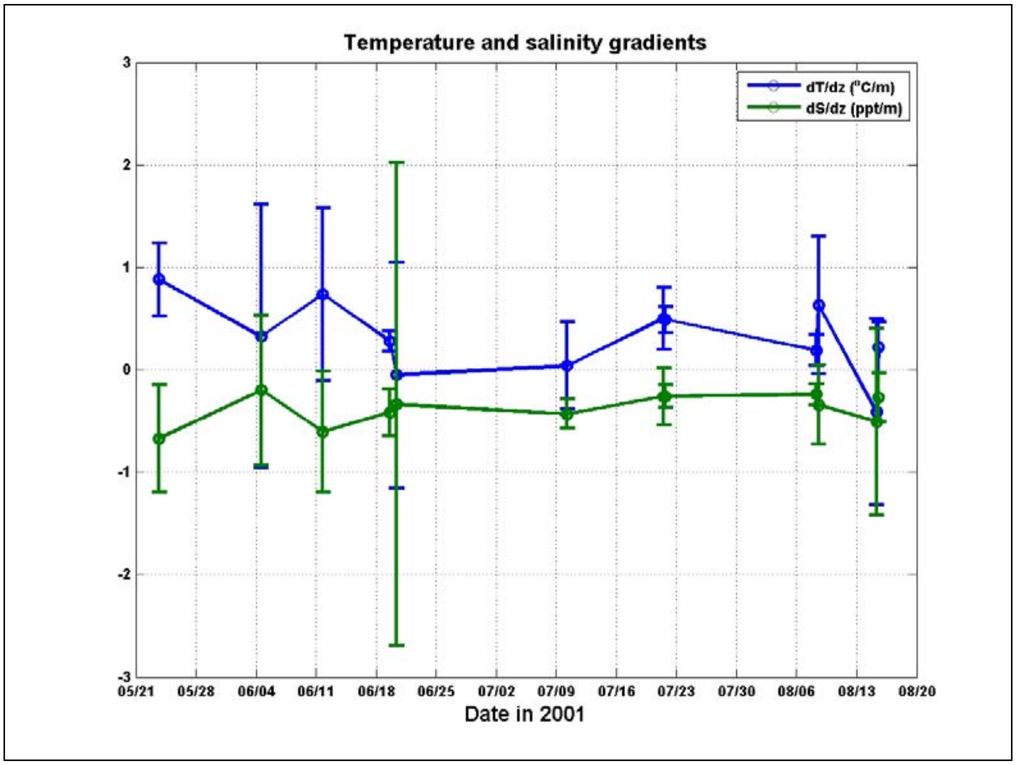

Figure 3. Vertical gradients of temperature and salinity at the deepest part of Arey's Pond. Error bars represent 95% confidence limits.

To determine if Arey's Pond stratification is persistent and stable, the Brunt-Vaisala frequency, or buoyancy frequency was calculated. The squared buoyancy frequency, N^2, calculated as a function of pressure, temperature, and salinity, is presented in Figure 4. The squared buoyancy frequency in Arey's Pond is always positive (indicating a statically stable density distribution) and with only two exceptions does the 95% confidence interval drop below zero. The buoyancy frequency is consistently positive and indicates a stable stratification since the temperature and salinity gradients reinforce (i.e., they both have a stabilizing effect) each other. Although salinity is more important than temperature in producing the vertical density gradient, temperature is also a factor. The mean squared buoyancy frequency for the entire record is 3.6 $x10^{-3}$ s^{-2}, which is a value typical of many stratified estuarine environments (Turner, 1981).

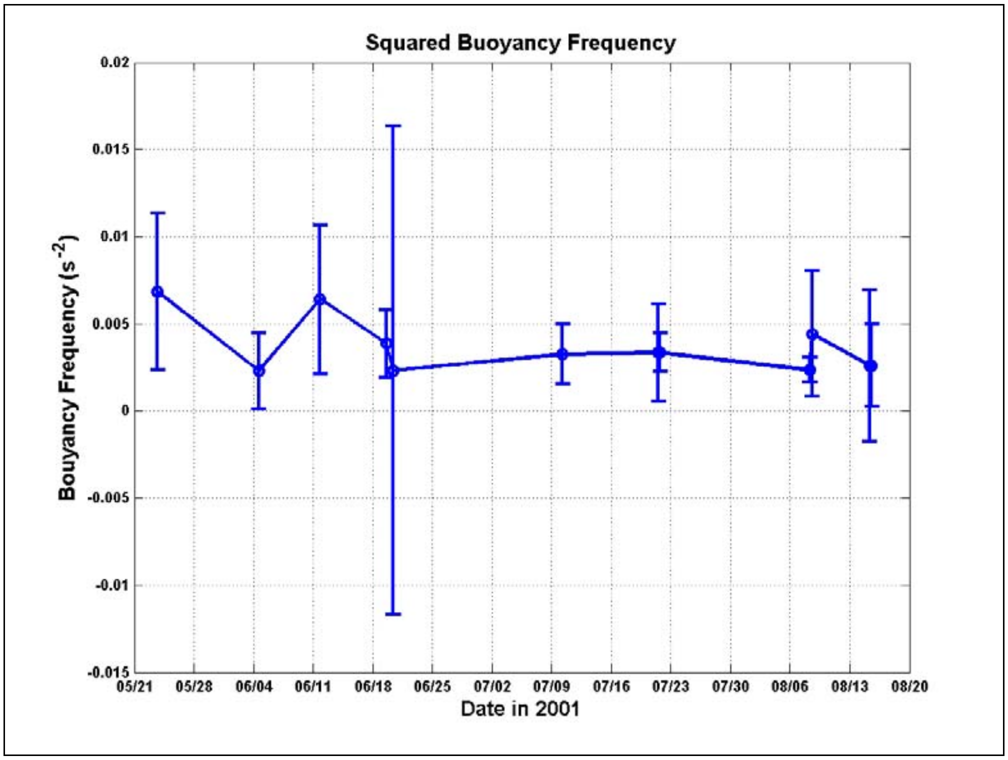

Figure 4. Depth-averaged vertical squared buoyancy frequency at the deepest part of Arey's Pond. Error bars represent 95% confidence limits.

In order to determine the potential ability of the velocity gradient (*du/dz*) to overcome the ability of Arey's Pond to remain stratified (or induce mixing), a stabilizing vertical density gradient can be estimated according to the Miles-Howard criterion by $Ri = N^2/(du/dz)^2$, where *Ri* is the gradient Richardson number. When *Ri* is less than ¼, then velocity shear is considered sufficient to induce mixing and overcome stratification. Numerous laboratory and field measurements have indicated that this theoretical result describes the mixing threshold in natural systems with reasonable accuracy (Turner, 1973). Assuming for simplicity that the velocity varies linearly with height throughout the water column, and that the velocity is zero at the bottom, this result corresponds to a depth-averaged velocity of *hN*. With the observed mean squared buoyancy frequency of $3.6 \times 10^{-3}\,\mathrm{s}^{-2}$, and a water depth (*h*) of 4 m representative of the deepest part of Arey's Pond where the measurements were obtained, the depth-averaged velocity required to produce mixing would need to be approximately 0.24 m/s. In reality, the depth-averaged velocity required to produce mixing may possibly be larger since the assumption of zero velocity at the bottom is an underestimate.

To determine if under normal conditions Arey's Pond would be able to overcome its stratification, it is useful to estimate the velocity in the channel entering Arey's Pond by means of a control volume continuity analysis. Without the hydrodynamic model or the modeling results available, a simple tidal prism approach was used to estimate the potential velocity in the Arey's Pond system. The MEP report estimates that the tidal prism (ΔV) for Arey's Pond is approximately 2,623,000 ft^3. Assuming that the volume varies approximately sinusoidally with a radian frequency corresponding to the M2 tidal constituent ($\omega = 1.4 \times 10^{-4}\ s^{-1}$), the maximum flowrate in the entrance channel must be $Q=1/2\ \omega\ \Delta V$. Therefore, the corresponding depth-averaged velocity is 0.12 m/s, estimating the channel breadth and depth form Figure 3 of the Horne and Horne report as 90 and 5 feet, respectively. Thus, even in the inlet to Arey's pond, where the fluid velocity must be much larger than the velocity in the pond itself, the flow is not strong enough to mix the water column against the stabilizing effect of the observed stratification. It is likely that not only Arey's Pond, but also the adjacent bodies of water may also be stratified, and that this stratification persists because of the relatively weak velocities. Additionally, the presence of persistent stable stratification likely explains the fact that the observed concentration of dissolved oxygen is smaller near the bottom than near the surface (Figure 5), since the near-bottom water is likely isolated from exchange with the atmosphere.

Therefore, based on the limited data available for this review, it appears that stratification may be a significant process in the upper embayments of Pleasant Bay and that by not including potentially important 3-D effects in the hydrodynamic and water quality models could lead to inaccurate estimates of circulation and nitrogen dispersion in the upper embayments.

2.2.1.2 Tidal Attenuation in Upper Subembayments

Many of the smaller sub-embayments in the Chatham portion of Pleasant Bay (e.g., Muddy Creek, etc.) have been studied in a separate MEP report (Howes, et al., 2003). Howes et al. (2003) study of these Pleasant Bay subembayments included more detailed bathymetric information and additional tide and current data to more accurately determine the tidal attenuation caused within these subembayments. This more local, site-specific data results in model calibration of the each subembayment to the observed attenuation occurring within each of these smaller subembayments. It is assumed the detailed sub-models calibrated and verified in this previous study are integrated into the larger Pleasant Bay study (Howes et al., 2006). Given the relative importance of all the smaller sub-embayments, where a majority of the water quality does not meet the required thresholds, it seems logical to ensure accurate tidal attenuation model calibration in the other smaller sub-embayments in the upper portions of the Pleasant Bay system (e.g., Arey's Pond, Kescayo Gansett Pond, etc.). However, no tidal observations were conducted in these upper sub-embayments during the overall tide data collection effort.

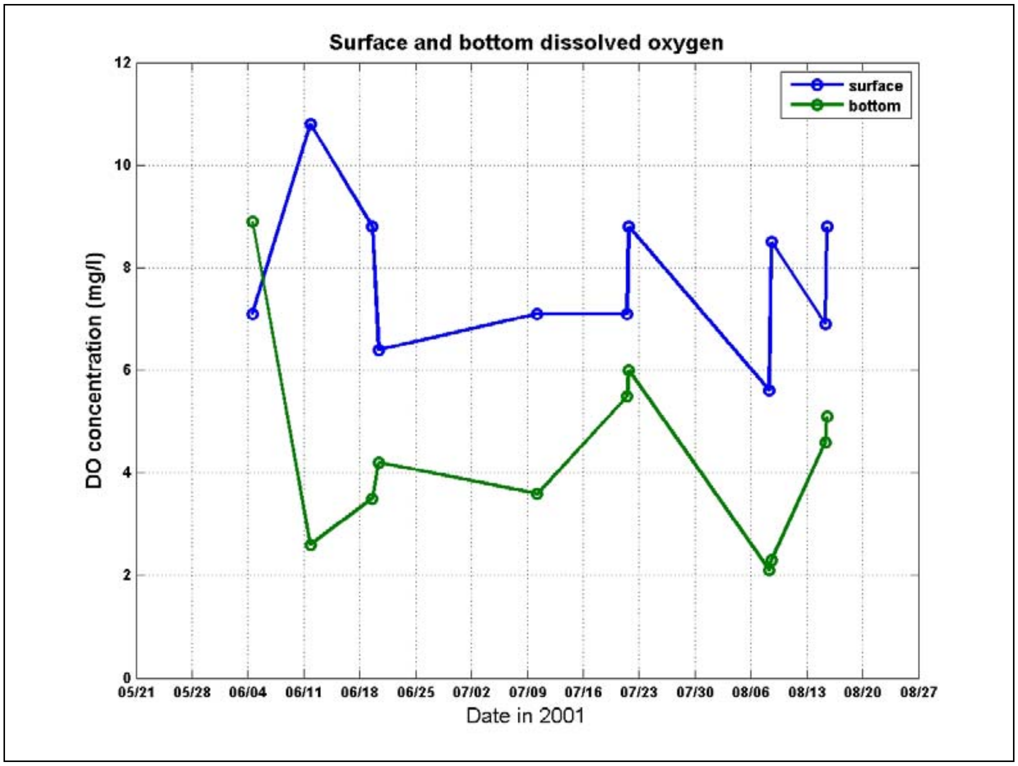

Figure 5. Surface and bottom concentrations of dissolved oxygen at the deepest part of Arey's Pond.

2.2.1.3 Simulation of Anthropogenic Structures

Historically, the RMA-2 hydrodynamic model was not capable of handling flow control structures (e.g., culverts, weirs, etc.), as the model was originally developed as a surface water, open channel hydrodynamic model. In more recent versions however, RMA-2 has been upgraded to include flow control structures. These upgrades have included the addition of 1-D control structures, which is available in version 4.20 and higher, and subsequently 2-D control structures, available in version 4.40 and higher (Donnell, 2006). The MEP Pleasant Bay report does not provide the version of the RMA-2 code that was used in the development of the Pleasant Bay hydrodynamic model, although it is assumed that RMA-2 version 4.5 was likely used.

Section V.2.2 of the MEP Pleasant Bay report discusses anthropogenic changes within the Pleasant Bay system consisting of structures built at the Route 28 crossings of Muddy Creek and Frost Fish Creek. The Muddy Creek Route 28 culverts consist of dual box culverts (2.6 feet by 3.7 feet), while Frost Fish Creek consists of 3 partially blocked 1.5 feet diameter culverts, as well as a single large culvert and weir structure upstream of the partially blocked culverts. The MEP report on Pleasant Bay does not contain any documentation on how these control structures were modeled within RMA-2, or if they were explicitly included at all. Additionally, (Howes, et al., 2003), which contains more detailed modeling of the Muddy and Frost Fish Creek , does not provide any additional discussion on the methodology for modeling the flow control structures. Howes et al.

(2003) does indicate that no 1-D elements were used in the modeling grid except for freshwater input areas. Therefore, flow control structures were not explicitly modeled using a 1-D control structure for Pleasant Bay. Since the methodology to simulate flow control structures in RMA-2 is an important aspect of the modeling of some of the Pleasant Bay sub-embayments, and since this is a relatively new feature in RMA-2, an explanation of the modeling approach for these flow control structures would be helpful.

In addition, the frictional coefficients used to represent the culverts are significantly higher than those published in literature (Chow, 1959; Barfuss and Tullis, 1994; Barfuss and Tullis, 1988; Bishop and Jeppson, 1975; Neale and Price, 1964; Tullis et al., 1990; Norman et al., 2001). Table 1 presents the typical range of frictional coefficients used for culverts, as presented in the Federal Highway Administrations Hydraulic Design of Highway Culverts (Norman et al., 2001). Partially blocked culverts may account for an increase in frictional coefficient; however, the 0.50 value is an order of magnitude higher than typical values.

If control structures were not utilized in the hydrodynamic grid, tidal attenuation may still have been adequately captured by the using standard 2-D elements with modified frictional coefficients. However, this approach may not adequately represent the actual dynamics of the flow control structure (especially if the culverts are fully flowing during portions of the tidal cycle), nor can it be modified to represent potential alternative structures with any level of design accuracy.

2.2.1.4 Tidal Residual

Based on Figure V-13 in the MEP Pleasant Bay report, there is significant tidal residual that exists after extracting 23 individual tidal constituents. Although only 23 tidal constituents are sometimes used by NOAA to compile their tide tables, the length of the 43 day tidal record should allow for the decomposition of more than 23 tidal constituents. For example, there are 35 standard tidal constituents that can be captured in a 40 day record. Considering the variation of the tidal residual is over 2 feet at Fish Pier (approximately 47% of the observed tidal range at the Fish Pier), it is feasible that some of this residual may actual be composed of tidal constituents that were not evaluated in the harmonic analysis. Although the tidal residual only accounts for approximately 10% of the overall energy, this could be better rectified through the inclusion of more tidal constituents, which may, in turn, enhance circulation slightly.

We understand that it is likely that a portion of the tidal residual is caused by atmospheric forcing (wind, rainfall, barometric pressure). Therefore, Figure 6 presents the climactic data observed by NOAA's National Climactic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html) at the Chatham Municipal Airport during the time period of the MEP tidal observations. The upper panel presents barometric pressure, the middle panel shows wind magnitude and direction, and the lower panel shows precipitation. These climactic data can be qualitatively used to assess the potential causes of the tidal residual. For example, the significant increase in water surface elevation on November 5 corresponds to a significant drop in barometric pressure on that day, while the increase in water surface elevation on November 29 may be caused by a combination of the significant rainfall and increased wind. However, the apparent low pressure system occurring on October 24, indicated as the cause of the largest tide residual (p. 105 of MEP report), does not seem to be the cause of this particular increase in water surface elevation. Therefore, there may be other factors that contribute to some of the tidal residual.

It is unclear if measured or predicted tides were used for the offshore tidal boundary conditions and for model calibration. However, if predicted tides, decomposed through harmonic analysis of the measured water surface elevation, are used to simulate the model, then the model could be improved through additional tidal constituents.

Table 3. Manning's n Values for Culverts (Norman et al., 2001).

Type of Culvert	Roughness or Corrugation	Manning's n
Concrete Pipe	Smooth	0.010-0.011
Concrete Boxes	Smooth	0.012-0.015
Spiral Rib Metal Pipe Corrugated Metal Pipe, Pipe-Arch and Box	Smooth 68 by 13 mm 2-2/3 by 1/2 in Annular 68 by 13 mm 2-2/3 by 1/2 in Helical 150 by 25 mm 6 by 1 in Helical 125 by 25 mm 5 by 1 in 75 by 25 mm 3 by 1 in 150 by 50 mm 6 by 2 in Structural Plate 230 by 64 mm 9 by 2-1/2 in Structural Plate	0.012-0.013 0.022-0.027 0.011-0.023 0.022-0.025 0.025-0.026 0.027-0.028 0.033-0.035 0.033-0.037
Corrugated Polyethylene	Smooth	0.009-0.015
Corrugated Polyethylene	Corrugated	0.018-0.025
Polyvinyl chloride (PVC)	Smooth	0.009-0.011

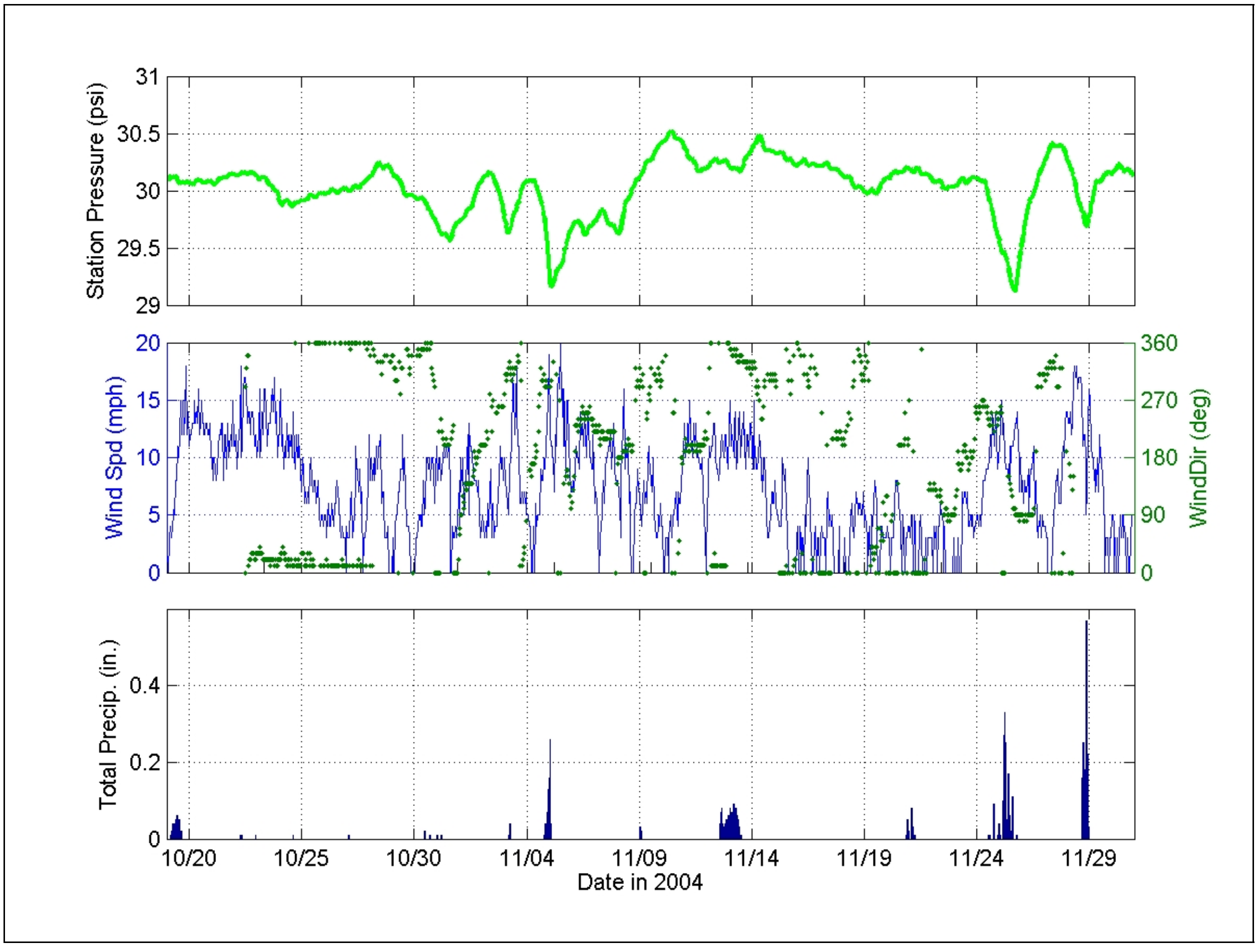

Figure 6. Barometric pressure, wind speed and direction, and precipitation observations during the 43 day tidal deployment period presented in the MEP Pleasant Bay report. Data collected by NOAA's National Climactic Data Center at Chatham Municipal Airport.

2.2.2 Minor Comments

This section provides questions and/or comments intended to request for clarification of the MEP report, and may not be significant in terms of the overall modeling results:

2.2.2.1 Data Collection and Analysis

- The track lines and survey dates associated with the NOAA GEODAS data are not shown. It may be useful to show the added coverage that was provided by these data, as well as the relative time scales when they were collected. Compared to many other MEP modeled embayments, the bathymetric data coverage for Pleasant Bay appears to be less than other MEP modeling embayments, especially in the middle and upper eastern portions of the system. If the data are sparse, local shallow or deeper areas (subject to possibly increased stratification) may not be well-represented in the model.

- Tidal datums were computed from the 43-day tidal record at stations in the Pleasant Bay system. As indicated in the MEP report, the National Oceanographic and Atmospheric Administration (NOAA) maintains a tidal datum located at Lydia Cove in Chatham, MA, which is based on 19 years of tide data. The MEP Fish Pier (PLB2) tidal station is located close to NOAA's Lydia Cove station. Since the MEP data are limited to a 43-day record, differences are expected between the tidal datums calculated by NOAA's long-term record and those calculated from the short-term MEP data. For example, from the NOAA tidal station at Lydia Cove (http://tidesandcurrents.noaa.gov/), the tidal range (MHW to MLW) is 4.63 feet, while at the adjacent Fish Pier location in the MEP report, Table V-1, the tidal range is 4.3 feet. The difference is reasonable; however, it is not clear whether the time period selected for model calibration, and subsequently for nitrogen dispersion modeling, is representative of longer-term tide data. If the tidal range used in the modeling is less than the long-term average it is possible there is an under prediction of mixing potential, which may introduce a conservative bias to the analysis.

- Since the circulation dynamics of the system are a critical component of the hydrodynamic and water quality modeling, it would be helpful to present all the transect data (similar to Figures V-14 through V-17) in an Appendix. In this manner, the reader could be educated on the observed flow dynamics throughout the tidal cycle (e.g., slack tides, transition periods from flood to ebb, etc.) As it stands, there is minimal representation of the physical circulation processes in the system. Comparisons of data and model predictions (as stated below) would lend tremendous insight to the processes, and help the community better understand the issues.

2.2.2.2 Hydrodynamic Modeling

- The MEP report indicates that, "For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models." Perhaps it would be worthwhile to show circulation dynamics throughout the tidal cycle at other locations throughout the system, similar to the flood and ebb velocities shown at the inlet (e.g., Figures V-28 and V-29). This would help understand the overall circulation dynamics of the system, which is generally lacking in the report. Model animations of circulation, for instance, would benefit the community.

- There is no mention or discussion of potential sea level rise and its influence on the modeling or dispersion in the MEP report. Given the current rates of predicted sea level rise, the influence of future sea level rise considered in the hydrodynamic or water quality models should at least be addressed.

- It is unclear whether a 5 or 7 day period was selected for model calibration. On p.113, the second paragraph refers to a 5 day calibration period, while the third paragraph refers to a 7 day simulation. There are similar inconsistencies related to the length of the calibration period throughout the report. In either case, it should be clarified why only 5-7 days were selected. It also would be helpful to document why the 5-7 day period selected is believed to provide a reasonable representation of the average tide range when compared to the long term tidal records.

- It is unclear if surface wind forcing was included in the hydrodynamic model. In model setup, no discussion of a surface wind boundary condition is provided, and in model calibration, it also appears that wind was not included. It is reasonable to not include the impacts of wind on the model, since the observed short-term winds over the time period of model calibration are not likely representative of average conditions. However, when discussing the flow rating curves in the model validation on p.120, it appears wind may have been included in the model. "The 'bumps' and 'skips' of the flow rate curve (more evident in the model output) can be attributed to the effects of winds (i.e., atmospheric effects) on the water surface…" This seems to indicate that some wind effects were included in the model.

- In order to enhance the model verification to spatial and temporal changes in the currents, it would be worthwhile to compare the magnitude and direction of the depth-averaged current observations with the model velocity vector results. This would provide added confidence that the model is accurately identifying the flow dynamics.

2.2.2.3 General Comments

- p.83 - The MEP report indicates that, "Tidal flushing will be utilized as the basis for a quantitative evaluation of water quality." This statement may result in some of the confusion related to tidal flushing, since the flushing rates and residence times presented later in the chapter are really qualitative measures used to provide an initial estimate of the tidal flushing associated with each sub-embayment. Ultimately, the more detailed water quality modeling effort, which directly utilizes the results of the hydrodynamic model, more accurately (and quantitatively) describes how tidal flushing influences the nitrogen concentrations within the Pleasant Bay System.

- p.85 - There is a citation for Kelley et al. (2003) in the first paragraph that appears to be missing from the references.

- p.97 - Figure V-8 uses a PLB nomenclature for the tidal stations; however, this nomenclature is not used to refer to the tidal stations at any other location in the report. It may be useful to include a table that ties the geographic nomenclature used throughout the rest of the report with the PLB nomenclature used in Figure V-8.

- p.85 – The last paragraph indicates that "…data from the five TDR stations within the system were used to calibrate and verify the model performance…"; although there are 6 TDR stations within the system that are used for calibration, while ADCP data were used for model verification.

- p.110 - There is a reference to Howes et al. (2005) in the first paragraph that appears to be missing from the references.

2.2.3 Response to WMVDC Comments

This section provides direct response to commentary and questions raised by the WMVDC. WMVDC comments/questions are presented in italics, with our observations and responses provided below each WMVDC comment. These comments are addressed separately for completeness, and because the comments did not provide the basis for the independent peer review presented in other sections of this report. Absent this section, some of the issues of importance to the WMVDC would have not otherwise been addressed.

The bathymetry surveys were conducted in 1997, 2000, and 2004. Would there have been any significant changes to depth in the upper ponds between 1997 and 2004?

- It is unlikely that any bathymetric changes occurred between 1997 and 2004 that would significantly impact the circulation dynamics or mixing characteristics of Pleasant Bay. However, it may be useful to show the added coverage that was provided by the NOAA data, as well as the relative time scales when they were collected.

Seven tide gauges were located in the Pleasant Bay System, figure V-8. Why weren't any tide gauges located along the eastern edge of Pleasant Bay, that is, along the Barrier Beach? How does the hydrodynamic model interpret the tidal rise in the eastward direction for the tide gauges in the Western section of Pleasant Bay, i.e., PLB4 and PLB5?

- It is likely that the six tide gauges deployed within the Pleasant Bay estuary were all deployed on the western edge of Pleasant Bay due to ease of access, as well as the availability of various structures and features for securing the tide gauges. The locations of the deployed tide gauges allow for adequate calibration of the hydrodynamic model and do not create any difficulties in the ability of the model to simulate the water surface elevation and/or circulation throughout the system. Potential variations in the water surface elevation between the western and eastern end of the embayment is likely negligible, and the hydrodynamic model is capable of identifying any unique variation in water surface elevation or circulation through time varying calculations using the governing equations. Unique circulation patterns that may develop within Pleasant Bay still can be identified by the hydrodynamic model regardless of the placement of the tide gauges. However, it would be useful to see maps or animations of tidal current predicted by the numerical model for different stages during the tidal cycle (e.g., slack high, peak flood, slack low, peak ebb, etc.). These maps would illustrate any unique circulation features that may develop, as well as show the overall circulation dynamics of the system.

Therefore, although it is likely that circulation patterns are more complex than a simple north/south propagation of water, as documented by Horne and Horne (2001), these features should be identified by the hydrodynamic model. Additionally, it is likely that these smaller magnitude circulation features have minimal impact on nitrogen transport.

Explain the reason for the difference between "Measured Tide" and the "Predicted Tide". How do these data relate to the July-August time-frame? Why were the measurements made in October-November, rather than in July-August, when most of the remainder of the report was addressed? Are the local velocities and gradients different in the summer months due to solar heating of the bottom sands and other materials?

- Measured tide refers to the actual observed time series of water surface elevation changes, while predicted tide refers to the decomposition of the observed time series of water surface elevation into known tidal constituents. These tidal constituents (e.g., M2, M4, S2, etc.) can be combined to create the time series of predicted tide that essentially removes all non-tidal processes (e.g., wind, rain, etc.) from the time series of water surface elevation. This allows for creation of a time series of only tidal processes, and eliminates any short-term, non-tidal factors from the observed data. It does not matter when the water surface elevation changes were observed, since there will be no change to the tidal-forced water surface elevations in various seasons. Tides, caused by the relative position of the Moon and Sun to the Earth, will not change based on the season. Therefore, the same tidally based water surface elevation changes will occur in all seasons.

The data in the middle chart (Fig. V-14) show some negative cross-current velocities in the middle of the channel, showing significant mixing patterns. From the middle chart (Fig. V-15.), it appears that there was mixing in the cross-channel direction. Are the cross channel currents included in the model?

- Depth-averaged cross channel currents are included in the model. Again, it would be useful to see all temporal transects from the ADCP survey, which would provide a better understanding of the flow dynamics at the channel cross sections.

The top chart (Fig. V-16) for the West Bay channel (entrance to The River from Little Pleasant Bay) velocities through the main channel of 1 to 2 ft/sec, but at the southwest bank of "backflow". The ebb flow in the West Bay Channel seems to be of moderate velocity (Fig. V-17). The middle chart appears to show reasonable cross current velocities, or good mixing. The charts also seem to show very low velocities along the bottom surface. Does the hydrodynamic model reflect these types of flows as well?

- The hydrodynamic model is capable of capturing all these types of flow. As discussed, it may be useful to present a comparison of modeled and observed current observations to ensure the model was identifying the temporal and spatial currents.

Is the "two-dimensional" modeling sufficient throughout the Pleasant Bay System?

- Refer to section B.1 of this review.

"Various friction and eddy viscosity coefficients were adjusted…" These parameters, or constants, were selected by trial and error, until a solution was obtained that satisfied the boundary conditions? Is there necessarily a single solution? There were no tide gauges on the east side of larger Pleasant Bay; would this cause a deficiency in the analysis?

- These parameters are adjusted until the modeled water surface elevations accurately match the observed water surface elevations throughout the Pleasant Bay system. The hydrodynamic model appears to incorporate a reasonable set of coefficients, within acceptable ranges (except perhaps for the culverts), that match the observed data. The lack of tide gauges placed along the eastern side of Pleasant Bay would not result in a deficiency in the modeling effort.

The model was calibrated in November 2004. This is a period where the bottom surface is colder than during July and August. Would all of the coefficients used in the "model" be temperature sensitive, and therefore be different in July and August?

- No, the model coefficients are not temperature sensitive, and the calibration would be the same since the forcing tides are independent of seasonality.

The Manning roughness coefficients were fairly close, except for Pleasant Bay and the culverts at Frost Fish and Muddy Creek. Is there an explanation?

- The Manning's roughness coefficients for all the embayments fall within the range of accepted frictional coefficients for natural systems. As discussed in section B.1, the methodology used to determine the closed conduit flow for the culverts of Frost Fish Creek and Muddy Creek is not presented. The frictional coefficients for the Frost Fish and Muddy Creek culverts are significantly higher than Manning's coefficients typically used to determine flow through a culvert (Chow, 1959; Barfuss and Tullis, 1994; Barfuss and Tullis, 1988; Bishop and Jeppson, 1975; Neale and Price, 1964; Tullis et al., 1990; Norman et al., 2001), as discussed in section B.1.

In Figures V-19 through V-25, the report shows a comparison of the model computed tides and the observed water levels at various locations throughout Pleasant Bay. All this is based on measurements taken over five days beginning November 13, 2004. This was the period of calibration. How did the model predict the tidal behavior in a time period in future years?

- The model has been accurately calibrated to the tides that currently occur within Pleasant Bay. The forcing oceanic tides, which are based on the relative position of the sun and moon to the earth, will remain the same in the future. However, this does not mean that the circulation and dispersion within the Bay will remain the same in the future. Factors such as bathymetric changes, geometry changes, anthropogenic impacts, inlet migration, barrier beach breaches and overwash, and sea level rise may all influence the tides and circulation within Pleasant Bay. This is not something the model can be expected to predict. However, the model can be used to determine what may occur under these various scenarios, which is the real utility of numerical modeling. The hydrodynamic model, as calibrated, is a useful tool to project these future changes to the system, and has been used to evaluate various future scenarios already (e.g., inlet migration, breaches, etc.).

In Figure V-27, the data are presented for the "mouth of the River" on November 23, 2003. Is the "mouth of The River" referred to here the same channel referred to in Fig V-17 as the "entrance to West Bay".

- Yes, we assume these are the same.

The "system residence time" seems to be a strange measurement. Does this measurement mean to imply that it will take over a year to completely flush out Muddy Creek, Round Cove, Pah Wah Pond, Areys Pond and Lonnies Pond [Table V-8]? Doesn't this parameter suggest that the fluid from these ponds just move in and out with very little exchange with the incoming tide? Does this imply an assumption of plug flow in the embayments and sub-embayments? It does not seem to be logical. Does the Pleasant Bay system work this way? How is "system residence time" used in the hydrodynamic model? Is this an appropriate way to describe the transport of nitrogen from a sub-embayment to the Atlantic Ocean?

- The concept of residence time, at least as presented in the MEP report, requires clarification in terms of how it relates to the actual nitrogen modeling. In the end, it is our understanding that the flushing rates and residence times presented in the MEP report are qualitative measures used to provide an initial estimate of the tidal flushing associated within each sub-embayment. However, due to the quantitative presentation of tidal flushing and residence times, the MEP report can easily be misinterpreted. Ultimately, the more detailed water quality modeling effort (RMA-4), which directly utilizes the results of the hydrodynamic model (RMA-2), more accurately (and quantitatively) describes how tidal flushing influences the nitrogen concentrations within the Pleasant Bay System. The residence times presented in Table V-8 are not utilized in computation of nitrogen concentrations or dispersion. Therefore, it may be somewhat confusing to the average reader since the residence time does present quantitative values and the MEP report does spend a fair amount of time discussing these values. As stated in the MEP Report, "Residence times are provided as a first order evaluation of estuarine water quality." Since the MEP approach uses numerical water quality modeling directly to determine the nitrogen concentrations (which should be far more accurate than simple residence time calculations), the residence time calculations based on tidal prism become almost irrelevant. In fact, RMA-4 could be used to directly provide quantitative residence times values if the RMA-4 model was applied to determine flushing rates (Letter et al., 2008; EMS-I, 2000).

Although the calculations of residence time in the MEP report are simplified (based primarily on consideration of tidal prisms) and their rationale and application are somewhat questionable, given that these values are not ultimately used in the water quality modeling, they should not be viewed as a major concern. The flushing rates presented are simply mathematical estimates of each of the subembayment residence times that should be viewed as estimates and relative comparisons.

2.3 WATER QUALITY MODELING

2.3.1 Key Comments

2.3.1.1 Water Quality Boundary Conditions (Bioactive vs. Total Nitrogen)

Of the approximately 33 MEP estuaries that have been completed to date, only the Pleasant Bay system (and its sub-embayments) has used bioactive nitrogen (as opposed to total nitrogen), for calibration and threshold development. The Bassing Harbor system (Howes et al., 2003), a smaller sub-embayment system of Pleasant Bay, also used bioactive nitrogen for model calibration.

This discrepancy (bioactive versus total nitrogen) is not well documented in the MEP Pleasant Bay report, at least in the modeling section of the report. For example, Table VI-2 in the MEP Pleasant Bay report provides the present loading conditions for total nitrogen modeling of the Pleasant Bay system; however, the water quality modeling is calibrated to bioactive nitrogen. Additionally, all modeling results, both present conditions and scenarios, present only bioactive nitrogen. This is likely a source of significant confusion to the average reader. For example, to the average reader, if the loadings are total nitrogen, then it would be intuitive that model-data comparisons should be in terms of total nitrogen. If the bioactive nitrogen is actual being modeled, then it would seem logical that a bioactive loading boundary conditions needs to be applied. As such, there needs to be clarification on the boundary conditions that were used in the water quality modeling, and the calibration technique applied.

In the Pleasant Bay MEP report, total nitrogen loading is applied and then compared directly to the bioactive nitrogen data, since the non-bioactive component of nitrogen (DON) is: (1) a component that is not included in the loading analysis; (2) is generated solely from sources in the water column, which RMA-4 cannot reproduce accurately; and (3) the DON is refractory (i.e., does not contribute significantly to phytoplankton production). As such, the DON portion of the data observations is not an important component of the total nitrogen. If this is true, then it is confusing that bioactive nitrogen is not used for model calibration and threshold concentrations in all MEP estuaries.

From the Bassing Harbor report (Howes et al., 2003), model calibration results are presented both for a total nitrogen simulation and a bioactive nitrogen simulation. The RMA-4 model does not calibrate well to total nitrogen results, and thus, the calibration technique was modified to compare to only bioactive nitrogen, such that the model comparison was improved. For these two simulations, it is assumed that the loadings stay the same (total nitrogen for atmospheric, watershed, and benthic flux), yet the modeling results are different (Figures VI-3 and VI-4 of the Howes et al, 2003 report) based solely on the background nitrogen level assigned at the boundary condition. Therefore, the background value assigned appears to have a significant influence on the overall nitrogen concentrations in the system.

Overall, the calibration technique, which appears to be different for Pleasant Bay then the remaining MEP estuaries, raises some concern over the ability of the water quality model to accurately simulate the actual nitrogen concentrations that were observed.

2.3.1.2 Selection and Sensitivity of Dispersion Coefficients

The calibration of the water quality model to bioactive nitrogen and salinity was performed by adjusting dispersion coefficients until the model results of concentration closely matched the observed data. The reasonably accurate representation of the time-averaged 2-D concentration fields that was achieved with the 2-D model through the tuning of the longitudinal dispersion coefficient, which is highly spatially variable in the model application, suggests a high degree of tuning. It is unfortunate that a model-data comparison of time-dependent concentrations (salinity or nitrogen) was not available and/or presented in the MEP Pleasant Bay report (as discussed below). It is possible that the time-dependent concentrations would not be represented well by the model and that only the time-averaged 2-D field could be simulated realistically by tuning the spatial variability of the diffusivity. The reported values of the model diffusivity are large in some areas, compared to those presented both in the RMA-4 Users Manual (Letter, 2008) and other sources (EMS-i, 2000). The larger values of diffusivity also contrast with many modern applications of 2-D and 3-D models in which the diffusivity is relatively small (i.e. controlled by the numerical scheme). The comparison with estimates of longitudinal diffusivity (*E)* in the Fischer et al. (1979) text are perhaps somewhat misleading, because the Fischer et al. (1979) values are laterally and vertically averaged over the cross-section of the channel. In other words, Fischer et al. (1979) values of dispersion were originally intended for assessments where the dispersion values needed to include diffusion caused by vertical and horizontal circulation dynamics. These dynamics were typically not explicitly included in the 1-D models that were considered state of the art in the late 1970s. This explains the potential order of magnitude differences between the RMA-4 recommended dispersion values (Letter, 2008) and those presented in Fischer et al. (1979). In theory then, the diffusivity (*D)* in a 2-D or 3-D model should arguably be much smaller than the Fischer et al. values because the scales responsible for dispersion are resolved by the model and thus do not need to be represented in terms of a large effective diffusivity. In other words, the 2-D model should be capturing a good portion of the horizontal dispersion dynamics that cause dispersion to occur. The larger dispersion coefficients that are required to calibrate the RMA-4 model may indicate that there are some important processes that are not being adequately captured by the hydrodynamic model (i.e., 3-D processes) or there is inadequate resolution to capture important 2-D processes.

The MEP Pleasant Bay report also does not discuss the potential variation in dispersion coefficients in the x and y directions, which are required input in the RMA-4 model. It is likely that the same dispersion coefficient was used for both D_x and D_y; however, this should be stated in the MEP report.

Perhaps significantly more important than the actual values of the dispersion coefficient is the significant spatial variability and highly sensitive nature of the dispersion coefficients. A sensitivity analysis was conducted by Howes et al. (2001) for the MEP linked model. The sensitivity analysis revealed that by far the most sensitive parameter in the overall linked model approach was the dispersion coefficient assigned in the water quality modeling. The Howes et al. (2001) sensitivity assessment found that by changing the dispersion values used in the calibrated model by 2x or -0.5x the selected value could change the nitrogen concentration anywhere from -19 to +93% depending on the location in the estuary. Therefore, even a small change in the dispersion coefficients would have a significant impact on the predicted nitrogen levels. Howes et al. (2001) expresses that although the nitrogen results are very sensitive to the selection of the dispersion coefficients, there remains a high confidence in the dispersion values used in the calibrated model. However, based on the variations and limitations in the actual calibration and verification methodology applied in the water quality model (discussed below), as well as the potential limitations of the RMA-4 model itself, it is not unreasonable to consider that modified dispersion coefficients could produce a water quality model that is still considered calibrated with measurably different nitrogen concentration levels.

2.3.1.3 Calibration and Verification of RMA-4

As discussed, it is unfortunate that the report includes only a time-averaged test of the ability of the model to simulate the measured nutrient and salinity fields. The lack of a time-dependent comparison leaves uncertainties regarding the quality of the advective processes represented in the 2-D model. There is a considerable amount of averaging of both the data and the model results that may mask potential limitations of the model. As such, even though no time series observations were available, it would be useful to present the time series results (time-varying salinity and nitrogen concentrations) from the water quality model. The time-varying model results would provide additional assurance that the selected calibration methodology and averaging approach is reasonable. For example, the time-varying nitrogen concentrations at mid ebb tide in the time series of model results could be directly determined, and the methodology of simply selecting the mid-point between maximum modeled bioactive nitrogen and average modeled bioactive nitrogen values to adjust for sampling at mid ebb tide could be verified.

In general, the methodology for calibration and verification of the water quality model appears to be inconsistent. For example, in the Pleasant Bay model calibration, the mid-point of the maximum modeled bioactive nitrogen and the average modeled bioactive nitrogen was compared to the mean measured bioactive nitrogen at each water quality monitoring station since sampling results were collected during mid ebb tide. However, for model verification, the modeled salinity values are not adjusted for the mid ebb tide sampling. For salinity, the average modeled salinity is compared to the averaged measured salinity. Further discrepancies exist in other MEP Reports. For example, in the Howes et al. (2003) study of Pleasant Bay sub-embayments in the Town of Chatham, the calibration targets were set such that the means of the measured data would fall within the range between the modeled maximum and modeled mean concentrations for station with a wide range of modeled concentrations, while those with less variability compared the mean value of both the model and data. This variation in the calibration methodology should be more clearly explained and justified to improve model credibility.

2.3.1.4 Mass Conservation in RMA-4

The RMA-4 model is sensitive to mass gain/loss across large closed boundary angles. The suggested minimum boundary angle between any two adjacent elements is 10° (EMS-i, 2000; Letter, 2008). This applies not only to the outer mess boundary, but also to the wet/dry interface. This means that any part of the finite element grid that dries will create a new wet/dry interface that remains relatively smooth. The MEP Pleasant Bay model applies element/nodal elimination for areas in the Pleasant Bay system that experiences wetting and drying during tidal fluctuations. This can cause significant problems with the conservation of mass. Additionally, the Pleasant Bay model grid contains numerous locations where the elements do not maintain a boundary angle of less than 10° (e.g., many of the inlet elements to the smaller sub-embayments).

The MEP Pleasant Bay report does indicate that a continuity of mass equation check is utilized to ensure that mass is conserved (p.132); however, no details on the mass conservation approach or the percent error in mass conservation is presented. Considering the significant mass conservation errors that can occur in finite element models, it would improve model confidence if the mass conservation checks were quantified. For example, RMA-4 version 4.5 provides a mass conservation check that can be implemented across many continuity lines, and produces a summary table that gives a percent gain/loss value for the constituent (in this case nitrogen) being simulated. This would ensure that the nitrogen modeling is not experience a significant gain or loss in nitrogen concentration caused by the numerical errors within the model.

2.3.1.5 RMA-4 Model Selection

RMA-4 was created to evaluate a substance that is evenly distributed vertically in the water, and evaluates the mixing and migration processes in depth-averaged flow regions. It will not provide accurate concentrations for stratified situations, and based on the data available, this may be the case for some of the smaller upper embayments within the Pleasant Bay system. One could also argue that 3-D measurements and a 3-D model are the state of the art for a project with large financial stakes such as the TMDL initiative for Pleasant Bay.

RMA-4 should not be considered state-of-the-art in water quality modeling, particularly for complex systems. Applications of the RMA-4 model have shown limitations in the models ability to model wetland nitrogen (Capps, 2001) and contaminant concentrations (Haralampides, 2000). Based on the work of Capps (2001), The RMA-4 models nutrients only superficially, thus, it is sufficient as a screening tool, but not robust enough to investigate wetland nitrogen processes. For example, RMA-4 can only simulate a first order decay rate, which oversimplifies the biochemical processes occurring as nitrogen evolves in an estuary, especially processes that may occur in shallow pond areas.

Although the MEP Pleasant Bay report indicates that the overall approach models total nitrogen as a non-conservative constituent, there are no dynamic biochemical processes that are occurring in the model. All of the boundary conditions and loading rates, including the benthic flux source and sinks, remain constant throughout the simulation. State-of-the-art models for nutrient mixing and transport are much more complicated, and involve numerous biochemical reactions, sources/sinks for each state variable, and interactive chemical processes. This includes depositional flux, diagenesis flux, and a wide range of sediment flux calculations between the water column and layers of the sediment. These types of dynamic sediment/water hydrodynamic and biochemical time-varying models are being regularly applied for TMDL studies in many other national regions (e.g., Christina River Basin, DE, Puget Sound, WA, San Diego Bay, CA, Anacostia River, DC, Lake Michigan, MI, Brunswick River, GA).

Overall, there are certain complex dynamics of Pleasant Bay that are not well-described by RMA-4.

2.3.1.6 Background Nitrogen Concentration Level

The background nitrogen concentration in the Atlantic Ocean region offshore of Pleasant Bay was set at 0.094 mg/L based on data collected at station PBA-17A in the summer of 2005. This was value was calculated on a single summer of data observations, which introduces potential atypical seasonal processes. Considering MEP requires a minimum of three years of baseline field data within the estuary in order to be simulated in the linked-model approach and multi-year averages are used for model-data comparisons, it would be reasonable that the background levels should also be sampled over multiple years. Although the data may not have been available at the time of the report, bioactive nitrogen concentrations observed at the same station (PBA-17A) and analyzed by SMAST during the summers of 2006 and 2007 were 0.079 mg/L and 0.071 mg/L, respectively. This indicates a potential short-term bias in the background concentration, and of the data observed, MEP uses the highest seasonal average. A reduction in the background concentration level may result in an approximately equal reduction of the bioactive nitrogen levels throughout the estuary.

2.3.2 Minor Comments

This section provides questions and/or comments intended to request for clarification of the MEP report, and may not be significant in terms of the overall modeling results:

- Assuming a vertical uniform concentration of either salinity or nitrogen does not appear to be a reasonable assumption for the entire Pleasant Bay estuary system (as discussed in section 2.2.1). Although some limited conductivity, temperature, and depth (CTD) profiles (a single cast) were collected in some of the smaller Chatham subembayments such as Crows Pond, Taylors Pond, and Little Mill Pond (Howes et al., 2003), the MEP report presents no data to verify the assumption of vertical uniformity in the upper sub-embayments of Pleasant Bay system.

- The specification of the nitrogen loading boundary conditions is ambiguous and could be clarified for the average reader. For example, the MEP report indicates the benthic regeneration and direct atmospheric loads were evenly distributed among another subset of grid cells which form in the interior portion of each basin. It would be helpful if the subset of interior cells and rates of flux were presented.

- In order to project benthic loading for future scenarios, the benthic flux values are assumed to vary proportional with the watershed load. This approach seems to be oversimplified and should be verified through literature and studies. This is further discussed in the benthic flux review topic area in this report.

2.3.3 Response to WMVDC Comments

This section provides direct response to commentary and questions raised by the WMVDC. WMVDC comments/questions are presented in italics, with our observations and responses provided below each WMVDC comment. These comments are addressed separately for completeness, and because the comments did not provide the basis for the independent peer review presented in other sections of this report. Absent this section, some of the issues of importance to the WMVDC would have not otherwise been addressed.

Is Pleasant Bay quiescent? Are there not significant currents producing mixing? If there were significant currents, would higher dispersion coefficients be needed to reflect the currents in Pleasant Bay?

- The circulation dynamics within Pleasant Bay are likely adequately described by the hydrodynamic model and these currents are directly input into the water quality model. Refer to section 2.3.1.2 of this review related to dispersion coefficients.

Why do the multi-year averages present the "best" comparison? What happens if all values are included in the comparison?

- No comment

Why is total nitrogen used as a "non-conservative constituent, where bottom sediments act as a source or sink of nitrogen…"?

- This statement simply refers to the specification of the benthic flux nitrogen loading rates in the water quality model. A negative benthic flux is a sink of nitrogen (removes it from that subembayment at the specified rate), while a positive benthic flux is a source of nitrogen (adds it to the subembayment at the specified rate). Therefore, the MEP report refers to this exchange as non-conservative.

Has the model been used for winter conditions? If no, why not? Has SMAST considered year-around material balances in its calculations?

- It does not appear as though the model has been applied to winter conditions; however, this is reasonable since summer conditions represent the worst case for nitrogen impacts within the estuary system. The worst case season should be used to ensure that the nitrogen concentrations meet threshold levels throughout the year. If averages over all seasons were utilized, nitrogen concentrations would likely exceed the thresholds during the summer seasons.

Is there only one set of dispersion coefficients that provide a solution to the inputs and boundary conditions, or are there multiple combinations? In other words, is there a unique solution to the mathematical computations?

- Based on the calibration and verification metric used in the MEP Pleasant Bay report, which involves significant averaging, there may be more than one combination of dispersion coefficients that would allow the model to fit the range of data observed. Refer to section 2.3.1.2 of this review related to dispersion coefficients.

At each time step the model computes Nitrogen over the entire grid and utilizes a continuity of mass equation to check these results. Question: Is this a Mass Balance calculation?

- Refer to section 2.3.1.4 of this review.

If the model was operated with "total nitrogen" inputs, how did the RMA-4 model predict the "bio-active" nitrogen concentrations?

- Refer to section 2.3.1.1 of this review.

Describes that an initial N concentration is applied to the entire model domain. Model was then run for a simulated 28 day spin-up period. Question: Why and for what reason? What is a "spin-up period"?

- Model spin-up is a standard procedure for simulation of water quality constituents. This is required in order to prime the model for the nitrogen loading rates by applying a initial uniform concentration to ensure the model is at a stable concentration. The recommended spin-up time is usually at least twice as long as it takes for the velocity field to move through the simulation area. The 28-day period is adequate to ensure that the model has adequately stabilized to the initial condition.

In the watershed loads, why were the contributions from "Natural Background Watershed Loads" [Pleasant Bay Report, Table ES-1a, Page ES-11.] not included? See Table VI-2, page 134. Or were they included?

- This question is unclear, since the reference to Table ES-1a is not referenced.

The report states that the concentration of "bio-active" nitrogen in the Atlantic Ocean was 0.094 mg/liter in 2005. Were any other measurements made at any other time? Shouldn't measurements have been made in at least one or two other years? Were measurements made of "total nitrogen" in the Atlantic Ocean, since this was the basis for the input data? In more than just 2005?

- Refer to section 2.3.1.6 of this review.

Nitrogen loads for each sub-embayment watershed were evenly distributed at grid cells that form the perimeter of the sub-embayment. Question: Was attenuation by the fringing marsh applied in the model?

- If the fringing marsh area is included in the model, the effects would be included. It is unclear where and how much of the fringing marsh is in the model domain; however, it is likely that this has a limited impact on the nitrogen dispersion.

"Calibration of the bio-active nitrogen model of Pleasant Bay proceeded by changing model dispersion coefficients so that the model output of nitrogen concentrations matched measured data." What does this mean?

- Dispersion coefficients, which can be modified for each sub-embayment, were adjusted until the model results best match the observed, averaged data of nitrogen concentrations.

How is the concentration for "bio-active" nitrogen, DIN+PON, derived from the total nitrogen input data? What is the conversion?

- Please refer to section 2.3.1.1 of this review, as well as the data tables of the sampling results, which provide direct laboratory measurements of DIN, DON, and PON.

Table VI-2 (pg. 134) shows that the total contribution of nitrogen (total N) from the direct atmospheric deposition (85.69 kg/day) and from benthic flux (184.519 kg/day) is 2.1 times the contribution from the watershed load of 127.203 kg/day. Aren't the contributions from septic systems, fertilizer, etc., relatively small?

- This question is unrelated to the water quality modeling, and involves the development of the nitrogen loading values.

What does "yearly data" mean? Were measurements made throughout a year? Or does it mean the "average of several years"?

- It is our understanding that yearly data means refers to the average of all years of observed nitrogen data (between 1995 and 2004). The data were first averaged over each year, and then the yearly averages were averaged to arrive at a single value. For each year, measurements were made during the summer months only.

Why is the one sigma measured data variance so large, especially for: Meetinghouse Pond, Upper Muddy River, and Frost Fish [CM-14]? The variance on the yearly measurements is significantly large, especially at: Upper Pochet, Upper and Lower Muddy Creek, and lower Frost Fish. Why?

- This is likely because the observed data is highly variable. In order to determine the exact nature of the variability all data observations would need to be evaluated. The data have not been provided for this review.

If the data represent the average of measurements made over several years, they would not describe trends in the concentrations, either increases or decreases. Aren't trends, if they occur, important?

- Trends in the nitrogen data observations may or may not be important depending on a wide variety of factors. The data have not been provided for this review.

How were the fresh water flows determined? Are they assumed to be the same for every year? How do they vary with annual rainfall and with municipal well production?

- Freshwater flows were determined from the USGS groundwater model, as presented in Table III-1 in the MEP Pleasant Bay report. They are assumed to be constant in the hydrodynamic and water quality model. A complete review of the USGS groundwater model would be required to determine potential impacts of annual rainfall fluctuations or municipal wells.

The first paragraph jumps right into conclusions of significant increases in nitrogen loads due to build-out. The impact is all about the assumptions used and there is no hint of how this was generated. What assumptions were used? Are there decision choices that could be made to lessen the impact?

- Discussion of the buildout scenario is discussed in chapter IV (p.44) of the MEP Pleasant Bay report. Please refer to that section to determine how the buildout scenarios were developed.

The model shows very poor correlation with field measurements for Upper and Lower Muddy Creek. Why?

- We agree the model is less accurate in the Muddy Creek area, which could be caused by a wide variety of factors, including the freshwater input, the ability of the model to simulate the flow control structures, etc. The exact reasons would need to be more thoroughly explained by the MEP technical team.

The benthic flux values in Table VI-6 are slightly higher than in Table VI-2. What was the methodology for determining the higher values in Table VI-6?

The benthic flux for Meetinghouse Pond is shown as 7.40 kg/day, compared to 14.365 kg/day in Table VI-2. Does that mean that the difference, 6.695 kg/day of total nitrogen (46.6%), derives from vegetative and marine matter decay? How was this determined? Is this calculation satisfied by an annual material balance?

For Arey's Pond, the number is 3.70 kg/day in the "no-load" case, compared to 5.669 kg/day in Table VI-2, or more than half. This means that in the current day scenario, in Arey's Pond, the contribution from the sediments during a summer month is 3.70 kg/day (61.7%) from natural matter and 2.30 kg/day from (38.3%) anthropogenic sources. How was this determined?

- All of these questions relate to determine the change in net benthic flux for the various scenarios. The methodology for determining the decrease or increase in benthic flux values is presented on p.144 of the MEP Pleasant Bay report. In order to project benthic loading for future scenarios, the benthic flux values are assumed to vary proportional with the watershed load. As discussed, this approach seems to be oversimplified and should be verified through literature and studies, and is further discussed in benthic flux review topic area in this report.

2.4 IMPACTS TO INLET MIGRATION AND BREACHES COMMENTS

2.4.1 Key Comments

It is clear the breaches of 1987 and 2007 have improved tidal flushing, and subsequently nitrogen dispersion, within the Pleasant Bay estuary system. However, the Nauset Beach-Monomoy Island barrier system is, and will continue to be a dynamic system that is shaped by a variety of physical processes and storm events. No one can determine with complete certainty how long the current system will maintain its current flushing ability, nor can anyone determine when the next storm may reshape the Nauset Beach coastline, create or close an inlet, or significantly change the shoals. Therefore, if the intent is to continue to allow the Nauset Beach system to be reshaped by the constant natural dynamics, then the preferred target design must be selected that reasonably meets the water quality limits under a majority of natural inlet scenarios (e.g., 1987 post-breach conditions). If an inlet management plan is implemented, then it may be feasible to reduce the uncertainty in the physical changes of the inlet and constrain the design level for a specific flushing scenario. Ultimately, the preferred design level that will meet the water quality needs to be determined by the Towns surrounding Pleasant Bay.

The calibrated and verified model was developed to evaluated potential future scenarios, and it is sufficiently flexible to evaluate a range of refinements and adjustments caused by naturally occurring changes to the system (i.e., future breaches, historical inlet locations, etc.). The model has already been employed to complete these types of assessments (Kelley and Ramsey, 2008) and shown relative changes to the existing conditions case. As long as there is confidence in the existing conditions model, then relative comparisons to other scenarios should produce reasonable results. However, at this point additional scenarios offer little additional information, until a specific target inlet scenario is identified.

2.4.2 Minor Comments

This section provides questions and/or comments intended to request for clarification of the MEP report, and may not be significant in terms of the overall modeling results:

- It is unclear if the pre-1987 breach conditions represent the worst case. Based on the work of Giese (1988), there may have historical conditions that would have created even worse tidal flushing.

- In the supplemental memorandum regarding Pleasant Bay Water Quality Model Update and Scenarios (Kelley and Ramsey, 2008), Table 2 shows a +2.3% change from background at Frost Fish Creek. This appears to be an error.

- Although the worst case scenario changes the boundary conditions to Nantucket Sound, it does not change the background concentration of nitrogen. The background concentration in Nantucket Sound should also be evaluated to ensure the correct value is selected.

2.4.3 Response to WMVDC Comments

This section provides direct response to commentary and questions raised by the WMVDC. WMVDC comments/questions are presented in italics, with our observations and responses provided below each WMVDC comment. These comments are addressed separately for completeness, and because the comments did not provide the basis for the independent peer review presented in other sections of this report. Absent this section, some of the issues of importance to the WMVDC would have not otherwise been addressed.

"The flushing analysis performed for the present study also incorporates existing conditions and the 'worst-case' pre-breach conditions." Does this statement refer to the 'worst-case' scenario of Chapter IX?

- It is unclear if the analysis in chapter IX is considered worst case conditions based on subsequent scenarios simulated (Kelley and Ramsey, 2008), as well as the historical location of the inlet. It appears as though the simulation in chapter IX is a representation of the pre-1987 breach conditions.

"As a suggestion, an inlet management plan should be developed to address possible future water quality problems that could occur as a result of less-than-optimal configurations of the Pleasant Bay inlet." What is possible? What can or should be done to maintain the hydraulic efficiency of the Pleasant Bay inlet system while

maintaining suitable habitats for the flora and fauna of the estuary? Does anything need to be done in the next 75 years?

- Development of an inlet management plan would involve a commitment to maintaining a relatively stable inlet that would allow for consistent tidal exchange and less variability in terms of the hydrodynamic characteristics of the system. This may consist of maintain an inlet at a given location and of a given size through structural controls (e.g., jetties) and/or continual maintenance (e.g., dredging, bypassing of sediment, etc.) or creation of improved inlets once the water quality levels were below a predetermined level. An inlet management plan would attempt to control the variability of the inlet migration, breaches, and shoaling, while keeping the water quality at a high level. An inlet management plan could be initialized sooner rather than later and would likely start with determining the feasibility of inlet management options.

2.5 ADDITIONAL OVERALL COMMENTS

The MEP Pleasant Bay study and report is a comprehensive and highly technical report. Overall the modeling is well conducted and produces reasonable results compared to the observed conditions. However, missing from the report is a simplified synthesis of the system dynamics, backed up by model and data, and describing how all the components of the MEP linked model approach work together to arrive at a final solution. This synthesis would indicate that the authors basically understand the system and that they have reason to believe that the model results are reasonable. The processes within Pleasant Bay as a whole are extremely complicated, and the modeling includes (or should include) representations of poorly understood processes (phytoplankton blooms, grazing by zooplankton, benthic exchange, uptake of dissolved oxygen, etc.). Average readers of the report are basically confronted with a situation in which they must choose to believe or disbelieve the complex model results. A qualitative description of the transport processes and estimates of the rates, backed up by data and model computations, might help convince readers that the system is understood well enough to make predictions about important quantities.

Additionally, it is reasonable that for an estuary of this size and complexity and importance that an evaluation and selection processes should have been conducted for the numerical modeling software. In Howes et al. (2001), a detailed assessment of approaches for the entire linked watershed-embayment methodology was conducted; however, this same comparison and selection process does not seem to have been conducted for the numerical models themselves. Understanding the strengths and weaknesses of the RMA series of models for Pleasant Bay specifically, including a sensitivity analysis, would help quantify the uncertainty in the model predictions.

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3.0 HEALTH OF EELGRASS AND BENTHIC COMMUNITY

The charge for this analysis as outlined in the Request for Proposals is summarized in the italicized paragraph:

In the Pleasant Bay Report, SMAST relates the health of eelgrass (primarily in Pleasant Bay and Little Pleasant Bay) and the benthic communities to nitrogen levels in the adjacent waters. The Total Maximum Daily Load (TMDL) calculated by the Commonwealth of Massachusetts DEP for the Pleasant Bay System is related to defined nitrogen concentrations. Using the Orleans area of Pleasant Bay as the basis, the consultant will evaluate: a) the relationship between the health of eelgrass and the benthic community and the composition of the local water column, including, but not limited to, total nitrogen, bioactive nitrogen, oxygen and salinity; b) the relationship between local oxygen concentrations (including hypoxia/anoxia) and nitrogen in the water column; and c) the history of eelgrass, whose decline is attributed primarily to nitrogen in the Pleasant Bay System, and assess any other mechanisms that might contribute to the observed decline.

3.1 OXYGEN AND NITROGEN IN THE WATER COLUMN

The basic relationship between nutrients and dissolved oxygen in the water column is: nutrients stimulate algal growth throughout the water column and on sediments - anywhere where there is enough light. Algae, which produce oxygen during daylight, respire using oxygen day and night, and upon death use oxygen in decay processes. With excessive nutrient loading and eutrophication, hypoxia/anoxia results especially in bottom waters where dead algae accumulate. When nutrients are sufficiently reduced so that algal production is also reduced, more healthy conditions can return. This has happened, for example, in Lake Erie. Recovery also depends upon the level of nutrients stored in the sediments, which will be recycled before being flushed from the system. Cleansing of the groundwater is slow but sensitive to weather, and will occur faster in years with heavy rainfall. There are sufficient references for the downward turn in estuarine health in response to excessive nutrient loading (i.e., more nutrients and more hypoxia (Anderson and Gilbert, 2002; Bowen et al. 2001; Valiela et al. 1992; Paerl et al. 1995; McClelland & Valiela, 1998; Smith et al. 1999)); however, there are limited actual cases of recovery yet realized in estuaries to date.

3.2 BOTTOM OXYGEN AND BENTHIC POPULATIONS

The following literature review supports the methods and conclusions that MEP reached regarding the composition and diversity of the benthic fauna in Pleasant Bay. The innermost parts of the bay are characterized by low diversity and the presence of opportunistic species or no infauna due to nitrogen over-enrichment.

Low oxygen concentration (hypoxic or anoxic conditions) in the bottom waters is widely used as an indicator of conditions in an estuary (Kemp, R. et al. 2005). Complete lack of oxygen (anoxia), even for a short period, allows very few macro-organisms, including eelgrass, to survive (Anderson, Glibert et al. 2002). Many small infauna are the most resistant; their absence is a good indicator of anoxia. *Capitella* and *Streblospeo* are the most resistant of these; they don't compete well with worms requiring better oxygen conditions so their presence is good indication that conditions are severely degraded. *Capitella* survives and reproduces only in sediments with relatively high organic matter, an indication of organic pollution such as results from nitrogen pollution (Ramskov and Forbes 2008). In Narragansett Bay benthic infauna of this sort are associated with pollution inputs and sediments with high oxygen demand (Valente, Rhoads et al. 1992). Samples from San Francisco Bay showed these polychaetes associated with sewage discharge (Thompson and Lowe 2004). Research in Korea found a similar result though the species there were different from those in the U.S. (Lim, Diaz et al. 2006). In a bay in Portugal cleanup of pollution resulted in the gradual decline of *Capitellids* and their replacement by a more diverse infauna (Cardoso, Bankovic et al. 2007). A study of 248 coastal and estuarine sites in the Gulf of Maine (Maine, New Hampshire, and Massachusetts) used 49 different criteria for benthic condition of which 10 gave strong ability to detect damaged sites. Of these three, which included abundance of *Capitella*, and faunal diversity gave over 80% ability to detect poor quality sites (Hale and Heltshe 2008). Another study in Sweden developed a benthic quality index in which *Capitella* was indicative of the lowest benthic quality (Rosenberg, Blomqvist et al. 2004).

Anoxia can be a highly variable condition. Anoxia is often present in the wee hours of the morning when respiratory processes have used the oxygen and photosynthesis has been absent for hours (Taylor and Howes 1994). However tidal exchanges can alter this, bringing in oxic waters in the pre dawn hours if currents are strong enough. The MEP graphs of oxygen illustrate this well for Pleasant Bay. But even so, a few hours of anoxia can prevent most organisms from surviving.

Decreased oxygen concentrations have a direct, adverse effect on eelgrass. Like most plants and animals, eelgrass requires oxygen to survive and grow. Although eelgrass produces oxygen during photosynthesis, the plants also require oxygen in the water column to keep their cells healthy. In addition, most of the oxygen produced during photosynthesis is not stored in plant tissue (Greve, 2003).

A number of studies have documented adverse effects of low oxygen on eelgrass. Holmer and Bondgaard (2001) showed a reduction in photosynthetic activity, leaf elongation rate, and the number of leaves per shoot in eelgrass plants exposed to low oxygen conditions. Greve (2003) showed a rapid response to reduced water column oxygen levels in eelgrass meristems - the meristem[1] quickly turns anoxic when the surrounding water is anoxic. Hypoxic conditions in sediment can affect eelgrass flower development (Plus et al 2003) and plant growth (Glaub et al. 2005).

Hypoxia is generally accompanied by increased hydrogen sulfide levels due to the activity of anaerobic sulfidic bacteria in sediments. Exposure to high sulfide levels leads to a complete cessation in photosynthetic activity in eelgrass after several days of exposure (Holmer and Bondgaard, 2001). In muddy (sulfidic) sediments, the leaves cannot transfer sufficient oxygen to their roots and rhizomes during hypoxia resulting in

[1] The meristem is the part of a stem or root from which new growth starts – it can be thought of as a root that grows new sprouts.

death by influx of sulfide into roots (Pedersen et al. 2004). This suggests a dual effect of low oxygen and high sulfides in eelgrass decline in eutrophic waterbodies.

Figure 7 is a modified version of Figure 18 in Kemp et al. (2005). It illustrates how nutrients (here nitrogen) affect algal growth. A greater abundance of algae uses more oxygen at night. When the algae sink and die, decomposition results in hypoxia/anoxia at depth. This, in turn, causes eelgrass disappearance and replacement of stable infaunal populations with *Capitellids* and other opportunistic infauna.

In summary, the changes in eelgrass in the inner parts of the Pleasant Bay System are most likely due to eutrophication (nitrogen loading), and exacerbated in some areas by boat disturbance of the bottom. Wasting disease and changes in circulation and sediment distribution certainly have had effects in the more open parts of the Bay with the latter probably more important.

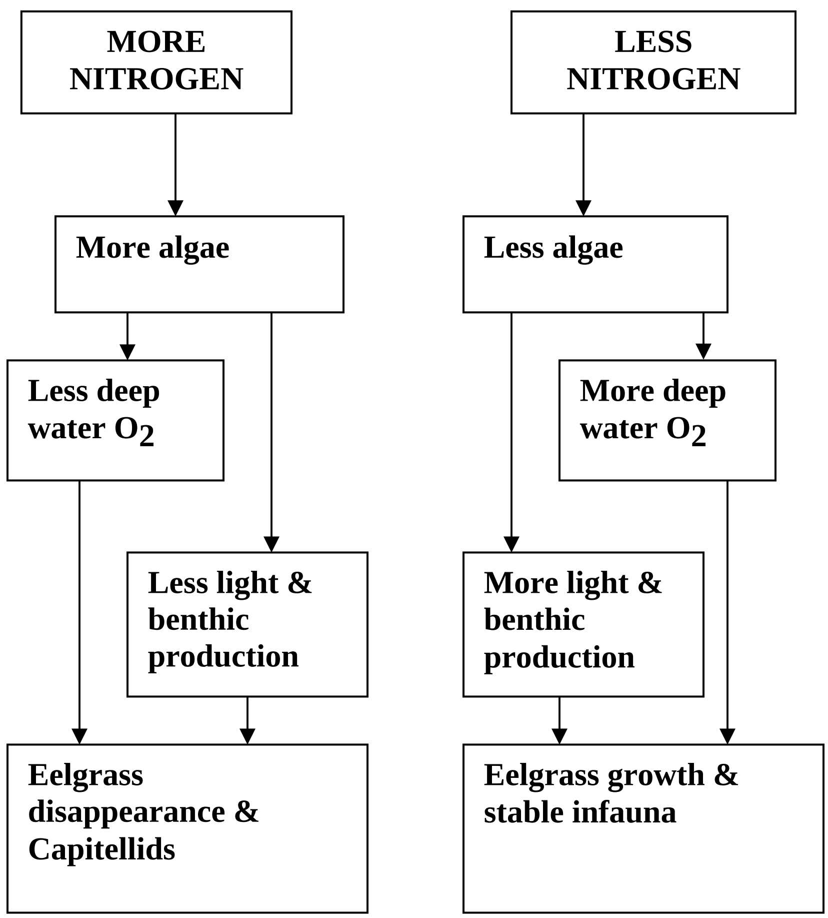

Figure 7 Affect of nitrogen on algal growth.

3.3 EELGRASS DISTRIBUTION

Eelgrass has been widely used, along with other sea grasses in areas where eelgrass is rare or lacking, as an indicator of estuarine health. This is partly because higher plants are relatively easy to see and map. They are also sensitive to some types of pollution, especially eutrophication (see Figure 7, modified Fig.18 (Kemp, R. et al. 2005)).

Eelgrass coverage using existing data is difficult to assess with much accuracy. Using only the '95 and '01 photos from the MEP report, it does seem that there has been a decrease, although the absolute amount of this decrease is difficult to quantify. There seems little doubt that eelgrass abundance and density has diminished in the innermost parts of the bay where there is less tidal flushing. This is consistent with the conclusion that the decrease in grass is a result of increased nitrogen loading.

Nitrogen stimulates dense algal growth, which produces hypoxia as it decomposes upon death. Algae, both micro- and macro-, also reduce light penetration to the bottom and to eelgrass both by floating in surface waters and by growing on bottom substrates including eelgrass.

A 42 year record in Chesapeake Bay showed a close connection between nitrogen loading and anoxia (eelgrass distribution was not measured) (Hagy, Boynton et al. 2004). Reduced light penetration in Waquoit Bay was linked with nitrogen pollution and a reduction in eelgrass shoot density and bed area. This suggests the eelgrass decline resulted from reduced recruitment and shoot death rather than reduced growth rate (Hauxwell, Cebrian et al. 2003, 2006). A thorough review of the scientific literature on eelgrasses decline and recovery round the world illustrates the strong connection between eelgrass abundance and nitrogen pollution and the complications that can arise in this relationship (Burkholder, Tomasko et al. 2007). Short and Burdick (1995) quantified the effects of excess nutrient loading on eelgrass in mesocosms. Excess nutrients caused a significant reduction in eelgrass growth, density, and biomass. The reduction in eelgrass biomass was linearly related to light levels. In addition plant morphology changed, with leaves becoming longer under high nutrient/low light conditions. These changes in eelgrass bed structure and biomass were brought about by stimulation of various forms of algae (microalgar, macroalgae, epiphytes) by excess nutrient loading.

The MEP statement that the eelgrass in these inner areas has been replaced by macroalgae reinforces the conclusion that nitrogen pollution has been the cause of eelgrass decline in the inner bay (Anderson, Glibert et al. 2002; Bintz 2002). This has been found in other areas such as Waquoit Bay in Falmouth (Short and Burdick 1996; Bowen and Valiela 2001; Lee, Short et al. 2004). For example Short and Burdick showed eelgrass growth, shoot density and recruitment were all directly related to light levels. Algae were stimulated by nutrients, shaded eelgrass and resulted in vegetation change from eelgrass to various forms of algae, macroalgae, epiphytic algae growing directly on eelgrass leaves and phytoplankton.

There are certainly losses of eelgrass as the result of new openings in the barrier island as sediments are moved and the grass is buried. The losses in these areas, near the new openings where flushing is greatest, are not the ones that are important in judging whether or not nitrogen loading is damaging eelgrass beds. That there was a large bay scallop harvest in '83 is consistent with good eelgrass beds in the more open parts of the system, but does not tell us about what was happening in the more confined parts. There were no N measurements in the bay in 1951, but we know there is more N in the system now because we know that the human population (both year round and seasonal) has increased, increasing the load of N to groundwater and hence to the bay. Valiela, Foreman, and Bowen (Valiela, Foreman et al. 1992; Bowen and Valiela 2001) have shown that there is more N entering the Cape's coastal systems in the latter years of the last half century.

Eelgrass wasting disease, responsible for the great declines in the 1930's, is still affecting eelgrass populations. The infection and effect on eelgrass populations is mostly limited to high salinity waters and is significantly less in brackish waters (Short, Muehlstein et al. 1987; Short, Ibelings et al. 1988; Short, Burdick et al. 1995). Since the definite decline of eelgrass in Pleasant Bay is in the more brackish areas and the persisting populations are in the more saline parts of the Bay, the decline of eelgrass in the inner parts of the bay is consistent with the cause of the decline being primarily eutrophication rather than wasting disease.

3.4 BIOACTIVE NITROGEN

Total nitrogen includes nitrogen in compounds that are slow to degrade and therefore do not release their nitrogen for use by plants (algae). Compounds such as lignin fit this category. In certain instances, it is not suitable to include these compounds when calculating the amount of nitrogen causing eutrophication. Bioactive nitrogen is nitrogen contained in compounds that are readily degraded, and release their nitrogen for uptake by plants. This includes that nitrogen already in inorganic form and usable by plants. When there is a high total nitrogen, it may be beneficial to focus on the bioactive portion in a system where there is flushing that will remove the resistant fraction. MEP did not include particulate organic nitrogen (PON) in their active fraction. If they had, the available nitrogen would have been larger, but it is not certain whether this would make a significant difference in the analysis. Some research that suggests organic nitrogen (dissolved and/or particulate) may contribute to eutrophication in estuaries. A more detailed investigation of this research is ongoing at the time this Draft Report was published.

3.5 BOATING ACTIVITY

The potential influence of boating activity was raised as a topic of interest in the course of conducting the peer review. Stirring up the bottom with props, dragging anchor chains, etc. exacerbates poor conditions if the bottom is muddy and has high organic content (Crawford 2002). If the bottom muds do not have high levels of labile organics, the effects will be less serious. If high nitrogen inputs have increased organic levels, the effects will be greater. It is reasonable to conclude that high nitrogen inputs have contributed to the effects of boats in creating anoxic conditions in Pleasant Bay. Boat effects are highly localized, especially in shallow waters, where the stirred up mud settles fairly rapidly. Even if nitrogen inputs were brought to zero now, it would take years for the effects of boats to be reduced because the labile organics and nitrogen concentration in the mud will decline slowly under natural conditions.

3.6 RECOVERY TIME

It is important to recognize that even if all sources of nitrate into local ground waters (septic systems, paved areas runoff, lawn fertilization) were to cease today, it would still be on the order of ten years before the nitrate from these sources was no longer entering the estuarine waters. It would take that long for all of the contaminated ground water to flow into the estuary. But the longer cleanup of nitrogen sources is delayed, the longer it will take for the damaged estuarine areas to recover.

The most rational measure of the return of estuarine health is probably nitrogen level. Using the nitrogen levels in relatively healthy subsystems as TMDL's is a reasonable approach, although for safety's sake it would be wise to exercise an appropriate level of caution when setting the compliance limits. A seemingly healthy embayment with a higher nitrogen concentration could potentially be verging on a negative response. The return of eelgrass and recolonization of desirable benthic faunas are both chaotic events (Frederiksen, Krause-Jensen et al. 2004). If conditions are ideal, season, currents, salinity, etc., then it can happen rapidly. If not it can take time. But if the eutrophication has been controlled, then recolonization will happen when conditions for colonization arise.

3.7 RESPONSE TO VALIDATION COMMITTEE COMMENTS

We have also tried to address some of the questions in Gregory S Horne's document from the Wastewater Management Validation and Design Committee of 11 November 2008. Because of variability in ecosystem processes, some of these questions could only be answered by having more measurements over time and having excellent coupled models dealing with phytoplankton production, circulation, and respiration. To the extent possible, some of these questions are addressed below.

In preparation at the time the Draft Report was published.

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APPENDIX A BIO SKETCHES

Kirk F. Bosma, P.E., M.C.E

Team Leader/Coastal Engineer

Project Role: Task 2 Hydrodynamic Modeling Technical Lead/Project Manager

Mr. Bosma is a Coastal Engineer at Woods Hole Group (since 1997) with specialization in the areas of numerical modeling, sediment transport, littoral processes, and beach profile evolution and analysis. He received his M.C.E. in the field of Coastal Engineering from the University of Delaware in 1996 and his B.S. in the field of Civil Engineering from Calvin College in 1994. Mr. Bosma currently serves as the Team Leader of the Coastal Sciences, Engineering, and Planning Division and has managed projects and engineered solutions related to beach nourishment, beach management, coastal structures, inlet stabilization, water quality, environmental permitting, and wave, tide, and current data collection. He is an active member of the American Society of Civil Engineers, American Shore & Beach Preservation Association, and the Association of Coastal Engineers.

Mr. Bosma also has extensive experience developing and employing numerical models for sediment transport, nearshore spectral wave transformation, particle transport, bathymetric evolution, and two- and three-dimensional hydrodynamic processes, and then analyzing the results. In addition, he has implemented technically advanced data analysis techniques to assess the coastal and oceanographic environment, including wave, tide, current, sediment and particle transport processes. As such, developing both data collection and numerical modeling programs, Mr. Bosma regularly uses the results of each to help guide coastal engineering design (e.g. beach nourishment, inlets, and coastal structures), determine impacts of dredging, define estuarine processes, develop marsh restoration plans, and complete sediment fate and transport studies. He has extensive experience in utilization of Unix- and PC-based software packages and programming languages to present, analyze, and solve engineering and scientific problems.

Recent types of coastal projects Mr. Bosma has managed include: beach nourishment plans, wave, current, and sediment transport modeling, beach nourishment design, marsh restoration projects, coastal engineering design, hydrodynamic mixing and transport studies, and borrow site impact assessment. Mr. Bosma is currently the project manager for three of the largest coastal restoration projects in the northeast, that include evaluation of a variety of coastal protection alternatives, implementation of a comprehensive data collection program, and hydrodynamic, hydraulic, wave and sediment transport modeling. His full resume is provided in Appendix B.

Heidi J. Clark, M.S., M.F.S., Ph.D.

Environmental Scientist

Project Role: Overall Literature Reviews/Technical Support

Ms. Clark is an environmental scientist with extensive experience in coastal ecology, environmental damage assessment, and habitat restoration. She has ten years experience in environmental science and consulting, with projects ranging from environmental damage assessment to seagrass restoration to dune revegetation. Ms. Clark remains active in coastal scientific research as well. She is currently working on a long-term study of the effects of shellfish aquaculture on water quality as part of a multi-investigator project at the Woods Hole Oceanographic Institution.

Prior work in landscape construction affords Ms. Clark an understanding of the many factors involved in habitat restoration and coastal construction projects. Her continued work in research and consulting has allowed Ms. Clark to develop research, writing, and project management skills. She has worked on both individual and multi-investigator projects, and has a proven ability to work effectively with personnel from government agencies, research scientists, individuals from civil society, and consultants. Ms. Clark has MFS and Ph.D. degrees from Yale University. The details of her professional credentials are provided on her resume in Appendix B.

Jeffrey C. Cornwell, Ph.D.

Biogeochemist/Research Professor

Project Role: Task 1 Benthic Flux Technical Lead/Project Manager

Jeffrey Cornwell's university laboratory at the University of Maryland Horn Point Laboratory has carried out a large number of sediment biogeochemical projects in lakes/reservoirs, marshes and estuaries since the late 1980's. Techniques have included 1) utilization of state of the art core incubation techniques for sediment-water solute and gas exchange, 2) measurements of denitrification using membrane inlet mass spectrometric analysis of gas ratios, 3) estimation of sedimentation and nutrient burial using radionuclide-based sediment dating, and 4) characterization of dredge materials for utilization for marsh creation.

Cornwell has also served on the Boston Harbor/Massachusetts Bay Model Evaluation Group, serving as a benthic biogeochemical expert. He has also participated in the evaluation of the coupled physical/biogeochemical model for Florida Bay (for the South Florida Water Management District). More recently, he has been the local organizer and a member of the steering committee for a workshop on the measurement of denitrification (see denitrification.org).

Dr. Cornwell is a member of the American Chemical Society; American Geophysical Union; American Society for Limnology and Oceanography; Estuarine Research Federation; Geochemical Society; Sigma Xi; and the Society of Wetland Scientists. His full CV is provided in Appendix B.

Nathan Dill, M.S.C.E.

Coastal Engineer/Modeler

Project Role: Technical Support for Task 2 Hydrodynamic Modeling

Mr. Dill received a Master of Science in Civil Engineering from Louisiana State University in 2007, and Bachelor of Arts with a major in Physics from Bowdoin College in 2002. His academic studies have given him a strong background in physical sciences with particular focus on free surface flow, water wave mechanics, sediment transport, coastal morphology, numerical modeling, and high performance computing. He is an expert with a broad suite of numerical models, and has extensive experience working directly with the computer code that supports these models. Previous experience as a high school Physics teacher has helped him hone his communication skills and ability to present abstract physical ideas in an easily understandable way. He also has prior service with a large A&E Corporate (URS), which gives him a broad base of experience. Professionally, he has gained experience in developing and applying numerical models in both PC and high performance computing environments for coastal restoration projects and also hurricane storm surge related problems. Additionally, he is skilled at applying standard software tools and developing efficient project specific tools to support data analysis in support of modeling projects. His resume is provided in Appendix B.

Robert Hamilton, Jr., M.C.E, Vice President

Senior Civil/Coastal Engineer

Project Role: Project Manager

Mr. Hamilton is a Civil/Coastal Engineer and Vice President for Business Development at the Woods Hole Group. He's been with the Woods Hole Group since 1994, and has previously served as Coastal Engineer, Business Unit Director, and V.P. for Scientific Operations. He is also a Director for the Northeast Shore & Beach Preservation Association as well as the Marine & Ocean Technology Network. He earned a B.S. in Civil Engineering from Lehigh University, and a M.S. from the University of Delaware Center for Applied Coastal Research. He is focused on development of business relationships and multi-disciplinary project and client management. His extensive market and contracting experience includes government agencies, architectural/engineering partners, offshore oil and gas producers, private owners/developers, power utilities, and manufacturing industries. He has strong technical, analytical, and problem-solving skills combined with an effective leadership, communication, negotiation, and personnel management approach.

His technical expertise is on solving problems related to shoreline erosion, coastal structures, water quality, environmental permitting, and the transport and dilution of thermal discharges and contaminants released into the marine environment. He also has multi-jurisdictional regulatory experience, including preparing EIS documents under NEPA, and has served as an expert witness. Mr. Hamilton's technical skills include numerical modeling and analyses of nearshore wave refraction, diffraction and breaking, sediment transport and shoreline change, and two- and three-dimensional hydrodynamic processes, including plume dispersion and mixing zones. His field skills include site assessments, wave and tide data collection, bathymetry data collection, beach profile surveying, and scientific SCUBA diving. Recent types of coastal projects in which Mr. Hamilton has participated are related to beach nourishment, salt marsh habitat restoration, dredging and dredged material disposal, and environmental resource impact assessment and management planning (including benthic and submerged aquatic vegetation). Mr. Hamilton will be the overall Project Manager, which is compatible with his current role as Project Manager for a DEP contract intended to optimize and develop a protocol for the MEP linked-model approach. His full resume is provided in Appendix B.

Michael S. Owens, B.S. (M.S. candidate)

Biogeochemist

Project Role: Technical support for Task 1 Benthic Flux

Michael Owens has 20 years of sediment biogeochemical experience and has been directly responsible for carrying out all of the denitrification measurements at Horn Point Laboratory working with Dr. Cornwell. He also has extensive experience in pore water and solid phase analyses. His M.S. will be completed in 2009; his work will show the vital importance of relatively small benthic animals on sediment processes in Chesapeake Bay mesohaline sediments. Mr. Owens' CV is provided in Appendix B.

Nadine A. Sweeney

Administrative Manager/Senior Publications Specialist

Project Role: Project Administration

Ms. Sweeney has been with Woods Hole Group since 1993, and has a complete understanding of the corporate management systems and procedures. She is also primarily responsible for the publication of high-quality deliverables, including layout, formatting, and production. She has a wide range of publication software skills, including expertise with MS Word, Excel, and PowerPoint, as well as graphics software experience with Adobe Photoshop and Illustrator. For operations management support, Ms. Sweeney is a MS Project specialist, including applications for individual project scheduling and planning, as well as program roll-ups for resource tracking across multiple projects, clients, and departments within Woods Hole Group. She also helps define and track work breakdown structures in support of Project Managers for individual projects. In support of financial management, Ms. Sweeney acts as the Project Manager's liaison with the Woods Hole Group accounting and finance department. Ms. Sweeney creates project and client files within the Wind-2 corporate financial management system, including entry and tracking of budgets for individual tasks and subtasks. With her experience and knowledge of management processes, Ms. Sweeney also has the intangible ability to effectively encourage Project Managers in their duties. Specifically, she helps Project Managers review and produce monthly (at minimum) project budget update reports, client invoices, and progress reports as required.

John M. Teal, Ph.D., P.W.S.

Ecologist

Project Role: Task 3 Eel Grass and Benthic Community Technical Lead/PM

Dr. John M. Teal is an ecologist who has spent most of his professional career at Woods Hole Oceanographic Institution. His areas of expertise are broad and include:

- wetland and coastal ecology
- submerged aquatic vegetation and benthic habitats
- salt and brackish marsh ecosystem structure and function
- fish nursery value, nutrient cycling, hydrology, productivity, eutrophication
- marsh restoration
- pollution effects and environmental risk

- groundwater influences on water bodies
- ground water contamination with nutrients
- wastewater treatment by natural and artificial wetlands
- petroleum pollution and hydrocarbon biogeochemistry
- nutrient dynamics
- marine birds and over-ocean migration of land birds
- coastal marine ecology including dune and beach ecology
- physiological ecology of fishes
- aquaculture and fisheries

He has served as a qualified expert witness in federal and state courts. He is the author of co-author of over 140 scientific publications. His 1969 book -- Life and Death of a Salt Marsh (Boston: Little Brown) -- has introduced the general public to the mysteries and importance of these fragile ecosystems.

Since 1993, Teal has been the principal wetlands consultant for the 20,000 acre salt and brackish marsh restoration and preservation project being conducted by Public Service Electric & Gas of New Jersey on the shores of Delaware Bay. This project involves the restoration of marshes degraded by both *Phragmites* invasion and/or by diking (restriction of circulation and exchange with the bay). His involvement began in the initial permitting stages, and has continued through the restoration planning, construction, and follow-up through an adaptive management program.

He has been a consultant to the Wetland Restoration and Banking Program in Massachusetts and has consulted with numerous groups on salt marsh restoration including the Massachusetts Water Resources Authority and the US Army Corps of Engineers. He has consulted on marsh restoration projects in North Carolina, Louisiana, and California.

Teal is a Certified Wetland Professional, past president of the Society of Wetland Scientists and has received the 1999 National Wetlands Award for Science Research (co-sponsored by the Environmental Law Institute, U.S.EPA, U.S. Fish & Wildlife Service, and National Marine Fisheries Service) and the 1999 Odum Award from The Estuarine Research Federation. He also has served on multiple National Research Council expert committees. His full resume is provided in Appendix B.

John H. Trowbridge, Ph.D.

Senior Scientist

Project Role: Comparative Analysis for Task 2 Hydrodynamic Modeling

Dr. Trowbridge has more than 22 years of academic and consulting experience in hydrodynamics, sediment transport, coastal processes, and oceanographic measurement programs. Dr. Trowbridge received his Doctorate in Oceanographic Engineering from the Massachusetts Institute of Technology (MIT) and Woods Hole Oceanographic Institution (WHOI) in 1983, his Masters of Science in Civil Engineering from MIT in 1979, and his Bachelor of Science in Civil Engineering from University of Washington in

1977. He currently is a part-time employee at Woods Hole Group, in addition to a full-time Senior Scientist at the Woods Hole Oceanographic Institution.

Dr. Trowbridge has been actively involved in the quality control and technical oversight facets of numerous Woods Hole Group projects. He has designed oceanographic measurement programs for the evaluations and improvement of coastal waves, currents, and sediment transport. He has developed simplified conceptual and analytical approaches to provide preliminary estimates, facilitate feasibility studies, design complex measurement programs, analysis methods for extraction of robust statistics from measurements. He has developed a code for numerical simulation of wave-driven currents and alongshore sediment transport on beaches.

Dr. Trowbridge has vast experience in the scientific background used to develop and simulate aquatic systems. Additionally, he plays a significant role in model design, development, and model implementations. His expertise in design and interpretation of field measurements and interpretation of field measurements is an essential element for understanding coastal systems and evaluating and improving models. The details of his professional credentials are provided on his resume in Appendix B.

Lee L. Weishar, Ph.D., P.W.S.

Senior Scientist/Coastal Engineer

Project Role: Corporate QA/QC

Dr. Weishar has more than 25 years experience in the fields of oceanography, coastal engineering, sediment transport, and nearshore processes. He serves on many professional societies, such as the Society of Wetland Scientists and Estuarine Research Federation, and is currently the Chair for the ASCE Wetlands Engineering Guidelines Subcommittee. For the past 15 years he has specialized in coastal engineering and wetland/marsh restoration. Dr. Weishar specializes in the integration of biological, ecological, and hydraulic data to develop wetland restoration designs and to ensure that the design will meet the restoration objectives. Additionally, Dr. Weishar specializes in evaluating the potential impacts of proposed restoration projects on existing wetlands and adjacent transitional, buffer, and upland areas.

Dr. Weishar's current work involves the restoration of both large and small scale salt marshes. He has been involved at the design, permitting and construction phases of the project for more than a decade. During the preliminary design phases of large scale projects, Dr. Weishar spearheads the preliminary hydraulic design and hydrodynamic analyses that proves to the client that a large scale restoration was feasible. Dr. Weishar has worked to perform critical examinations of the marsh restoration performance through frequent onsite visits and analytical analyses. Dr. Weishar helped pioneer the applications of Ecological Engineering and Adaptive Management in the field of marsh restoration.

Dr. Weishar provided the initial preliminary diagnostic hydraulic modeling and resource area evaluations to determine the feasibility of the large scale (10,000 acre) restoration program in the Delaware Bay. These investigations examined the potential effects of the restoration project on ground water, septic systems, and private drinking wells. During this project Dr. Weishar presented the restoration design to the public during frequent meetings with the stakeholders. He also worked closely with local boards to answer their concerns about the large scale wetlands restoration project. The successful implementation of this project required close interaction with the New Jersey state environmental agencies, New Jersey Attorneys Generals Office, National Fish and Wildlife, US Army Corps of Engineers, National Marine Fisheries, and concerned citizens. He also has recently supported wetland restoration projects in Scarborough, ME, South Cape Beach, MA, Nonquit, MA, and others. He is an active publisher of conference papers and proceedings, as well as peer reviewed journals, and the details of his professional credentials are provided on his resume in Appendix B.

APPENDIX B RESUMES

KIRK F. BOSMA, M.C.E., B.S., P.E.

Team Leader/Coastal Engineer

Qualifications Summary

- More than 15 years diverse professional experience in the fields of coastal sciences and engineering, specializing in the areas of project management, numerical modeling, field collection programs, sediment transport, and littoral processes
- Strong written and verbal communication skills
- Implemented technically advanced data collection, analysis, and numerical modeling techniques to assess marine, coastal and oceanographic environments
- Managed multi-disciplinary coastal and marine projects requiring team management, scientific analysis, environmental sensitivity, diverse coordination, and cost-effective solutions
- Developed various hydrodynamic and hydraulic models for water quality assessment, marsh restoration projects, discharge and mixing design, bridge scour, dredging impacts, and contaminated sediment fate and transport
- Managed and/or performed environmental impact studies for water resource projects, SUPERFUND sites, concentrate discharges into rivers and estuaries, and marine and coastal projects
- Numerical model experience with REF/DIF S, SWAN, STWAVE, GENESIS, RMA-2, RMA-4, RMA-10, RMA-11, MIKE 21, EFDC, CGWAVE, SED-2D, ACES, RMATRK, CORMIX, SSTM, WAVAD, ADCIRC and EDUNE

Professional Affliations

Member, Association of Coastal Engineers (ACE)
Member, Coasts, Oceans, Ports, and Rivers Institute (COPRI)
Associate Member, American Society of Civil Engineers (ASCE)

Fields of Expertise

Managing projects and developing engineered solutions related to coastal structure design, beach nourishment, beach management, inlet stabilization, water quality, environmental permitting, impacts of offshore dredging, marsh restoration, and wave, tide, and current data collection. Coordinating field data collection and numerical modeling projects. Numerical modeling and analyses of sediment transport, nearshore spectral wave transformation, particle transport, bathymetric evolution, two-and three-dimensional hydrodynamic processes, water quality, and mixing processes. Extensive experience utilizing software packages and programming languages to present, analyze, and solve engineering and scientific problems. Experienced in coastal engineering design and planning, coastal restoration, beach nourishment plans, wave, current, and sediment transport modeling, evaluation of a variety of coastal protection alternatives, beach nourishment design, marsh restoration projects, borrow site impact assessment, and implementation of a comprehensive data collection and wave and sediment transport modeling programs. Providing expert testimony for marine and coastal physical processes and numerical modeling.

Higher Education

P.E., Professional Engineer, Massachusetts License #45849
M.C.E., Civil Engineering-University of Delaware (1996)
B.S., Civil Engineering-Calvin College (1994)

Employment History

2001-Present Coastal Engineer/Team Leader, Woods HoleGroup
1997-2001 Coastal Engineer, Woods Hole Group
1994-1996 University of Delaware (Teaching and Research Assistant)
1992-1994 McNamee, Porter and Seeley, Inc.

Key Projects

Saco River and Camp Ellis Beach Section 111 Project, Saco, ME, U.S. Army Corps of Engineers – Project Manager/Coastal Engineer
Managed, coordinated, and conducted a comprehensive field data collection and numerical modeling scope of work for the Saco River and Saco Bay region. The field data collection effort consisted of a 2.5 month wave, current, and tidal observation deployment using two strategically located wave Acoustic Depth Current Profiler (ADCP) systems, a high resolution near shore bathymetric survey, and a ADCP current survey of the river hydrodynamics. The coastal monitoring data set is being utilized to calibrate and verify a series of state-of-the-art wave models ranging from generation scale (Atlantic Ocean), through transformation scale (regional), down to the local and near field scales. The advanced modeling effort includes spectrally based wind-generation (WAVAD), transformation (STWAVE and CGWAVE), and Boussinesq (MIKE 21BW) wave models. Model output is being used in sediment transport modeling on both a regional and local scale. The calibrated models are being used to assess a wide range of shore protection alternatives aimed at mitigating the erosion caused by federally maintained coastal structures. The project involves a high level of coordination between regulatory agencies, the federal government, State of Maine senators, US army Corps of Engineers, Town officials, and the local community.

Hydrodynamic Characterization And Sediment Transport Potential at The Former Callahan Mine Property, Brooksville, ME, Maine Department of Transportation – Project Manager/Coastal Engineer
Managed and conducted a field data collection program, developed a numerical hydrodynamic model, and performed a sediment transport evaluation for a Superfund Site in Brooksville, ME. Goose Pond Estuary is a site of environmental concern and is classified as a Superfund site on the National Priorities List by the Environmental Protection Agency (EPA). The site is the former location of a zinc/copper open-pit mine where mining operations were conducted adjacent to and beneath the tidal estuary. When mining operations ceased, the property was flooded and it is now hydraulically influenced by the tides of Penobscot Bay, as well as a small upland stream. Phase I included the collection of field hydrodynamic data to help provide insight into the overall circulation within Goose Pond, and the exchange with Goose Cove and Penobscot Bay. Phase I also provided a basis for understanding potential transport processes between Goose Pond, Goose Cove, and Penobscot Bay. The field data collection program was also designed to provide input and calibration data for the subsequent numerical modeling tasks. Utilizing the data collected, a 3-D hydrodynamic model was implemented, calibrated, and verified to characterize the circulation within the Goose Pond Estuary system. The model was used to simulate a range of conditions, including spring and neap tidal conditions, high and low freshwater inflow conditions, as well as storm surge events within Goose Pond. Hydrodynamic model results were used to evaluate overall circulation patterns within Goose Pond under a range of environmental conditions in order to identify the water and volumetric exchange between

Key Projects (continued)

Goose Pond and Penobscot Bay. Finally, a sediment transport model was developed to determine the fate and transport of contaminated material within the estuarine system and Penobscot Bay.

Nantasket Beach Seawall Repair and Reservation Master Plan Services, Hull, MA, Massachusetts DCR - Project Manager/Coastal Engineer
Led a project ream to assess the Nantasket Beach Reservation Property. The Reservation has been used as a recreational beach by Greater Boston residents since the 1800s and is currently owned and operated by the Massachusetts Department of Conservation and Recreation (DCR). Nantasket Beach serves as a valuable resource from both a commercial and recreational standpoint. The beach and the associated waterfront amenities serve as the defining feature for the Town of Hull and represent a significant draw for visitors and summer residents. Nantasket Beach has experienced ongoing erosion over the past 150 years, especially the public beach at the southern end of the system. Woods Hole Group conducted a detailed coastal processes study focused on determining potential alternatives to address the ongoing coastal erosion. The barrier beach system was simulated using state-of-the-art wave and sediment transport models to understand existing conditions, and assess potential alternatives. The project evaluated the performance of the existing seawall, as well as determined potential structural alternatives to enhance the beach and improve beach nourishment performance. The performance and lifetime of the beach nourishment were assessed in order to provide guidance on potential long-term solutions and future nourishment requirements.

Herring River Estuary Restoration Project, Wellfleet, MA, Town of Wellfleet – Project Manager
Currently managing a project to restore the Herring River Estuary System, which represents a significant floodplain (the largest estuary on outer Cape Cod). The restoration is geared towards developing a plan to restore up to 1,000 acres of wetland area. Coordinating and developing a complex hydrodynamic numerical model that will address numerous concerns associated with re-establishing increased tidal exchange, as well as provide the necessary information to design an appropriate system of dikes, culverts, and road crossings. The modeling program involves evaluation and selection of the best model for application to the Herring River Estuary, model set-up, calibration, and verification, and simulation of a range of alternatives and physical conditions. The complex numerical modeling simulates both the hydraulics of the system and the salinity distribution throughout the estuary. The model results are used to design new engineering openings and water control structures.

Mixing Zone Evaluation, Whiting, IN, BP Products North America - Project Manager
Performed a third party peer review of an existing mixing zone submittal, including engineering design, confirmation of the mixing zone analysis (with specific evaluation of the implementation of the modeling), determination of the physical processes, and assessment of the diffuser design. The evaluation also included site-specific ambient water current measurements at the proposed discharge location to more accurately characterize the receiving waters. The water current observations were then used to develop more representative conditions and appropriate scenarios for modeling the dispersion and mixing zone. The distribution of water current observations and the percent occurrence of each mixing ratio were used to develop a probability density function of the dispersion ratios and provide design guidance/recommendations for diffuser orientation, design, and layout.

Key Projects (continued)

Engineering Services and Environmental Impact Evaluation – Hammonasset State Park, Madison, CT, Connecticut DEP - Project Manager/Coastal Engineer
Managed and performed an engineering assessment and environmental impact study/report for Hammonasset Beach in Madison, Connecticut. Hammonasset Beach State Park contains Connecticut's largest public swimming beach and campground and is one of the region's most valued recreational and natural resources. During the winter of 2004-2005, severe storms resulted in the loss of a ¼-mile section of the beach on the western end of the park and significant damage to the boardwalk. Despite ongoing stop-gap measures to address the erosion problem, the beach continues to experience significant erosion and the boardwalk and beach remain at risk. Consequently, the Connecticut Department of Environmental Protection (DEP) was concerned about the viability of the western portion of the beach and park for recreational use and was seeking to identify the most cost-effective and long-term course of action to remedy this urgent situation. Therefore, an Environmental Assessment and Impact Evaluation was conducted to study the shoreline erosion problem, identify and evaluate the feasibility of alternative solutions, evaluate the potential impacts on Hammonasset Beach and the surrounding environment, and make recommendations as to the preferred solution. The proposed project consists of three distinct, but related elements: (1) Compilation and review of existing data and studies, as well as collection of new baseline topographic, bathymetric, sediment, and wave data; (2) an engineering feasibility study to identify and analyze beach management alternatives; and (3) an Environmental Impact Evaluation (EIE) pursuant to the Connecticut Environmental Policy Act (CEPA) to further analyze alternatives, identify potential adverse impacts and any necessary mitigation, and ultimately to support the selection of a recommended course of action.

Coastal Flood Protection Structure Evaluation, Chatham, MA, Coastal Engineering, Inc. – Coastal Engineer
Completed an independent review of an existing coastal revetment in Chatham, MA to determine structural integrity related to wave forces. The existing stone revetment structure was evaluated to ensure that adequate design, construction, and maintenance have been undertaken to provide reasonable assurance that the structure can provide durable protection during the 100-yr (base) flood. The analysis included development of the physical parameters that represent the 100-yr flooding event and then evaluated the structural design against the 100-yr flooding physical parameters, including toe protection, backfill protection, pressure distribution and wave forces, structural stability at the minimum and critical water levels, material adequacy, etc.

Reverse Osmosis Concentrate Dilution Analysis and Ambient Water Characterization, Melbourne, FL, Reiss Environmental, Inc. - Project Manager and Coastal Engineer
Led a team of engineers and scientists in an evaluation of an existing Reverse Osmosis (RO) discharge. The scope of work included the collection of field data and application of a model to characterize the dilution of the existing RO discharge. The purpose of the evaluation was to assess whether a mixing zone could be permitted within the existing water quality regulations at the State and Federal level. Observations included bathymetry, a full suite of water quality constituents, and long-term, tide, current, and salinity observations. These data were used to develop a mixing zone model for constituents of concern.

Key Projects (continued)

Analysis of Shoreline Change for Western Beach, Scarborough, ME, U.S. Army Corps of Engineers - Project Manager

Led the project that used a computer-based shoreline mapping methodology, within a Geographic Information System (GIS) framework, was used to compile and analyze changes in historical shoreline position between 1864 and 2003 for Western Beach, Saco Bay, Maine. The purpose of this task was to quantify changes in shoreline position for three (3) specific periods, (1864-1944, 1962-1977, and 1986-2003) using the most accurate data sources and compilation procedures available, and to characterize areas of erosion and accretion. This project's overall goal was to evaluate changes in the coastline of Western Beach due to significant modifications to the Scarborough River Inlet and entrance region. In addition to evaluating the shoreline change data, a projected shoreline was produced using the shoreline movement rates of the pre-1962 or pre-Scarborough River jetty construction time from 1864-1944. Using the rates prior to project construction, a projected shoreline position was estimated assuming no project had taken place and the rates continued to exist over the entire 139-year time span. The results indicated had the shoreline continued to erode at the same rates as seen from 1864-1944, the shoreline would have retreated significantly on either end of Western each, while experiencing a slight advance in the center.

Waquoit Bay Yacht Club Revetment Repair, Waquoit, MA, Waquoit Bay Yacht Club - Project Manager and Coastal Engineer

Assessed and designed a repair to an existing revetment protecting the Waquoit Bay Yacht Club. Significant gaps in the toe of the structure had developed allowing for removal of the finer grain sediments from the core. In this region of revetment, which is most critical, there is significant washout of the backfill of the revetment. At Waquoit Bay Yacht Club, continued cavity formation and subsequent collapse of the existing revetment would present an immediate threat to the structural stability of the clubhouse. A wide range of alternatives were assessed and the preferred alternative was selected and designed that consisted of the installation of filter fabric behind the existing structure, the addition of a bedding and drainage stone layer behind the structure, the addition of a stormwater runoff trench at the crest of the existing structure, the addition of clean backfill material behind the structure as needed, and addition of compatible beach material in front of the structure planted with marsh species and encouraged to develop into salt marsh. Also provided construction oversight and permit compliance inspections.

Nonquitt Salt Marsh Restoration, South Dartmouth, MA, EA Engineering – Project Manager

Managed and performed a numerical circulation model directed at the restoration of the Nonquitt Salt marsh system. The project consisted of implementation of a field data collection program, development and calibration of a numerical circulation model (RMA-2), and the application of the calibrated model to determine the potential impact of design changes aimed at improving circulation. Working with the National Oceanic and Atmospheric Administration, and the U.S. Fish and Wildlife Service, the purpose of the study is to assess the effects of anthropogenic effects on the marsh ecosystem.

Key Projects (continued)

Peer Review of the Florida Bay Hydrodynamic and Salinity Model, Florida, South Florida Water Management District – Coastal Engineer
Served as an expert peer reviewer of the hydrodynamic modeling effort for the Florida Bay and Florida Keys Feasibility Study. The model is required to simulate circulation, salinity stratification and distribution, and water quality behavior in the Florida Bay and Reef Tract utilizing a standardized set of field data. Offered expert opinions based on knowledge, expertise, and practical experience in conducting, analyzing, and applying similar hydrodynamic modeling strategies. The peer review included assessment of the grid methods and optimization techniques to determine spatial density, scale, and distribution, the adequacy of calibration and verification, and the quality and extent of the input data and model parameters.

Beach Nourishment and Inlet Stabilization at Sandwich Town Beaches and Dredging the East End of the Cape Cod Canal, Sandwich, MA, Town of Sandwich - Project Manager/Coastal Engineer
Managed and performed comprehensive beach management plan for all Town of Sandwich beaches, including evaluation of the physical processes governing sediment transport, alternatives analysis for shore protection measures and inlet stabilization, and appropriate beach maintenance and usage. The project consisted of numerical modeling of alternatives and final design for establishing a long-term beach/dune restoration plan, as well as relocation and design of a jettied tidal inlet. Required excellent communication and close coordination with numerous agencies, local officials, sub-contractors, and multiple clients. The regulatory process is currently underway.

Numerical Modeling of Storm Surge Induced Hydrodynamics and Pollutant Transport, New Bedford, MA, Confidential Client - Project Manager/Coastal Engineer
Simulated the hydrodynamics and resulting pollutant transport due to the effects of a historical hurricane in the New Bedford Harbor Region, including the immense flooding of the upland due to the accompanying storm surge, and the release and transport of chemicals from a confidential entity. Through numerical modeling of this complex phenomena, hydrodynamic results, coupled with pollutant input data, pollutant mass rate, duration of release, and time of release, pollutants were released from a single specific area to quantify the transport pathways and concentrations due to the storm surge caused by the hurricane. This project also requires expert testimony and technical analysis of wave energy, breaking, set-up, diffusivity, and mixing.

Thermal Modeling Analysis for Proposed Cooling Plant on Lake Waban, Wellesley College, Wellesley, MA, Vanasse Hangen Brustlin, Inc. - Project Manager
Performed thermal and analytical modeling of design alternatives for a proposed cooling water discharge plant on Lake Waban in Wellesley, MA. Two methods of analysis (analytical and computer model) were used to determine the mixing of temperature concentration, and the ability of the Lake to receive the discharged waters under peak demand (representing a worst-case scenario under August conditions). The purpose of this analysis was to simulate the mixing and dilution of the discharge waters with the ambient water of Lake Waban under worst-case conditions, discuss the results of the modeling effort, and provide recommendations related to potential design modifications.

Key Projects (continued)

Characterization Study of Delaware River Detritus, Hancock's Bridge, N.J., PSE&G, - Project Manager
Conducted an assessment of the ability of hydroacoustic technology to detect detrital material throughout the water column. Never utilized for this specific application, use of the innovative technology saved the client from other costly alternatives. Phase I of the study consisted of controlled laboratory testing in an enclosed basin and was performed with samples taken from the Delaware Bay Estuary. The results indicated that hydroacoustic technology could be utilized for identifying detritus within the Delaware Bay Estuary. Phase II of the study consisted of implementation of the hydroacoustic technology in the Delaware Bay Estuary. Field sampling also included Acoustic Doppler Current Profiler (ADCP) measurements, net captures, Conductivity Temperature Depth (CTD) casts, and Optical Backscatter Sensor (OBS) profiles. Responsible for project management, analysis and interpretation of the acoustic return signals, and reporting. Biomass estimates were determined from the measured currents and captured detrital material and compared to the integrated hydroacoustic signal. Future phases consist of detailed field measurements, 3-dimensional detrital transport modeling, and evaluation of mitigation oriented engineered solutions and management strategies.

3 Related Studies:
a) Environmental Studies Relative to Potential Sand Mining on the Continental Shelf for Beach Replenishment, Offshore Alabama, Alabama, U.S. Mineral Management Service.
b) Environmental Survey of Potential Sand Resource Sites: Offshore New Jersey, NJ, U.S. Mineral Management Service.
c) Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration, North Carolina, U.S. Mineral Management Service - Coastal Engineer/Numerical Modeler
The following is a description of projects a, b, and c:

Key member of a vast multi-disciplinary team conducting large-scale studies to address environmental issues raised by the potential dredging of sand from the inner continental shelf offshore New Jersey, Alabama, and North Carolina. Quantified the potential modifications to waves that cross within identified borrow areas due to offshore dredging. Determined the impacts of offshore dredging and subsequent beach nourishment on local and regional sediment transport patterns, coastal and nearshore sedimentary environments, and local shoreline processes. Performed state-of-the-art spectral wave modeling for assessing modifications to the wave field and input into nearshore circulation and offshore and nearshore sediment transport models. The results of the ongoing studies will enable Minerals Management Service to monitor Key Projects (continued) and assess the potential impacts of offshore dredging activities and to identify ways in which dredging operations can be conducted to minimize or preclude long-term adverse impacts to the environment.

Key Projects (continued)

Observations of Ocean Wave, Tide, and Current Processes Offshore of Little Bay, Montserrat, Montserrat, U.K., Mouchel Consulting, Ltd. - Project Manager/Coastal Engineer/Field Data Collection
Installation and monitoring of a real-time data acquisition system connected via a cable link to the shoreline in Little Bay, Island of Montserrat. Ocean wave, tide, and current data were collected and analyzed. Responsible for QA/QC of collected data. Observations from the one-year deployment will be utilized to develop and design a new harbor on the Island.

San Francisco Airport Expansion Project, San Francisco, CA, URS Corp. - Coastal Engineer
Served as a Team Engineer working on the preparation of an Environmental Impact Report/Environmental Statement (EIR/EIS) for the San Francisco Airport Expansion Project. WHG has deployed a suite of Sediment Transport Monitoring Systems (STMS) to collect seasonal current, wave, and suspended sediment concentration measurements in each of the Bay's characteristic environments. Responsible for analysis and interpretation of hydrodynamic and sediment dynamic measurements, estimation of sediment flux, modeling of sediment transport, and report generation.

Physical Sampling and Sediment Transport Analysis at Weymouth Neck, Weymouth, MA, Massachusetts DEP - Project Manager/Coastal Engineer
In this region, concerns have been raised that the metals (arsenic, copper, lead, and zinc) found in upland areas may have migrated into the sub-tidal area surrounding the peninsula. As a precursor to the chemical sampling, developed an analytical sediment transport model that was geared towards assisting in defining appropriate areas to perform sub-tidal chemical sampling. The model required a field investigation in order to determine the physical characteristics of the sub-tidal sediment within the Weymouth Neck region (including Upper Neck Cove, Lower Neck Cove, and Weymouth Back River), as well as generation of local physical processes (winds, waves, tides, and currents) in the vicinity of Weymouth Neck Peninsula. The analytical model was used to identify areas of erosion and deposition in the sub-tidal regions surrounding the peninsula. The results of the model are used as a tool to assess, justify, and bound the chemical sampling locations around the peninsula.

Evaluation of the Great Creek Outlet Structure, Milford, CT., Fuss & O'Neill, Inc. - Project Manager/Coastal Engineer
In an ongoing project, provided coastal processes analysis, analytical modeling, outlet structure assessment, and design support services for evaluating the impact of an outlet structure on downdrift erosion. Engineering alternatives are being evaluated through sediment transport analytical modeling to determine potential mitigation measures. Wave transformation modeling and sediment transport modeling are focused to assess the parameters of the outlet structure (e.g., height, length, culvert depth, etc.) and provide design guidance for corrective action and potential nourishment.

Key Projects (continued)

Hydrodynamic Modeling and Sediment Transport Analysis During Temporary Tunnel Storage in Fort Point Channel, Boston, MA, Gannett Fleming, Inc. - Coastal Engineer/Project Manager
Conducted a hydrodynamic and sediment transport modeling study of Fort Point Channel, MA to determine the impact caused by temporary storage of floating tunnel sections on existing conditions and industrial water usage. Completed technical report presenting the hydrodynamic and potential sediment transport results, which was utilized to assist in engineering methodology and design.

Analysis and Design of Revetment Structures at Hingham Shipyard, Hingham, MA, Sea Chain, L.L.C. - Coastal Engineer
Completed a fast-track study and design of revetment structures at Hingham Shipyard on Weymouth Back River. The study focused on analyzing the relevant coastal processes, and optimizing the design to gain the most upland area, while minimizing adverse impacts to the nearby salt marsh and other nearshore wetland resource areas. Analysis for the design included wave modeling, storm surge analysis, extremal analysis, wave reflection analysis, wave runup and overtopping analysis, revetment design and stone sizing, and sediment transport analysis.

Power Plant Effluent Mixing Zone, FL, Confidential Client - Coastal Engineer
Project Engineer involved in the investigation of the discharge from a once-through cooling system at a coastal power plant. The cooling water effluent at this station was found to have seasonally low dissolved oxygen. Woods Hole Group's investigation sought to identify the source of the dissolved oxygen depression, investigate regulatory issues, and to examine potential technologies for increasing effluent dissolved oxygen. Specifically, performed numerical particle tracking simulations in order to identify water pathways to the intakes. Additionally, a review of existing data and previous work was conducted. This revealed that the seasonally low dissolved oxygen was a widespread phenomenon in ambient waters. Because the station was not responsible for the overall dissolved oxygen depression, a mixing zone was identified as a potential regulatory solution to any minor impacts from the discharge. Engineering alternatives to raise the effluent's oxygen content were also investigated.

Particle Tracking Analysis and Improvements to the Near-Field Boundary Condition, Hancock's Bridge, NJ, Public Service Electric and Gas Company - Coastal Engineer
Completed a numerically driven particle tracking study for the Delaware Bay and estuary system to identify detrimental sources of detritus within the system. The particle tracking model, utilized in concert with a validated hydrodynamic model, was utilized to statistically evaluate near- and far-field impacts to a cooling water intake. Recommendations were provided to improve management and recycling practices, as well as provide future steps for numerical modeling of appropriate engineered solutions, which would result in safer and more cost-effective operations.

Key Projects (continued)

Ocean Currents Offshore Eastern Trinidad, Trinidad, Amoco Production Company - Coastal Engineer

Developed and performed in-depth data analysis of ocean conditions off the eastern coast of Trinidad based on data collected during recent measurement programs in the area. Observations were utilized to investigate coastal ocean processes active at the site and extrapolate the observations to predict future extremal and operational conditions. Conducted a detailed literature review, assessed the structure and variability of the observed currents, separated the current into specific process components using advanced numerical analysis techniques, formulated an extremal value analysis, and completed technical writing of a final report. Results of the study provided recommendations for design criteria and operational procedures.

Historical Shoreline Change Analysis: Western Town Line to Horton Point, Southold, NY, Town of Southold - Coastal Engineer

Conducted an assessment of the history of storm activity in Long Island Sound. Wind and tide records were analyzed and Generalized Extremal Value (GEV) calculations were completed to determine the historical behavior and return periods of major storm events. Results of the analysis were correlated to historical shoreline change and incorporated to determine the rate and extent of erosion and accretion along the Southold coastline.

Tidal Current Characteristics of St. Lucie Inlet, St. Lucie, FL, Coastal Technologies Corporation - Coastal Engineer

Performed data analysis of observations of tidal currents in the St. Lucie Inlet to map the temporal variation in the spatial structure of flow through several Inlet cross-sections. These high-resolution measurements of tidal current velocities were obtained using a vessel-mounted Acoustic Doppler Current Profiler (ADCP) coupled with a GPS-based integrated navigation (IN) system. Results of the surveys show current energy focused in the deeper southern and center channels of the Inlet. The south channel was characterized as 'flood dominant', with stronger flood currents than ebb currents, which tend to transport sediments into the Inlet interior. The center channel was characterized as 'ebb dominant', with stronger ebb currents than flood currents, tending to move sediments out of the Inlet to form an ebb tide shoal. The geometry of the waterway, hard structures, and the alongshore coastal currents appeared to modify the spatial structure of the tidal currents through the Inlet cross section.

Hydrodynamic and Tidal Flushing Study of Pleasant Bay Estuary, Chatham, MA, The Pleasant Bay Steering Committee - Coastal Engineer

Assisted Pleasant Bay Steering Committee with a study of tidal flushing for the Pleasant Bay system as part of the overall resource management plan for the estuary. The measurements and calculations performed provided information to evaluate the water quality of Pleasant Bay and several sub-embayments throughout the estuarine system. Collected tide and bathymetry data necessary to support hydrodynamic modeling and flushing analysis. Results of the study were incorporated into a water quality evaluation performed by the Cape Cod Commission.

Publications and Presentations

Bosma, K. and B. Caufield, "Integration of Multiple Wave Models from Generation Scale to Nearshore Scale. A Practical Application in Maine, USA," 8th International Wave Hindcasting and Forecasting Workshop, Oahu, Hawaii, 2004. Keynote Speaker.

Caufield, B.A., and K.F. Bosma, Use of a Large Scale Spectral Wave Generation Model to Define Input into a Nearshore Wave Transformation Model. 8th International Wave Hindcasting and Forecasting Workshop, Oahu, Hawaii, 2004.

Bosma, K.F. 2002. "Coastal Processes Evaluation in Development of a Long-Term Beach Management Plan, Sandwich, Massachusetts." Proc. of Northeast Shore and Beach Preservation Association, Northeast Beaches: A Balancing Act, Woods Hole, MA.

Jachec, S.M. and Kirk F. Bosma. 2001. "Sediment Transport Related to Potential Sand Mining Offshore New Jersey." Proc. of Waves 2001 Conference, San Francisco, CA.

DiMassa, D. and K.F. Bosma. 2000. "Hydroacoustic Measurement of Detritus from the Delaware Bay Estuary." Proc. of Oceans 2000 Conference, Providence, RI.

Wood, J.D., K.F. Bosma, and J.S.Ramsey. 1998. "Tidal Current Characteristics of St. Lucie Inlet." Proc. 11th Annual National Conference on Beach Preservation Technology, Tallahassee, FL.

Bosma, K.F. 1997. "Beach Profile Analysis Along the Delaware Atlantic Coastline." Master's Thesis, University of Delaware, Newark, DE.

Bosma, K.F. and R. A. Dalrymple. 1996. "Beach Profile Analysis Around Indian River Inlet, Delaware, U.S.A." Proc. 25th Intl. Coastal Engineering Conf., ASCE, Orlando, FL.

Chawla, A., Bosma, K.F., Gobbi, M., and M.N. Herrman. 1995. "Gravity Waves on a Gently Sloping Beach." CACR, University of Delaware, Newark, DE.

Bosma, K.F. 1995. "Investigation of Delaware State Profiles." CACR, University of Delaware, Newark, DE.

HEIDI J. CLARK, PH.D.

Environmental Scientist

Fields of Expertise

Research, technical writing, and project management for coastal and marine environmental issues. Technical specialties include field and desktop data collection, analysis, and reporting for all types of audience. Areas of scientific expertise include coastal water quality, aquaculture, nutrient cycling in terrestrial and coastal environments; contaminant fate and transport; contaminated site assessment, cleanup, and restoration; ecological risk assessment; natural resource damage assessment including habitat equivalency analysis, and environmental impact assessment; carbon emissions reduction and carbon trading analysis. Special interest and expertise in collaborating with economists, policy analysts, and others on multi-disciplinary projects.

Higher Education

Ph.D., Environmental Science-Yale University (2000)
M.F.S., Forest Science-Yale University (1997)
M.S., Exercise Science-University of Massachusetts (1991)
B.A., Biology-University of California, Santa Cruz (1987)

Employment History

2009-Present Environmental Scientist. Woods Hole Group
2005-2008 Associate. Industrial Economics Incorporated
2003-2005 Coastal Scientist. Woods Hole Group
2001-2003 Guest Scientist. Woods Hole Oceanographic Institution
1995-2001 Self Employed Environmental Consultant
1996-1997 Aquaculture Technician, Marine Biological Lab
1995-2000 Guest Student, Woods Hole Oceanographic Institution.

Qualifications Summary

- Fifteen years research and consulting experience with industry, government, and scientific institutions
- Extensive field and laboratory research on nitrogen cycling in coastal environments and shellfish aquaculture
- Research and technical reporting on habitat restoration, aquaculture development, and carbon sequestration in coastal environments
- Experience with ecological risk assessment and natural resource damage assessment
- State and federal permitting, including preparation of Environmental Impact Statements
- Restoration planning for riverine and coastal dredging projects
- Coastal dune, vernal pool, and riparian corridor restoration planning, project construction and monitoring
- Collaboration with economists on a variety of projects including environmental policy analysis, program evaluation, and bio-economic model development

Key Projects

Literature Review and Database Development: Long Island Sound Dredged Materials Management Planning - Environmental Scientist
Project management and technical work on a review of literature on dredge materials management for Long Island Sound. Project includes collection of all relevant publications and gray literature, and summary of information in an Access database. The database and information therein will be used to develop a Dredged Materials Management Plan for Long Island Sound.

Remediation Project Support: New Bedford Harbor Superfund Site - Environmental Scientist
Project management, data collection, and technical reporting on New Bedford Harbor remediation dredging. Ongoing work includes field data collection, data analysis, and technical reporting on progress removing PCB contamination in New Bedford Harbor.

Carbon Sequestration and Carbon Trading in the Agriculture and Aquaculture Industries- Environmental Scientist/Project Manager
Project management, data collection, and technical reporting on carbon sequestration and trading on the Chicago Climate Exchange. Special emphasis on carbon sequestration and trading in the agriculture industry, and potential for carbon offset provision by the aquaculture industry.

Natural Resource Damage Assessment and Restoration Planning: Lead-Zinc Mining Sites in the Tri-State (Oklahoma, Missouri, Kansas) Area - Environmental Scientist
Assessment of damages to riverine resources resulting from lead-zinc mining. Work included data collection and analysis; evaluation of contaminant fate and transport, technical reporting, and support for litigation. Restoration planning included riparian corridor development and in-stream habitat improvement projects.

Natural Resource Damage Assessment: Kuwait Oil Damage from 1991 Gulf War- Environmental Scientist
Assessment of damages to coastal and marine resources resulting from oil released during the 1991 Iraqi invasion of Kuwait. Work included assessment of ecosystem services lost due to oil damage, estimates of recovery time, and development of appropriate restoration projects. Presented results to the United Nations Compensation Commission (UNCC) in Geneva.

Ecological Effects of Acid Deposition: Support for EPA's Retrospective Evaluation of the Clean Air Act and Amendments - Environmental Scientist/Project Manager
Review of literature on environmental damage due to acid deposition in the United States. Work included compilation of extensive database and annotated bibliography, as well as a written report on the subject.

Key Projects (continued)

Liquid Natural Gas (LNG) Deepwater Port Environmental Impact Statement (EIS): Support for US Coast Guard's EIS Development - Environmental Scientist/Project Manager

Preparation of Marine Resources sections of an EIS for a deepwater LNG port. Work included evaluation of pre-project conditions, potential impacts on fish, benthic communities, and other marine resources. Also included consultation with resource agencies regarding time of year restrictions on project construction, endangered species impacts, and essential fish habitat assessment.

Publications and Presentations

"Carbon Trading and the Aquaculture Industry: Potential (or Lack Thereof) for Shellfish Farmers to Provide Carbon Credits on the Chicago Climate Exchange". Report to Barnstable County Cooperative Extension. December, 2007.

"Bio-economic Model of Shellfish Aquaculture: Using Aquaculture as Part of a Comprehensive Nitrogen Management System for Coastal Watersheds on Cape Cod". Report to NOAA/CICEET. 2007.

"Economic Value of Natural Resource Services Potentially Impacted by a Change in Cooling Water Regime at the Haynes and AES Alamitos Generating Stations". Prepared for Los Angeles Department of Water and Power. May 2005.

"Monitoring and Assessment of the Environmental Consequences of the Iraqi Aggression in Kuwait: Damage Assessment Report". Prepared for Safege, Nanterre, France. May 2004.

Clark, H. and J. Kremer. 2004. "Estimating direct and episodic atmospheric deposition to a coastal waterbody". *Marine Environmental Research.* June.

Clark, H., W. Clark, D. Murphy, W. Burt, and D. Leavitt. 2002. "A review of seagrass restoration programs and technologies with reference to application on Cape Cod". *Environment Cape Cod* October.

Clark, H. 2002. "Seagrass Restoration on Cape Cod: Review of Appropriate Methods and an Eelgrass Planting Trial for Eastham Harbor". Summer 2002.

Clark, H. 2000. "Ecological Risks Associated with Nutrient Loading in Coastal Waters: Reducing the Risks by Restoring Shellfish". Ph.D. Dissertation, Yale University.

Clark, H. 1999. "Fate and ecological effects of nitrogen in coastal waters" *in* Industrial Economics, Inc. "Benefits Assessment of Decreased Nitrogen Deposition to Estuaries in the United States Attributable to the Clean Air Act Amendments, 1990-2010". Work Assignment 4-11, Task 7 for the US Environmental Protection Agency, Section 812 - Prospective Ecological Benefits Assessment of the CAAA.

Publications and Presentations (continued)

Vogt, KJ. Gordon, J. Wargo, H. Clark and collaborators. 1997. Ecosystems: Balancing Science and Management Springer, New York.

Johnson, K., K.A. Vogt, H.J. Clark, O.J. Schmitz, D.J. Vogt. 1996. "Biodiversity, and the Productivity and Stability of Ecosystems" *Trends in Ecology and Evolution* 11(9):372-377.

Clark, H. and G. Wikfors. 1996. "Oysters as processors of particulate organic nitrogen: quantitative and qualitative relationships between inputs and outputs" *Journal of Shellfish Research I15(2):457.*

CURRICULUM VITAE

JEFFREY C. CORNWELL

University of Maryland CES
Horn Point Laboratory
P. O. Box 775
Cambridge, MD 21613
(410) 221-8445; FAX# (410) 221-8490; cornwell@hpl.umces.edu

POSITIONS HELD:

Research Associate Professor Horn Point Laboratory 1996-present
Research Assistant Professor Horn Point Laboratory 1989-1996
Research Associate, Horn Point Laboratory 1986-1989
Assistant Research Scientist, Texas A&M University 1985-1986
Post-Doctoral Research Associate, Texas A&M University 1984-1985
Research Assistant, University of Alaska 1976-1983

DEGREES:

Hobart College, B.S., Chemistry with Honors, 1976.
Honors Project: "Mercury and zinc in the sediments of Seneca Lake, NY".

University of Alaska, Ph.D., Chemical Oceanography, 1983.
Dissertation: "The geochemistry of manganese, iron and phosphorus in an arctic lake".

RESEARCH INTERESTS:

- Biogeochemistry of nutrients and metals in aquatic sediments
- Estuarine chemistry and water quality
- Metals, nutrients and stable isotopes in tidal and non-tidal wetlands
- Freshwater chemistry and ecology
- Biogeochemistry and geochemistry of dredged sediments
- Denitrification in aquatic sediments

PUBLICATIONS:

1980's

Blackburn, T.R., J.C. Cornwell and T.R. Fogg, 1980, Mercury and zinc in the sediments of Seneca Lake, Seneca River and Keuka Outlet, N.Y. J. Great Lakes Res., 6, 68-75.

Whalen, S.C. and J.C. Cornwell, 1985, Nitrogen, phosphorus and organic carbon cycling in an arctic lake. Can. J. Fish. Aquat. Sci., 42, 797-808.

Cornwell, J.C., 1985, Sediment accumulation rates in an Alaskan arctic lake using a modified ^{210}Pb technique. Can. J. Fish. Aquat. Sci., 42, 809-814.

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Morse, J.W., F.J. Millero, J.C. Cornwell and D. Rickard, 1987, The chemistry of the hydrogen sulfide and iron sulfide systems in natural waters. Earth Sci. Rev., 24, 1-42.

Cornwell, J.C., 1987, Phosphorus cycling in arctic lake sediments: adsorption and authigenic minerals. Arch. Hydrobiol., 109, 161-179.

Morse, J.W. and J.C. Cornwell, 1987, Analysis and distribution of iron sulfide minerals in recent anoxic marine sediments. Mar. Chem. 22:55-69.

Cornwell, J.C. and J.W. Morse, 1987, The characterization of iron sulfide minerals in anoxic marine sediments. Mar. Chem. 22:193-206.

Whalen, S.C., J.C. Cornwell and V. Alexander, 1988, Comparison of chemical and biological N budgets in an Arctic lake: implications for phytoplankton production. SCOPE/UNEP Sonderband, 66:99-115.

1990's

Morse, J.W., J.C. Cornwell, T. Arakaki, S. Lin and M. Huerta-Diaz, 1992, Iron sulfide and carbonate mineral diagenesis in Baffin Bay, Texas. J. Sed. Petrol. 62:671-680.

Cornwell, J.C. and S. Banahan, 1992, A silica budget for an Alaskan arctic lake. Hydrobiologia, 240:37-44.

Cornwell, J.C., 1992, Cation export from Alaskan arctic watersheds. Hydrobiologia, 240:15-22.

Cornwell, J.C. and G.W. Kipphut, 1992, The sediment biogeochemistry of manganese- and iron-rich sediments of Toolik Lake, Alaska. Hydrobiologia, 240:45-59.

Neill, C. and J.C. Cornwell, 1992, Stable isotopes used to trace the utilization of algae and macrophyte detritus in a prairie marsh food web. Wetlands, 12:217-224.

Marcus, W.A., C. Nielsen and J.C. Cornwell, 1993, Sediment budget-based estimates of trace metal inputs to a Chesapeake estuary. Env. Geol. Wat. Sci. 22:1-9.

Kana, T.M., C. Darkangelo, D. Hunt, J. Oldham, G. Bennett, and J.C. Cornwell, 1994, A dissolved gas analyzer based on membrane inlet mass spectrometry for rapid high precision analysis of N_2, O_2, and Ar in environmental water samples. Anal. Chem. 66:4166-4170.

Owens, M. and J.C. Cornwell, 1995, Sedimentary evidence for decreased heavy metal inputs to the Chesapeake Bay. Ambio 24: 25-27.

Conley, D.J., W.M. Smith, J.C. Cornwell and T.R. Fisher, 1995, Transformations of particle-bound phosphorus at the land-sea interface. Est. Coastal Shelf Sci. 40:161-176.

Cornwell, J.C., C. Neill, and J. C. Stevenson. 1995. Biogeochemical Origin of δ^{34}S Isotopic Signatures in a Prairie Marsh. Can. J. Fish. Aquat. Sci. 52:1816-1820.

Cornwell, J.C., and P.A. Sampou. 1995. Environmental controls on iron sulfide mineral formation in a coastal plain estuary. (ACS Symposium Series, In: Vairavamurthy, M.A. and M.A.A. Schoonen (eds.), Geochemical Transformations of Sedimentary Sulfur, pp. 224-242, American Chemical Society, Washington, DC.).

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Stribling, J.M. and J.C. Cornwell. 1997. Identification of important primary producers in a Chesapeake Bay tidal creek system using stable isotopes of carbon and sulfur. Estuaries 20:77-85

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2000's

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Merrill, J.Z. and J.C. Cornwell. 2000. The Role of Oligohaline and Tidal Freshwater Marshes in Estuarine Nutrient Cycling . pp. 425-442. In: M.P. Weinstein and D.A. Kreeger (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers.

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Schneider, A.R., H.M. Stapleton, J. Cornwell, and J.E. Baker. 2001. Recent declines in PAH, PCB, and toxaphene levels in the Northern Great Lakes as determined from high resolution sediment cores. Environ. Sci. Technol., 35(19):3809-3815.

Newell, R.I.E., M.S. Owens and J.C. Cornwell. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. Limnol. Oceanogr. 47:1367-1369.

Rooth, J.E., J. C. Stevenson and J.C. Cornwell. 2003. Increased sediment accretion rates following invasion by Phragmites australis: the role of litter. Estuaries 26:475-483.

Petersen, J.E., W. Michael Kemp, R. Bartleson, W.R. Boynton, C.C. Chen, J.C. Cornwell, R.H. Gardner, D.C. Hinkle, E.D. Houde, T.C. Malone, W.P. Mowitt, L. Murray, L.P. Sanford, J.C. Stevenson, K.L. Sundberg and S.E. Suttles. 2003. Multiscale experiments in coastal ecology: improving realism and advancing theory. Bioscience 53:1181-1197.

Porter, E.T., J. C. Cornwell and L. P. Sanford. 2004. Effect of Oysters (Crassostrea virginica) and Bottom Shear Velocity on Benthic-Pelagic Coupling and Estuarine Water Quality. Mar. Ecol. Prog. Ser. 271:61-75.

Mason, R.P., E.-H. Kim, and J.C. Cornwell. 2004. Metal Accumulation in Baltimore Harbor: Current and Past Inputs. Applied Geochemistry 19:1801-1825.

Lomas, M.W., T.M. Kana, H.L. Macintyre, J.C. Cornwell, R. Nuzzi and R. Waters. 2004. Interannual variability of *Aureococcus anophagefferens* in Quantuck Bay, Long Island: natural test of the DON hypothesis. Harmful Algae 3:389-402.

Kana, T.M., M.W. Lomas, H.L. MacIntyre, J.C. Cornwell and C.J. Gobler. 2004. Stimulation of brown tide organism, *Aureococcus anophagefferens*, by selective nutrient additions to *in situ* mesocosms. Harmful Algae 3:377-388.

MacIntyre, H.L., M.W. Lomas, J.C. Cornwell, D.J. Suggett, C.J. Gobler, E.W. Koch and T.M. Kana. 2004. Mediation of benthic pelagic coupling by microphytobenthos: an energy- and material-based model for initiation of blooms of *Aureococcus anophagefferens*. Harmful Algae 3:403-437.

Newell, R.I.E., T.R. Fisher, R.R. Holyoke and J.C. Cornwell. 2005. Influence of eastern oysters on N and P regeneration in Chesapeake Bay, USA. Pp 93-120 In: R. Dame and S. Olenin (eds.) The Comparative Roles of Suspension Feeders in Ecosystems. NATO Science Series IV – Earth and Environmental Sciences.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel1, W.D. Miller, R.I.E. Newell, M. R. Roman, E.M. Smith, J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: Historical trends and ecological interactions. Marine Ecology Progress Series. 303:1-29.

Stribling, J.M., O.A. Glahn, X. Mara Chen and J.C. Cornwell. 2006. Microtopographic variability in plant distribution and biogeochemistry in a brackish marsh system. Marine Ecology Progress Series320:121-129.

Kana, T.M., J.C. Cornwell and L. Zhong. 2006. Determination of denitrification in the Chesapeake Bay from N_2 accumulation in bottom water. Estuaries and Coasts 29:222-231.

Mason, R.P., E.H. Kim, J.C. Cornwell and D. Heyes. 2006. An examination of the factors influencing the flux of mercury, methylmercury and other constitutents from estuarine sediment. Marine Chemistry 102:96-110.

Cook, P., F. Wenzhöfer, R. N Glud, O. Galaktionov, B. Eyre, S. Rysgaard, J.C. Cornwell and M. Huettel. 2006. Measuring denitrification in permeable sediments: Insights from a 2 dimensional simulation analysis and experimental data. L&O Methods 4:294-307.

Porter, E.T., M.S. Owens and J.C. Cornwell. 2006. Effect of manipulation on the biogeochemistry of experimental sediment systems. Journal of Coastal Research 22:1539-1551.

Stribling, J.M., J.C. Cornwell and A. Glahn. 2007. Microtopography in tidal marshes: ecosystem engineering by vegetation? Estuaries and Coasts 30:1007-1015.

Crump, B.C. , C. Peranteau, B. Beckingham, and J. C. Cornwell. 2007. Respiratory succession and community succession of bacterioplankton in seasonally anoxic estuarine waters. Applied and Environmental Microbiology 73:6802-6810

Jordan, T.E. J.C. Cornwell, W.R. Boynton and J.T. Anderson. 2008. Changes in phosphorus biogeochemistry along an estuarine salinity gradient: The iron conveyer belt Limnology and Oceanography, 53:172-184.

Boynton, W.R., J. D. Hagy, J. C. Cornwell, W. M. Kemp, S. M. Greene, M. S. Owens, J. E. Baker and R. K. Larsen. 2008. Nutrient Budgets and Management Actions in the Patuxent River Estuary, Maryland. Estuaries and Coasts 31:623–651

Hopfensperger, K.N., S.S. Kaushal1, SE.G. Findlay and J.C. Cornwell. Influence of plant communities on denitrification in a tidal freshwater marsh of the Potomac River, U.S.A. Journal of Environmental Quality *In Press*.

PUBLICATIONS/REPORTS AT UMCES:

1. Cornwell, J.C. and R.J. Barsdate, 1977, Sensitivity of arctic lakes to phosphorus loading, p. 57-61, In Technical Session Papers to the 18th Alaska Science Conference, Alaska Division of AAAS, Anchorage, Alaska.

2. Cornwell, J.C., 1983, The geochemistry of manganese, iron and phosphorus in an arctic lake. Ph.D. Dissertation, University of Alaska, Fairbanks

3. Cornwell, J.C., 1987, Migration of metals in sediment pore waters: problems for the interpretation of historical deposition rates. In Proceedings of the 6th International Conference on Heavy Metals in the Environment, Vol. 2, p. 233-235, New Orleans.

4. Cornwell, J.C. and J.C. Stevenson, 1990, Toxic substances in submerged aquatic vegetation beds. Report CBRB90-H1-1, Maryland Department of Natural Resources.

5. Cornwell, J.C., J.M. Stribling and J.C. Stevenson, 1990, Biogeochemical Studies at the Monie Bay National Estuarine Research Reserve. Final Report NA89AA/D C2 130, NOAA National Estuarine Research Reserve System. 69 pp.

6. Cornwell J.C., J. Stribling and J.C. Stevenson, 1994, Biogeochemical Studies at the Monie Bay National Estuarine Research Reserve. In Proceedings of the 13th International Conference of the Coastal Society, p. 645-655, Washington, D.C.

7. Zelenke, J.L., J. Stevenson and J.C. Cornwell. 1994. Deposition of inorganic and organic phosphorus in Maryland tidal marshes: a preliminary analysis. In: Toward a Sustainable Coastal Watershed: The Chesapeake Experiment. Proceedings of a Conference. Chesapeake Research Consortium Publication No. 149 pp. 630-633.

8. Baker, J, R. Mason, J.C. Cornwell, J Ashley, J. Halka and J. Hill. 1997. Spatial mapping of sedimentary contaminants in the Baltimore Harbor/Patapsco River/Back River System. Final Report to Maryland Department of the Environment. UMCES 97-142.

9. Cornwell, J.C. and M. Owens. 1998. Sediment biogeochemistry at Site 104 Open Water Placement Area. Final report to Maryland Environmental Service Under Contract to the Maryland Port Administration. TS-167-98.

10. Cornwell, J.C. and M. Owens. 1998. Benthic phosphorus cycling in Lake Champlain. Final report to Hydroqual, Inc. Under Contract to the Lake Champlain Management Conference. TS-168-98.

11. Cornwell, J.C. and M. Owens. 1999. The Nutrient Chemistry of Sediment Dredging: Sediment Nutrient Inventories and Fluxes. Final report to Maryland Environmental Service Under Contract to the Maryland Port Administration. TS-187-99

12. Cornwell, J.C. and W.R. Boynton. 1999. Sediment Water Oxygen and Nutrient Exchanges at Shoal and Channel Stations in the Upper Bay. Final report to Maryland Environmental Service Under Contract to the Maryland Port Administration. TS-186-99

13. Cornwell, J.C. 1999. Estimation of Potential Nutrient Releases Associated With Placement Activities at Site 104. Final report to Maryland Environmental Service Under Contract to the Maryland Port Administration. TS-188-99

14. Cornwell, J.C., M. Owens and L Pride. 2000. Nitrogen and Phosphorus Releases During Dredging: Assessing Potential Phosphorus Releases and Refinement of Ammonium Release Estimates Final report to Maryland Environmental Service under contract to the Maryland Port Authority. TS-230-0

15. Cornwell, J.C. and M.S. Owens. 2000. Nitrogen Cycling in Florida Bay Mangrove Environments: Sediment-Water Exchange and Denitrification. Final Report to South Florida Water Management District

16. Cornwell, J.C. and M. Owens. 2002. Triadelphia Sediment-Water Exchange Study. Final report to WSSC. TS-364-02.

17. Malone, T.C., W.C. Boicourt, J.C. Cornwell, L.W. Harding, Jr., and J. C. Stevenson. 2003. The Choptank River: a mid-Chesapeake Bay index site for evaluationg ecosystem reponses to nutrient management. Final Report to USEPA Contract R826941-01-0

18. J. C. Cornwell, J. C. Stevenson, L.W. Staver, K. Mielcarek and E. Kiss. 2005. Wetland plant viability and wetland sediment monitoring 2003-2004. Final Report to Maryland Port Administration. TS-484-05

19. Cornwell, J.C., E. Kiss and M.S. Owens. 2005. Hart-Miller South Cell Pond Chemistry 2004. Final Report to Maryland Port Administration. TS-485-05.

20. Cornwell, J.C. 2006. Characterization of Bed Sediment Behind the Lower Three Dams on the Susquehanna River: Activities of Anthropogenic Gamma Emitting Isotopes. Final Report to Susquehanna River Basin Commission. TS-507-06

21. Bailey, E.M., M.S. Owens, W.R Boynton, J.C. Cornwell, E. Kiss, P.W. Smail, H. Soulen, E. Buck, and M. Ceballos. 2006. Sediment phosphorus flux: pH interactions in the tidal freshwater Potomac River estuary. UMCES Final Report to the Interstate Commission on the Potomac River Basin. TS-505-06

22. Cornwell, J.C., E. Kiss and M.S. Owens. 2006. Hart-Miller South Cell Chemistry 2005. UMCES Report TS-513-06. UMCES Final Report to Maryland Environmental Services on behalf of the Maryland Port Administration. TS-513-06

23. Cornwell, J.C. and M.S. Owens. 2007. Development of an estuarine phosphorus sub-model for incorporation into the new-generation Potomac River Environment model: phosphorus data and laboratory experiments. UMCES final report to Limno-Tech Inc. on behalf of the Metropolitan Washington Council of Governments. TS-563-07

GRANTS AND CONTRACTS AT UMCES

1. Cornwell. Lead mobility in anaerobic environments. Brookhaven National Laboratory. 2/87-9/87. ($8,000).

2. Cornwell/Stevenson. Nitrogen and sulfur cycling process studies in the Delta Marsh Ecology Research Program. Delta WWRS. 4/87-3/89. ($15,000).

3. Stevenson/Cornwell. Toxic substances in submerged aquatic vegetation beds; Springtime herbicide concentrations in SAV beds. Maryland DNR. 6/87-9/88. ($11,500).

4. Stevenson/Cornwell. Environmental impacts of pH on submersed aquatic vegetation in Chesapeake Bay. Maryland DNR. 11/87-10/88. ($42,907).

5. Cornwell/Sampou/Kemp. EPA sediment data collection program: anaerobic processes component. MDE. 4/88-12/89. ($129,960).

6. Cornwell/Ward. Toxic metals deposition in sediments of Maryland reservoirs and Chesapeake Bay: impact on water supplies and habitat quality. Maryland WRRC. ($26,925)

7. Cornwell. Responses of a major land margin ecosystem to changes in terrestrial nutrient inputs: internal nutrient cycling, production and export. P, Fe, S cycling component. NSF. 9/88-11/94. ($182,236).

8. Stevenson/Cornwell. Anacostia wetlands demonstration project. District of Columbia/EPA. 3/89-2/92. ($102,646).

9. Glibert/Kana/Cornwell. Rates of utilization and fluxes of nitrogenous nutrients in a Chesapeake Bay subestuary; Sources and fates of nitrogenous nutrients in a Chesapeake Bay subestuary. Water Resources Research Center. 5/89-4/91. $39,646.

10. Cornwell/Sampou/Kemp. MDE/EPA sediment data collection program: sediment composition and nitrogen cycling. 7/89-6/90. ($59,513)

11. Cornwell/Stevenson. Marine sulfate inputs and the degradation of coastal marsh soils: biogeochemical enhancement of marsh loss? NOAA Estuarine Reserve. 9/89-8/90. ($35,154).

12. Cornwell. Phosphorus mobility in estuarine particulates: an experimental approach. Water Resources Research Center. 5/91-4/92 ($12,907).

13. Cornwell. Pb-210 Analysis. Maryland Geological Survey. ($10,000).

14. Cornwell. Direct measurements and biogeochemical controls of sediment-water flux of trace metals from estuarine sediments. Sea Grant. ($93,317). 1/92-12/93.

15. Malone, Kennedy et al. Multiscale Experimental Environmental Research Center. USEPA. (10 year program). (Cornwell lead P.I. grants: $38,876; $334,666; $222,791; $78,527; $44,224; $13,548)

16. Cornwell. Onondaga Lake sediment nutrient study. PTI Environmental Services. ($77,382).

17. Cornwell. Water quality in the Anacostia River: Metals and nutrients. Interstate Commission on the Potomac River Basin. 9/92-9/93. ($17,488).

18. Cornwell. Short-term and long-term sequestering of nitrogen and phosphorus in northern Chesapeake Bay marshes. NOAA. 6/93-5/95. ($50,010).

19. Cornwell. Benthic phosphorus cycling in Lake Champlain. USEPA. (07-5-23342; 07-5-23424; $110,000)

20. Cornwell. Determination of the volume of contaminated sediments in the Anacostia River: Sediment geochronology. Interstate Commission on the Potomac River Basin. 5/95-12/95. ($6,500).

21. Harrell, Glibert, Kana, Cornwell. Water quality and waste management in aquaculture production. NERAC. 5/95-8/95. ($37,284).

22. Cornwell. Sediment biogeochemical processes in Jamaica Bay, New York. NYC/Hydroqual Inc. 9/95-12/96. ($180,000).

23. Newell, R.C., J.C. Cornwell and J.H. Tuttle. Can increasing stocks of oysters in Chesapeake Bay serve to improve water quality? Maryland Sea Grant. 2/96-1/98. ($79,599).

24. Baker, J.E., R.P. Mason and J.C. Cornwell. Spatial mapping of contaminants in Baltimore Harbor/Patapsco River/Back River System. Maryland Department of the Environment. 3/96-5/97. (HPEL part $36,000)

25. Kana, J.C. and J.C. Cornwell. Denitrification in tidal river/marsh ecosystems. National Science Foundation/Environmental Geochemistry. 9/96-12/99. ($249,985).

26. Zelenke, J. and J.C. Cornwell. Graduate Fellowship-Freshwater marshes of the Hudson River as nutrient sinks. 9/96-5/97. ($13,000).

27. Cornwell. Sediment oxygen demand and nutrient fluxes from Delaware River sediments. Delaware River Commission. 9/96-7/98. ($23,700).

28. Cornwell. Carbon and electron acceptor cycling in lake and estuarine sediments during early diagenesis. National Science Foundation/Ecosystems. 6/ 1996-5/1998. ($43,344).

29. Cornwell. Sediment biogeochemistry at site 104 open water placement area. Maryland Environmental Service. 5/96-8/97. ($17,000).

30. Cornwell, J.C. Metal fluxes from sediments in the Back River and Patapsco River estuaries. Baltimore City Department of Public Works. 8/97-6/98 ($25,955).

31. Zelenke and Cornwell. Denitrification in the Maryland National Estuarine Research Reserves. NOAA/Research Reserves. 6/97-5/98. ($16,495).

32. Cornwell. Hart-Miller Island Well Monitoring. Maryland Environmental Service. 8/97-5/98. ($9,999).

33. Cornwell. Baltimore Harbor Sediment Metals: Dissolved Exchange With Overlying WaterVersus Sediment Burial. Maryland Sea Grant. 12/97-1/98. ($58,000).

34. Cornwell/Kana. Nutrient Cycling in Oligohaline Sediments and Marshes: Is Denitrification a Major Sink for Nitrogen? Maryland Sea Grant. 2/98-1/00. ($100,000).

35. Cornwell. The nutrient chemistry of sediment dredging; sediment nutrient inventories and fluxes. Maryland Environmental Service. 1998. ($85,715).

36. Cornwell. Loch Raven sediment geochronology. Maryland Geological Survey. 1998. ($25,000).

37. Malone, Boicourt, Cornwell, Harding and Stevenson. The Choptank River: A Mid-Chesapeake Bay Index Site for Evaluating Ecosystem Responses to Nutrient Management. USEPA. 9/98-8/01. ($596,096).

38. Cornwell. Sediment-Water Nutrient Exchange in Tridelphia Reservoir. Washington Suburban Sanitary Commission/Versar Inc.. 3/99-12/99. ($19,215).

39. Kemp, Cornwell. Role of Benthic Communities in the Cycling and Balance of Nitrogen in Florida Bay. 8/99-7/00. ($50,000).

40. Kana, MacIntyre, Cornwell. ECOHAB: Benthic pelagic coupling and Long Island Brown Tide. NOAA. 9/99-8/02. ($696,021).

41. Cornwell, Kana. Environmental Controls of Denitrification in Estuarine Sediments. Sea Grant/NOAA. 2/00-1/02. ($124,652).

42. Glibert, Kana, Cornwell. Biocomplexity of Aquatic Systems: Relating Diversity of Microorganisms to Ecosystem Function. National Science Foundation. 8/00-7/05. (Cornwell $257,133).

43. Cornwell, Kemp. Nitrogen and Phosphorus Biogeochemistry of Florida Bay Sediments. NOAA. 8/00-10/02. ($235,674)

44. Cornwell. Experimental Pond Biogeochemistry at Hart Miller Island. MES/MD Port Administration. 12/01-12/02. ($128,146)

45. Newell, Cornwell, Merrit. Quantifying the Magnitude of Nitrogen and Phosphorus Removal of Oysters in Chesapeake Bay. MD Sea Grant. 02/02 – 01-04. ($130,668)

46. Sanford, Cornwell. Bottom Sediment Erodability in Northern Chesapeake Bay. MD Sea Grant. 02/02 – 01/03. (07-5-23581; $95,000).

47. Cornwell, Kemp. SFP 2002: Nitrogen and Phosphorus Mass Balance Models and Nutrient Biogeochemistry in Florida Bay. NOAA. 2002 – 2004. ($263,737)

48. Cornwell/Boynton. Collaborative Research: Origin of N Limitation in Estuarine Waters. NSF Ecosystems. 2002-2005 ($410,667)

49. Kemp, Murray, Cornwell. Sediment Biogeochemistry and Seagrass Bed Development: Implications for Restoration and Sustainability. MD Sea Grant. 02/03-01-05 ($128,000)

50. Cornwell. Poplar Point Sediment Geochronology. NOAA/Philadelphia Academy of Natural Sciences. 2004. ($27,000).

51. Cornwell. Biogeochemical Analysis of Poplar Island dredge sediments. MPA/MES. 2003-4. ($150,000)

52. Cornwell. Examination of Sediment Phosphorus Flux- pH Interactions in the Tidal Freshwater Potomac River Estuary. Interstate Commission on the Potomac River Basin. $84,478. 4/04 – 4/05.

53. Cornwell. Biogeochemistry of Suspended Phosphorus in the Potomac River. USCOE/Limnotech. $135,000. 05/2005-12/2006.

54. Cornwell/Kana. Predicting the Restoration Trajectory and Water Quality Value of Benthic Microalgae in Shallow Water Chesapeake Sediments. $138,000. Maryland Sea Grant, 02/2005 - 01/2008.

55. Cornwell. Poplar Island Cell 3D Sediment and Plant Monitoring Program; Chemistry. $208, 259. Maryland Port Administration, 07/2005-02/2007.

56. Cornwell. HMI Interior Sediment Chemistry and Plant Composition. $45,392. Maryland Port Administration. 07/2005-02/2006.

57. Cornwell. Denitrification and Nutrient Balance in Corsica River Sediments, Maryland. Maryland Department of Natural Resources. $46,524. 7/2006-6-2007

58. Stevenson/Cornwell. Sediment and Plant Monitoring at South Cell of Hart Miller Island. Maryland Port Administration/ Maryland Environmental Service. $75,679. 2007-2008

59. Stevenson/Cornwell. UMCES Poplar Cell 3D Monitoring Program: Sediment and Plant Dynamics 3rd Year. Maryland Port Administration/ Maryland Environmental Service. $102,345. 2007-2008

60. Cornwell/Owens. Sediment and Chemistry Technical Support: pH mapping. Maryland Port Administration/ Maryland Environmental Service. $65,832. 2007-2010.

61. Cornwell/Owens. Sediment and Chemistry Technical Support: Time Course of Acid Generation During Crust Management of Dredge Sediment. Maryland Port Administration/ Maryland Environmental Service. $65,935. 2007-2008

62. Cornwell/Palinkas. Nutrient Balance in Corsica River Sediments: Improved Estimates of Nutrient Burial and Denitrification. Maryland Department of Natural Resources. $20,000. 07/2007-06/2008.

63. Cornwell/Newell. Assessing Ecosystem Effects of Harvesting Geoducks. Washington State Sea Grant. $200,000. 2008-2010.

64. Cornwell/Kana. Advancing Methods for Measuring Denitrification in Terrestrial and Aquatic Systems: A Workshop. $7,760. 2008.

GRANTS AND CONTRACTS AT CHESAPEAKE BIOGEOCHEMICAL ASSOCIATES

Sediment-Water Exchange of Nutrients and Gases in Grand Calumet River Sediments. Mead and Hunt/U.S. Army Corps of Engineers. 2000.

Delaware Tidal River Sediment-Water Exchange Study. DNREC. 2001-2003.

Coastal Bay Denitrification. Maryland Coastal Bays Program. 2002-2003

A Study of Phosphorus Release from Byllesby Reservoir, July 2004. Cities of Fairibault and Owatanna, Minnesota. 2004.

Passaic River Erosion Testing and Core Collection. Malcolm Pirnie/USEPA. 2005

Sediment Nutrient Fluxes and Denitrification in Jamaica Bay. Battelle Memorial Institute. 2005-2008

Spokane Lake Sediment Nutrient Fluxes. Wastewater Management, City of Spokane. 2006

Nutrient Flux Study: Murderkill River. Kent County Levy Court. 2007-2008

pH Effects on Phosphorus Flux From Spokane Lake Sediments. Wastewater Management, City of Spokane 2007

Redox Effects on Phosphorus Flux From Spokane Lake Sediments. Wastewater Management, City of Spokane 2007

HONORS AND AWARDS:

New York State Regents Scholarship, 1972-1976; Hobart College Presidential Scholarship, 1972-1976; Freshman Chemistry Award, Hobart College, 1973; Most Valuable Player Varsity Basketball, 1972/73, 1973/74; Bullard Analytical Chemistry Prize, Hobart College, 1976; State of Alaska Graduate Fellowship, University of Alaska, 1979-82; Outstanding Student, Marine Science, University of Alaska, 1982.

PAPERS REVIEWED

American Chemical Society Symposia; American Journal of Science; Aquatic Geochemistry; Aquatic Microbial Ecology: Biogeochemistry; Estuarine, Coastal and Shelf Science; Environmental Monitoring and Assessment; Estuaries; Geochemical Journal; Geochimica et Cosmochimica Acta; Hydrobiologia; Journal of Environmental Quality; Journal of Marine Research; Journal of Sedimentary Petrology; Limnology and Oceanography; Marine Chemistry; Marine Geology; Nature; Proceedings of the Ocean Drilling Program; Science of the Total Environment

PROPOSALS REVIEWED

National Science Foundation (Marine Chemistry, Biological Oceanography, Ecosystems, Polar Programs, Hydrology); Sea Grant (National Program, Alaska, Delaware, Hawaii, Louisiana, Maryland, New York, Rhode Island, South Carolina, Texas); Hudson River Foundation; USEPA (Bay Program); Maryland Power Plant Research Program; NOAA

REVIEW PANELS

Kentucky DOE/EPSCOR Program; NOAA Coastal Ocean Program; NOAA/NURP; NJ Sea Grant; Boston Harbor Model Evaluation Group

MEMBERSHIPS

American Chemical Society; American Geophysical Union; American Society for Limnology and Oceanography; Estuarine Research Federation; Geochemical Society; Sigma Xi; Society of Wetland Scientists

ACADEMIC AND LABORATORY SERVICE ACTIVITIES

Co-Head of Horn Point Summer Intern Program 1989-1990
Sea Grant Research Experience for Undergraduates Selection Committee (1989-1993; 2002-present)
MEES Environmental Chemistry AOC Admissions Committee
Facilities Committee (1994-1995)
Analytical Services Committee (1987-1995, 1997, Chair 2002/3)
Education Committee (1996, 2007-)
Boat Committee (Chair; 1999/2000, 2001/2, 2004-2006)

OTHER ACTIVITIES

Power Plant Topical Research Program Geochemistry Review Committee
Chesapeake Bay Toxics Loading Review Committee
Baltimore Harbor Toxics RAP Stakeholders Group (1995-1996)
Maryland Sea Grant REU Selection Committee

DEPARTMENTAL SEMINARS

Appalachian Environmental Laboratory; Chesapeake Biological Laboratory; Duke University, Marine Biological Laboratory Ecosystems Center; Old Dominion University Oceanography Department; Smithsonian Environmental Research Center; University of Maryland College Park Chemistry Department; University of Maryland Eastern Shore Environmental Science; University of South Carolina; University of Virginia Environmental Science; Virginia Institute of Marine Science, University of North Carolina Oceanography Department, USGS/Reston

CLASSES TAUGHT

Spring 1991.	MEES 698H.	Sediment Biogeochemical Techniques. 3 credits.
Summer 1993.	MEES 698S.	Marine Biogeochemistry. 3 credits. (Cornwell/Conley).
Spring 1996-8	MEES 698H.	Environmental Geochemistry II. (Harvey/Cornwell)
Spring 1996.	MEES 608y	Methods: Sediment Biogeochemistry (Cornwell)
Spring 1998	MEES 608J	Phosphorus Biogeochemistry

Lectures in Stable Isotope Techniques, Marine Geochemistry, Chemical Oceanography and Wetlands (MEES 645) and other graduate courses

GRADUATE STUDENTS SUPERVISED (Current Students in Bold)

Geremia, Marion , M.S., MEES Program/UMCP, graduated 1993. Thesis Title: "A Comparison of Sediment, Heavy Metal and Nutrient Retention in Natural and Manmade Wetlands in Centennial Park, Maryland". Current Employment: US Army Corps of Engineers.

Stribling, Judith , Ph.D., MEES Program/UMES, graduated 1994. Dissertation Title: "Sulfur and Nutrient Chemistry of *Spartina Alterniflora* Loisel. in a Low Salinity Marsh". Current Employment: Asst. Prof., Salisbury State University.

Liebert, Amy, M.S., MEES Program/UMCP, Environmental Geochemistry, graduated 1997. Thesis Title: AMetabolism and Nutrient Cycling in Experimental Marsh Sediments@.

Elka Porter, Ph.D., MEES Program/UMCP, co-advisor with L. Sanford, graduated 1999. Dissertation Title: "Physical and Biological Scaling of Benthic-Pelagic Coupling in Experimental Ecosystem Studies". Current Employment: Post-Doc, Chesapeake Biological Laboratory

Zelenke, Jennifer, Ph.D., MEES Program/UMCP, Environmental Geochemistry, graduated 1999. Dissertation Title: "Tidal Freshwater Marshes as Nutrient Sinks: Nutrient Burial and Denitrification". Current Employment: National Academy of Science

Haberkern, Erik, M.S., MEES Program/UMCP, Ecology. Graduated 2000. Thesis Title: "Algal production and nitrogen cycling in tidal marshes".

Bryner, Jeanna, M.S., MEES Program/UMCP, Environmental Geochemistry. Graduated 2000. Thesis Title: "The effects of iron and sulfur on phosphorus dynamics along a tidal gradient in fresh/oligohaline marshes".

Coley, Teresa, M.S.., MEES Program, Environmental Geochemistry. Graduated 2003. "Effects of flow on sediment biogeochemistry".

Eric Nagel, M.S., MEES Program, Environmental Science. Graduated 2004. "Nitrogen fixation in benthic microalgal mats: an important source of new nitrogen to benthic communities in Florida Bay".

Jessica Burton, M.S. MEES Program, Environmental Science. Graduated 2005. "The effect of benthic microalgal photosynthetic production on nitrogen fluxes across the sediment-water interface in a shallow, sub-tropical estuary".

Rebecca Holyoke, Ph.D. MEES Program Environmental Science. Graduated 2008. "Biodeposition and Biogeochemical Processes in Shallow,Mesohaline Sediments of Chesapeake Bay"

Jennifer O'Keefe, M.S. MEES Program, Environmental Science. Sediment biogeochemistry across the Patuxent River estuarine gradient:geochronology

Michael Owens, M.S. MEES Program, Environmental Geochemistry. Topic: Meiofauna influences on benthic fluxes.

Christopher Chick, M.S. MEES Program. Benthic Micoalgal Production.

Yonghui Gao, Ph.D. Mees Program, Environmental Chemistry.

Emily Seldomridge, M.S. MEES Program, Environmental Science.

GRADUATE COMMITTEES: (Current Total = 8; graduation date in brackets, current graduates = 63)

M.S.

1. Susan Hill (Stevenson), HPL (1989)
2. Linda Hurley (Harrell), HPL (1989)
3. Charlotte Nielsen (Marcus), UMCP (1990)
4. Phillipe Hensel (Stevenson), HPL (1992)
5. Neal Greenburg (Harrell), HPL (1992)
6. William Kuhn (Kemp), HPL (1992)
7. Ricky Arnold (Dennison), HPL (1992)
8. Erik Smith (Kemp), HPL (1992)
9. Mike Williams (Fisher), HPL (1992)
10. Marion Geremia (Cornwell), HPL (1993)
11. Marilyn Ailes (French), UMES (1993)
12. Duane Hunt (Glibert), HPL (1993)
13. Tyler Abbot (Jesien), HPL (1994)
14. Jackie Takacs (Harrell), HPL (1995)
15. Alison Bryant (Ducklow), HPL (1995)
16. Koichiro Nakanishi (Baker), CBL (1996)
17. Catherine Stokes (Sampou/Kemp), HPL (1996)
18. Kellie Merrell (Stevenson), HPL (1996)
19. David Jasinski (Boynton), CBL (1996)
20. Amy Liebert (Cornwell), HPL (1997)
21. Sean Michael Crawford (Sanford), HPL (1998)
22. Jeanna Bryner (Cornwell), HPL (2000)
23. Erik Haberkern (Cornwell), HPL (2000)
24. Joshua Schmitz (Stevenson), HPl (2000)
25. Teresa Coley (Cornwell),HPL (2003)
26. Josh Traband (Fisher), HPL (2003)
27. Eric Nagel (Cornwell), HPL (2004)
28. Jessica Burton (Cornwell), HPL (2005)
29. Mike Rearick (Mason), CBL (2004)
30. Lynne Heighton (Siefert), CBL (2005)
31. Sarah Greene (Boynton), CBL (2005)
32. Kristin Mielcarek (Stevenson), HPL (2006)
33. Michael Owens (Cornwell), HPL
34. Jennifer O'Keefe (Cornwell), HPL (2008)
35. Chris Chick (Cornwell), HPL
36. Emily Seldomridge (Cornwell), HPL

Ph.D.

1. Joseph Seraphy (Harrell), HPL (1992)
2. Theresa Paluskiewicz (Chao), HPL (1993)
3. Louise Wooten (Roman), HPL (exam only)
4. Monde Mayekisko (Hocutt), HPL (1994)
5. Aaron Mabaye (Hocutt), HPL (1994)
6. Cathy Wigand (Stevenson), HPL (1994)
7. Judith Stribling (Cornwell), HPL (1994)
8. Craig Carlson (Ducklow), HPL (1994)
9. Mark Marvin (Capone), CBL (1995)
10. Ken Moore (Kemp), HPL (1996)
11. Marilyn Ailes (Rebach), UMES (1996)
12. Debra Lonergan (Capone), CBL (1996)
13. Jordan Adelson (Helz), UMCP Chemistry (1997)
14. Juanita Urban-Rich (Roman), HPL (1997)
15. Mine Berg (Glibert), HPL (1998)
16. John Petersen (Kemp), HPL (1998)
17. Chung-Chi Chen (Kemp), HPL (1998)
18. Kim Warner (Capone), CBL (1998)
19. Jennifer Zelenke (Cornwell), HPL (1999)
20. Elka Porter (Sanford/Cornwell), HPL (1999)
21. Miao-Li Chang (Sanford), HPL (1999)
22. Vallen Emery Jr. (Wright), CBL (1999)
23. Reno Nguyen (Harvey), CBL (2000)
24. Matt Mills (Sebens), UMCP Zoology (2000)
25. Andy Zimmerman (Canuel), VIMS (2000)
26. Janina Benoit (Mason), CBL (2000)
27. Gary Smith (Newell), HPL (2001)
28. John Brawley (Costanza),CBL (2002)
29. Jill Rooth (Stevenson), HPL (2003)
30. Joyce Dewar (Stevenson), HPL, dnf
31. Rick Bartleson (Stevenson), HPL (2004)
32. Zhenghua Jin, (Boicourt) HPL (comps only)
33. Eun Hee Kim (Mason), CBL (2004)
34. Carrie Miller (Mason), CBL (2005)
35. Carolyn Miller Solomon (Glibert), HPL (2006)
36. Jessica Davis (Kemp), HPL (2007)
37. Rebecca Holyoke (Cornwell), HPL (2007)
38. George Walbusser (Marinelli), CBL (2007)
39. Laura Belicka (Harvey), HPL (2008)
40. Hanna Silvennoinen, Kuopio Finland (2008)
41. Rebecca Fox (Fisher), HPL
42. Yonghui Gao (Cornwell) HPL
43. Ji Li (Glibert), HPL

NATHAN DILL, M.S.C.E., B.A.

Coastal Engineer

Professional Affiliations

Associate Member, Association of Coastal Engineers (ACE)

Fields of Expertise

Conducting numerical modeling efforts for the simulation of hydrodynamics and water quality in the coastal environment and selecting the appropriate model software for the job, Applying and developing tools with various software and programming languages to support model development and meaningfully present model results, Utilizing high performance computing and parallel programming to increase performance of numerical models and related data analysis.

Higher Education

M.S.C.E., Louisiana State University (2007)
B.A., Physics-Bowdoin College (2002)
Passed Fundamentals of Engineering Exam (2008)

Employment History

2007-Present	Coastal Engineer, Woods Hole Group
2006-2007	Coastal Scientist, URS Corp
2004-2007	Research Assistant, Louisiana State University
2002-2004	Physics Teacher, Northfield Mount Hermon

Key Projects

Herring River Estuary Restoration Project, Wellfleet, MA, Town of Wellfleet – Coastal Engineer/Modeler
Currently Conducting a numerical modeling program to support planning for restoration of over 1000 acres of wetland within the Herring River Estuary in Wellfleet, Massachusetts; the largest Estuary on Cape Cod. After evaluating the potential application of over twenty different hydrodynamic models, the

Key Projects (continued)

Environmental Fluid Dynamics Code (EFDC) was chosen as the most suitable model for the project. The modeling program included the development of a large curvilinear-orthogonal grid,

Qualifications Summary

- Experience applying numerical models to support studies for coastal restoration and coastal protection projects including hurricane storm surge simulations
- Experience developing large finite element grids for parallel ADCIRC simulations
- Strong background knowledge of coastal processes and coastal hydrodynamics
- Strong written and verbal communication skills
- Knowledge of high performance computing concepts and parallel programming experience using MPI and OpenMP
- Numerical model experience with EFDC, ADCIRC, PADCIRC, RMA2, HEC-RAS, CORMIX, StormCAD
- Programming experience with MATLAB, SCILAB, FORTRAN, C

calibration and verification of the model for simulating hydrodynamics and salinity throughout the estuary, simulations of various alternatives for the restoration of tidal exchange to the estuary, and support for the design of engineering structures for restoration. This large complex system contains more than a dozen hydraulic control structures (dikes, culverts, sluice gates, flap gates) and a vast floodplain making the modeling effort particularly difficult. Significant enhancements were made to the EFDC code to overcome these difficulties including: developing a multi-threaded version of EFDC with OpenMP to decrease simulation time. Developing subroutines for explicitly calculating flow through various control structures (sluice gates, flapper gates, box culverts, pipe culverts), enhancing the GEFDC grid generation code to account for aspect ratio control and sliding boundary points making it possible to generate a nearly orthogonal grid covering over 1000 acres with resolution down to 2 meters using only 85,000 cells, and modifications to the wetting/drying code to aid in simulating smooth flooding and draining of the vast inter-tidal zone in the estuary.

Sengekontacket Pond ENF/EIR, Town of Edgartown, Massachusetts – Coastal Engineer/Modeler
Performed data analysis for bathymetric and water-level data collected by Woods Hole group for the project. Used the collected data to construct and calibrate a RMA2 model of Sengekontacket and Trapps ponds to simulate tidal circulation.

Feasibility Analysis of Alternate Discharge Locations for Reverse Osmosis Water Treatment Plant in Melbourne, FL. Reiss Environmental Inc - Coastal Engineer/Modeler
Assessed the feasibility of increasing the discharge volume and relocating the outfall for Reverse Osmosis (RO) concentrate produced by the Melbourne RO water treatment plant. Concerns of negative water quality impacts at times of low flow at the current outfall in the Eau Gallie River and increased demand for potable water in the City of Melbourne have led to the desire to find a more suitable discharge location for the RO concentrate produced by the plant. Both the Indian River Lagoon and the Atlantic Ocean were considered as alternatives. Data collected from previous studies were used to determine the necessary mixing zone sizes that would be required to meet Florida water quality standards for the radio-nucleotides combined radium (226/228) and gross alpha, and potential for acute toxicity was assessed by examining the bulk dilution. Different diffuser designs, including a single port and a multi-port diffuser were considered for each location.

Assessing Baseline and Modified Astronomical Tide Propagation in the Pontchartrain Basin Using ADCIRC, LA – Graduate Assistant (work conducted as a research assistant at Louisiana State University under the direction of Clinton Wilson and Bob Jacobsen for URS Corp. under contract to U.S. Army Corp of Engineers)
Developed a large finite element mesh (~300,000 nodes) for a parallel ADCIRC model of the Lake Pontchartrain basin. Executed model simulations and performed pre and post processing of model data. The model was developed to evaluate the potential impact on tidal circulation within the Pontchartrain basin caused by the introduction of barrier structures for storm protection and hydrologic restoration. Astronomical tides were simulated in the basin and

Key Projects (continued)

resulting tidal amplitudes and currents were examined to demonstrate the relative effect on tidal circulation caused by alternative restriction scenarios of major tidal passes.

Mississippi River Re-introduction into Maurepas Swamp, Reserve, LA – Coastal Scientist (completed while working for URS Corp.)

Performed pre and post processing for parallel ADCIRC simulations of a proposed Mississippi River diversion into the Maurepas swamp. Developed a particle tracking code (in SCILAB language) to aid in steady-state flow field visualization and estimation of median residence time of diverted water. Performed mesh modifications to calibrated model to add the proposed diversion channel then conducted various simulations with further modification to maximize distribution and residence time of diverted water. Simulations were also conducted to evaluate the potential effect of the diversion on the drainage of nearby communities whose storm water drains into the swamp. For this evaluation output from a SWMM model of the drainage network was used to provide boundary conditions for the ADCIRC model and vice-versa in an iterative fashion to simulate a rainfall event.

Publications

Dill, Nathan L. 2007. “Hydrodynamic Modeling of a Hypothetical River Diversion Near Empire, Louisiana” Master’s Thesis, Louisiana State University, Baton Rouge, LA.

Wilson, Clinton S., Nathan Dill, William Barlett, Samantha Danchuk, and Ryan Waldron. 2007. “Physical and Numerical Modeling of River and Sediment Diversions in the Lower Mississippi River Delta” ASCE Coastal Sediments 2007, 1, 749-761.

Qualifications Summary

- Provides strategic advice and a high level of service to key clients
- Manages multi-disciplinary projects
- Maintains diverse technical expertise related to coastal and environmental sciences and engineering
- Completes QA/QC review of deliverables
- Possesses strong writing and verbal communication skills
- Delivers short and long-term sales objectives
- Establishes and implements strategic plans for corporate growth

ROBERT P. HAMILTON JR., M.C.E., B.S.

Vice President of Business Development
Coastal Engineer

Professional Affiliations

Northeast Shore and Beach Preservation Association, Director
Marine and Ocean Technology Network, Director
American Society of Civil Engineers

Fields of Expertise

Business and Project Management in Environmental Consulting sector with focus on coastal and oceanographic environments. Business and client development in government, private, power utilities, oil and gas, and manufacturing markets. Technical specialty solving problems and managing projects related to planning, engineering design and environmental permitting for shore protection, dredging, habitat restoration, and infrastructure development (e.g., seawalls, pipelines) in the coastal zone. Advanced technical skills related to numerical modeling, data collection and analysis, and integration with environmental policy and stakeholder requirements to solve complex, multi-disciplinary problems.

Higher Education

M.C.E., Civil Engineering-University of Delaware (1994)
B.S., Civil Engineering-Lehigh University (1992)

Employment History

2003-Present	Vice President, Business Development, Woods Hole Group, Inc.
2001-2003	Vice President, Scientific Operations, Woods Hole Group, Inc.
1998-2001	Business Unit Director, Woods Hole Group, Inc.
1994-1998	Coastal Engineer, Aubrey Consulting, Inc.
1993-1994	Teaching and Research Assistant, University of Delaware
1991-1992	Civil Engineering Assistant, KCI Technologies, Inc.

Key Projects

Environmental Planning and Consulting Services Task Order Contract, US Army Corps of Engineers New England District – Senior Engineer/Corporate Support
Woods Hole Group is the prime contract holder for a Task Order contract with USACE NED that will extend up to 5 years and $15M beginning in November 2008. The scope of work includes a diverse suite of environmental consulting services, such as field data collection and monitoring, laboratory studies, risk assessments, EIS preparation, HTRW site support, and other specialty service areas as required by NED and other Districts within the North Atlantic Division (e.g., oceanography, coastal modeling, environmental economics, archaeology, etc.). Mr. Hamilton developed the team, led the proposal effort, and completed the contract negotiation process. He will support the ongoing Program in a corporate function, and provide project management and technical support for some of the individual Task Orders.

Hydraulic Study to Assess Feasibility of Tidal Restoration within Stony Brook, Town of Brewster, MA – Coastal Engineer/Project Manager
Completed a field data collection and numerical modeling investigation of the Stony Brook system upstream from Rte. 6A to assess the potential for restoration of salt marsh habitat and the anadromous fish run. The scope of work included collection of synoptic tide and salinity data, calibration of a hydrodynamic and salinity model (EFDC), evaluation of restoration alternatives, and recommendations for conceptual engineering alternatives and potential environmental impacts. Woods Hole Group also made a contribution to the Corporate Wetlands Restoration Partnership (CWRP) in the form of bathymetric data collection, land surveying, and numerical modeling.

Reverse Osmosis Water Treatment Facility Discharge Dilution Analysis and Environmental Impact Assessments, Various Locations in Florida as Prime and Subcontractor– Engineer/Project Manager
Demand for potable drinking water has spurred a need for desalination facilities to supplement the local freshwater supply in Florida. For communities in the Town of Jupiter, Palm Coast, Tarpon Springs, City of Melbourne, and the South Martin Regional Utility, Woods Hole Group has conducted dilution studies of reverse osmosis discharge concentrate. The scopes of work have been diverse, involving field data collection (water quality and circulation parameters), numerical modeling (CORMIX and EFDC), and environmental impact studies. Contaminants of interest have included heavy metals, radionuclides, and overall acute toxicity. Results from the work include support for environmental permit approvals, including mixing zones, and engineering recommendations for diffuser configurations to support expansion of water treatment facilities while minimizing environmental impacts.

Optimize the Massachusetts Estuaries Project's Linked Modeling Approach, MA Department of Environmental Protection – Engineer/Project Manager
Woods Hole Group has a contract with the MA DEP to evaluate and optimize the linked modeling approach used by the MA Estuaries Project (MEP). The scope of work includes preparation of a protocol that Towns and stakeholders can implement to obtain appropriate information from the MEP team, and perform independent analysis. Woods Hole Group also is charged with testing the protocol on a particular embayment, ensuring that the protocol can reproduce the MEP results, and testing the sensitivity of the model to certain input parameters. This contract is of high importance to the participating communities that are dependent upon the MEP findings to plan large-scale

Key Projects (continued)

wastewater facilities improvement projects. The contract is currently expected to be completed in 2009.

Dubai Arabian Canal Design Support and Water Quality Analysis, Confidential Client – Engineer/Project Manager
A private developer is planning to develop the biggest and most complex civil engineering project in the Middle East, called the Dubai Arabian Canal, which is a 75 km man-made waterway that will be a focal point for mixed use development, cultural attractions, and recreation. Woods Hole Group supported the conceptual design by investigating alternatives to improve circulation in the canal and help enhance water quality. A phased numerical modeling approach (RMA-2 and EFDC) was implemented to evaluate flushing times and particle pathways for various alternatives involving flow control structures. The problem was made complex because there is little natural tidal difference between the two ends of the proposed canal. Results were used to recommend a conceptual operational plan for phasing the opening and closing of flow control structures within the canal to optimize net circulation.

Environmental Impact Statement (EIS) for the HubLine Natural Gas Pipeline, Massachusetts Bay, MA, Federal Energy Regulatory Commission (FERC) c/o Foster Wheeler, Inc. – Project Manager
Prepared marine portion of the EIS for the controversial HubLine pipeline working under tight scheduling constraints. Compiled data and formulated environmental impact assessment of impacts related to physical oceanography, sediment transport and geology, marine benthic habitat, as well as marine fisheries and shellfish. The scope included preparation and approval of an expanded Essential Fish Habitat (EFH) Assessment. Close cooperation with Foster Wheeler and FERC was required. The document was accepted by the federal authorities, and provided the basis for the state and local level environmental impact report, permits, and monitoring/mitigation protocols. The project was constructed.

Revetment Reconstruction Planning, Design and Permitting, New Seabury, MA, Private Landowners – Project Advisor
Worked with the community to assemble a cooperative group of individual land owners, condominium associations, and community groups to plan, design, permit, and construct a revetment repair project. Special provisions were required to secure environmental permits, as well as access and escrow agreements for utilization of private property for construction vehicles and materials. The coastal engineering design was improved to ensure more lasting protection than previously realized. Contractor bids were selected and screened, and a preferred contractor was selected. The project was constructed.

Beach Nourishment Planning, Siasconset Beach, Nantucket, MA, Siasconset Beach Preservation Fund – Project Manager
Lead technical team to prepare conceptual design, borrow site investigation, and environmental impact assessment for large-scale beach nourishment project. The conceptual design included a design template, plan form layout, and sand volume quantity calculations and cost estimates for a beach nourishment project to include approximately 2 million c.y. of sand. The conceptual design also included an evaluation of various sand retaining structures, designs, and cost estimates to extend the design life of the nourishment. Borrow site identification work included bathymetry, side scan

Key Projects (continued)

sonar, and sub-bottom surveys, as well as sediment sampling and coring to delineate potential sand sources of sufficient quality and quantity. Environmental assessment field work included collection and analysis of benthic grab samples, fisheries trawls, and bottom habitat mapping, along with compilation of existing fisheries data and statistics and fishermen surveys. Data, interpretations, and conclusions were prepared, and incorporated into a Draft Environmental Impact Report (DEIR).

Scarborough Marsh Restoration, Maine Department of Inland and Marine Fisheries and US Army Corp of Engineers c/o Normandeau Associates, Inc. - Project Manager
Completed data collection, numeral modeling, and alternatives analysis required to develop viable marsh restoration alternatives. Data collection included tides, current and salinity gauge deployments, as well as current (ADCP) and bathymetry surveys. Circulation (RMA-2) and salinity (analytical dispersion) models were developed, including wetting and drying of the marsh plain for existing conditions and restoration alternatives. A conceptual design for marsh restoration, including waterfowl and fisheries habitat enhancements and minimization of *Phragmites* encroachment, was presented. Marsh channels and bridge openings were sized, and the potential for upland flooding was modeled (DYNLET). Design recommendations were incorporated to a USACE cost/benefit analysis to select the preferred alternative. Funding is pending for final design, permitting and construction.

Evaluation of Thermal Discharge and Intake Processes and Regulatory Compliance at Salem and Hope Creek Stations, Newark, NJ, Public Service Electric and Gas Co. - Coastal Engineer/Project Manager
Key member of a multi-disciplinary team conducting 316(a) and 316(b) federal water quality standards regulatory demonstrations. Performed numerical modeling, data analysis, and technical writing to support a comprehensive hydrothermal and biothermal assessment of a cooling water discharge system in an Estuary. Completed analysis of the region of influence of cooling water intake on circulation patterns and waterborne eggs and larvae. Completed extensive and innovative scope of work of unprecedented scientific and engineering defensibility within required fast-track schedule. Excellent communication with team members and the client was essential for the successful completion of this project. NJDEP granted approval based on comprehensive materials that demonstrated compliance with 316(a) and 316(b) requirements.

Natural Resources and Beach Management Plan for Sandy Neck Beach, Town of Barnstable, MA - Project Scientist and Manager
Lead multi-disciplinary team to develop a management plan for a controversial set of beach users related to ORV use, private property access, endangered species protection (i.e., piping plovers, least terns, and diamondback terrapins), recreational use, and municipal management and revenue needs/objectives. Conducted research, site assessments, public and environmental regulatory workshops; prepared documents; held public hearings; and obtained environmental permits. Final management plan was used to resolve pending appeals of environmental permits, resolve stakeholder conflicts, and secure new permits for beach use.

Beach Profile Monitoring, Siasconset Beach, Nantucket, MA, Siasconset Beach Preservation Fund – Project Manager
Worked with a technical team to conduct quarterly beach profile surveys and annual bathymetry surveys for six (6) years and continuing. Analyzed data to compute beach volume change as basis

Key Projects (continued)

for evaluating success of shore protection measures. Prepared technical reports for wide range of stakeholders, including regulatory agencies and private landowners.

Peer Review of Comprehensive Coastal Management Plan, Palm Beach, FL, Town of Palm Beach - Coastal Engineer/Project Manager
Served as Town's expert Coastal Engineering Peer Review Consultant. Reviewed long-term comprehensive management plans, and presented targeted recommendations to improve the performance and cost-effectiveness of future shore protection projects. Key recommendations included a phased approach to a 30-year barrier-wide shoreline erosion management plan, including specific beach nourishment and coastal structures projects. An adaptive management and monitoring strategy also was incorporated to improve the design of future projects based on the performance of past projects. The resulting plan allowed for high priority projects to be permitted and constructed in the short-term, and provided the basis for substantial savings of municipal and state tax dollars.

Identification of 1-, 10-, 20-, and 50-Year Design Wave Conditions for the Deer Island Waste Water Treatment Facility Shoreline Protection, Boston, MA, Parsons Brinckerhoff - Coastal Engineer/Project Manager
Completed storm wave modeling and analysis to support the design of extensive shore protection structures for a large wastewater treatment facility in Boston, MA. The scope of work included specification of offshore wave conditions in Massachusetts Bay, wave diffraction/refraction modeling (REF/DIF) into Boston Harbor, and site-specific extremal analysis to calculate design conditions for wave height, period, runup and overtopping. Results were used to size armor stone, and specify revetment toe depth and crest elevation. Maintained long-term support throughout the duration of the project.

Tidal Flushing and Water Quality Assessment of Cape Cod Estuaries, Cape Cod Commission and Municipalities - Coastal Engineer/Project Manager
Designed and participated in field data collection programs related to bathymetric surveying and tide gauging. Completed numerical modeling of tidal circulation (RMA-2) and water quality (RMA-4) processes, and technical report writing. Work was completed within the Three Bays Estuary, Popponesset Bay, Centerville River, Upper Bass River, Pleasant Bay, Red Brook Harbor, and West Falmouth Harbor. Presented results at public meetings. Results included residence time calculations that were used by the Cape Cod Commission to determine impacts of current and future developments. Results also provided a basis for the Massachusetts Estuaries Program to evaluate manageable nutrient loading rates and needs for wastewater management facilities.

Historical Investigation of Industrialization and Sediment Contamination, Newark, NJ, Confidential Client - Coastal Engineer/Project Manager
Conducted in-depth historical investigation of industrialization, including identification of the number and types of industries and characteristics of waste streams. Correlated the industrial development history with historical records of contamination in sediment cores. Developed relational database and GIS to query and visualize vast data sets. Used by client as strategic planning tool for managing environmental liabilities.

Key Projects (continued)

Field Data Collection and Numerical Modeling of Circulation Patterns in the Delaware Estuary, Salem, MA, Public Service Electric and Gas Co. - Coastal Engineer/Field Data Collection
Completed a large-scale data collection and numerical modeling study of the Delaware Estuary. The data collection program consisted of wave, tide, current, bathymetry, salinity, temperature, and meteorological instrument deployments and surveys. Some data were reported real-time via a cable link to the shoreline. The vast data set was consolidated and used to calibrate a three-dimensional numerical circulation model (RMA-10) of the Estuary-wide processes. Particular emphasis was placed on characterizing circulation patterns in the vicinity of a cooling water intake and discharge system to identify processes contributing to the accumulation of detritus in the intake basin. Recommendations were provided for improving station operations to prevent detritus accumulation, which resulted in safer and more cost-effective operations, and helped reduce operational down time.

Shoreline Erosion and Management Planning and Beach Nourishment Performance Monitoring, Town of Jupiter Island, FL – Coastal Engineer/Project Manager
The Town of Jupiter Island has a long-term commitment to managing coastal erosion through beach nourishment by dredging sand from the offshore regions and placing sand on its beaches. Woods Hole Group worked with the Town to develop a large-scale beach nourishment design. Mr. Hamilton completed the bulk of the technical work for the project, including wave data collection and analysis, wave modeling (REF/DIF), sediment transport modeling, and shoreline change modeling (GENESIS). The models were developed and calibrated to the Jupiter Island coast from St. Lucie Inlet south to Jupiter Inlet. The calibrated models then were applied to simulate a range of shore protection alternatives, including various beach nourishment design configurations, and combinations of coastal structures to hold the sand on the beaches. Beach nourishment projects were constructed in 1996 and in 2003 according to the updated design. Beach profile monitoring data were collected and analyzed, and demonstrated that the new project design provides improved protection, including hurricane flood damage control. Substantial costs were saved by nourishing longer stretches of the shoreline, over-nourishing at historical hot-spots of beach erosion, and insisting on a course grain size. The more robust design also proved effective at minimizing hurricane damage. The design also qualified the project for damage claims from FEMA in response to storm-induced erosion.

Winthrop Shores Restoration Program - Coastal Engineer/Project Manager
Served as WHG project manager for this public lands improvement project, responsible for the analysis of coastal processes and design of shore protection measures, primarily beach replenishment. Other considerations of the project included roadway and public access, and improvement of a marsh wetland area. The project required a careful combination of technical expertise with practical public considerations.

Offshore Disposal Site Selection, Salisbury, MA, Massachusetts Department of Environmental Management - Coastal Engineer/Project Manager
Collected bathymetry and side scan sonar data. Conducted wave and sediment transport modeling and analyses to select an appropriate nearshore site for dredged material disposal. Data collected under challenging winter marine environmental conditions so that schedules could be maintained. Permits were successfully obtained for the project.

Key Projects (continued)

Evaluation of Dissolved Oxygen Processes and Regulatory Compliance at Big Bend Station, Tampa Electric Company - Project Manager
Provided strategic environmental management advice and technical support services for permit applications and consent order implementation. A variety of compliance vehicles were evaluated, including consistency with governing water quality standards, mixing zone definition, and a variance from otherwise applicable standards. Technical aspects included data collection (DO, temperature, currents, tides, bathymetry, sediments), and numerical/analytical modeling of 3-D circulation, water quality, and particle transport. Results provided the technical basis to negotiate with the Florida DEP regarding appropriate water quality monitoring and compliance standards.

Sediment Transport Study - Evaluation of Causeway on Coastal Processes, Westport, Massachusetts, Massachusetts Department of Environmental Management – Coastal Engineer/Modeler
Task leader for comprehensive wave and sediment transport modeling investigation. Completed detailed wave refraction, diffraction and breaking model (REF/DIF) that simulated nearshore wave transformations around a long causeway/island system. Integrated the wave modeling results into a detailed longshore sediment transport model that included sandy and cobble beaches, as well as rocky intertidal shoreline. Completed cross-shore beach profile modeling for a range of average and storm conditions. Calibrated and verified model results with measurements of bathymetry, beach profiles, and historical analysis of shoreline change data. Evaluated a range of shore protection alternatives as the basis for a beach management plan.

Publications and Presentations

Ivanov, L.I., B.A. Magnell, R.A. Catalano, R.P. Hamilton, and L. Fagan. 2007. "Met-Ocean Measurements and Seasonal Variability of the Wind Profile in Nantucket Sound." American Wind Energy Association, Conference Presentation and Proceedings

Hamilton, R.P. Jr., Z. Willis, R. Lunde, R. Rayner, B. Magnell, and H. Kite-Powell. 2007. "Ocean Observing Systems Overview and Business Opportunities." OceanTech Expo. Panel Moderator.

Hamilton, R.P. Jr. 2006. "Using Real-Time Environmental Data to Manage Maritime Emergencies." Ocean Innovation Conference. Invited Speaker.

Hamilton, R.P. Jr., B. Caufield, L. Ivanov, and C. Johnsen. 2006. "Beach Monitoring and Beach Nourishment Design at Siasconset, MA." National Conference on Beach Preservation Technology, Florida Shore and Beach Preservation Conference Presentation.

Hamilton, R.P. Jr., C. Bryant, J. Spurgeon, and M. Utku. 2000. "Beach Replenishment Performance at Jupiter Island, FL." Florida Shore and Beach Preservation Conference Presentation.

Ramsey, J.S. and R.P. Hamilton Jr. 1997. "Analysis of Sediment Transport Patterns and Shore Protection Alternatives at Westport, MA." National Conference on Beach Preservation Technology, Florida Shore and Beach Association, Conference Proceedings.

Publications and Presentations (continued)

Hamilton, R.P. Jr., J.S. Ramsey, and D.G. Aubrey. 1996. "Numerical Predictions of Erosional Hot-Spots and Optimization of Shore Protection Alternatives at Jupiter Island, FL." National Conference on Beach Preservation Technology, Florida Shore and Beach Association, Conference Proceedings.

Ramsey, J.S., R.P. Hamilton, Jr. and D.G. Aubrey. 1995. "Nested Three-Dimensional Hydrodynamic Modeling of the Delaware Estuary." 4th International Conference on Estuarine and Coastal Modeling, ASCE Waterway, Port Coastal and Ocean Division.

Hamilton, R.P. Jr., R.A. Dalrymple, J. Oltman-Shay, and U. Petrevu. 1994. "Wave Group Forcing of Low Frequency Surf Zone Motion." American Geophysical Union, Fall Meeting, San Francisco, CA.

Hamilton, R.P. Jr. and R.A. Dalrymple. 1994. "Estimating Two-Dimensional Wave Spectra: Application of the Maximum Likelihood and Maximum Entropy Methods, CACR." University of Delaware, Newark, DE.

BIOGRAPHICAL SKETCH for Michael S. Owens

Advanced Senior Research Assistant, Horn Point Laboratory Phone: 410-221-8465
University of Maryland Center for Environmental Science FAX: 410-221-8490
PO Box 775, Cambridge, MD 21613 USA Email:owens@hpl.umces.edu

Education:

University of Maryland College Park
Completed course work toward Master of Science in Environmental Chemistry
Projected graduation June 2008

Salisbury State University, B.S., Chemistry, 1988
Biology Minor
Graduated Magna Cum Laude

Professional Experience:

2000-Pres.	Advanced Senior Research Assistant, Horn Point Laboratory University of Maryland
1995-2000	Senior Research Assistant, Horn Point Laboratory University of Maryland
1988-1995	Research Assistant, Horn Point Laboratory University of Maryland

Publications:

Owens, M. and J.C. Cornwell, 1995. Sedimentary evidence for decreased heavy metal inputs to the Chesapeake Bay. Ambio 24: 25-27.

Cornwell, J.C., D.J. Conley, M. Owens and J.C. Stevenson. 1996. A sediment chronology of Chesapeake Bay eutrophication. Estuaries, 19:488-499.

Newell, R.I.E, J.C.Cornwell and M.S.Owens. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. Limnology and Oceanography 47: 1367-1379.

Porter, E.T., M.S. Owens and J.C. Cornwell. Effect of manipulation on the biogeochemistry of experimental marine systems. Journal of Coastal Research 22:1539-1551.

Boynton, W.R., J. D. Hagy, J. C. Cornwell, W. M. Kemp, S. M. Greene, M. S. Owens, J. E. Baker and R. K. Larsen. 2008. Nutrient Budgets and Management Actions in the Patuxent River Estuary, Maryland. Estuaries and Coasts 31:623–651.

Qualifications Summary

- Wetland and coastal ecology
- Salt and brackish marsh ecosystem structure and functions: fish nursery value, nutrient cycling, hydrology, productivity, eutrophication and marsh restoration
- Pollution effects and environmental risk
- Groundwater influences on water bodies
- Ground water contamination with nutrients
- Wastewater treatment by natural and artificial wetlands
- Petroleum pollution and hydrocarbon biogeochemistry
- Nutrient dynamics
- Marine birds and over-ocean migration of land birds
- Coastal marine ecology including dune, beach, and submerged aquatic vegetation (e.g., eel grass) ecology
- Physiological ecology of fishes
- Aquaculture and fisheries

JOHN M. TEAL, PH.D.

Partner

Professional Affliations

Teal Partners, 567 New Bedford Road, Rochester, MA 02770
Email: teal.john@comcast.net
Professional Wetland Scientist 0001198

Scientist Emeritus, Woods Hole Oceanographic Institution

Fields of Expertise

Biology

Ecology

Biogeochemistry

Higher Education

Harvard University BA 1951; MA 1952; Ph.D. 1955

Employment History

Woods Hole Oceanographic Institution, Research Associate, 1961-1963; Assistant Scientist, 1963-1965; Associate Scientist, 1965-1971, Senior Scientist, 1971- 1994; Chair, Biology Dept., 1982-1985; Seward Johnson Chair in Biology, 1986-1989

Institute of Oceanography, Dalhousie University, Assistant Professor, 1959-1961

University of Georgia Marine Institute, Assistant Professor, 1955-1959.

Key Projects

Estuarine Enhancement Program, Public Service Enterprise Group of NJ, Delaware Bay – Senior Ecologist
Provide advice on wetland and coastal ecology, adaptive management for a salt marsh restoration project of over 10,000 acres, 1993-present

Bronx Zoo, Wildlife Conservation Society, NY Consulting ecologist
Provided expertise for using wetlands for treatment of runoff at the Bronx Zoo, 2000-2004.

Pine Street Canal Superfund Site, Burlington VT – Consulting ecologist and biogeochemist
Provided expertise on wetland ecology, and fate & transport of hydrocarbons working with USEPA, VT DEP, USF&W, and Green Mountain Power (PRP) at a freshwater wetland superfund site; 1990's.

Scarborough Marsh Restoration – Consulting ecologist
Provided expertise for the restoration of upper regions of Scarborough marsh where tidal restrictions had led to marsh deterioration. Maine Department of Inland Fisheries and Wildlife, 2001- 2004.

Restoration of Fox River, Wisconsin, Superfund Site – Consulting ecologist
Provided expertise on cleanup and restoration of PCB contaminated Fox River for PRP's. 1990's to 2003.

Envisioning the Future of the Gulf Coast – Coastal Ecologist
Participant in meeting of experts from round the world making recommendations to state and federal governments for future of coastal Louisiana and Mississippi, 2006.

NRC Committee "Drawing Louisiana's New Map" – Coastal Ecologist
Participated in NRC committee meetings and composition of report addressing land loss in coastal Louisiana. 2002-2005.

Science Board of the Louisiana Coastal Area (LCA) Ecosystem Restoration Program – Coastal Ecologist
Participating in meeting of experts working with USGS to advise Army Corps on restoration of coastal Louisiana, on-going.

Natural Attenuation of Nitrogen in Wetland and Waterbodies - Principal
Contributed knowledge, experience and technical review of wetland literature for MA DEP, 2006- 07.

South San Francisco Bay Salt Pond Restoration National Science Panel – Marsh Ecologist
Participated in board of international scientists advising USF&W, Cal Fish and Game, and Cal Coastal Conservancy on the restoration of the salt ponds in South San Francisco Bay. 2003-2007.

NRC Committee on Science and Policy for the Coastal Ocean – Marine Ecologist

Participated in NRC committee meetings and composition of reports for improving interactions between science and policy in dealing with coastal oceans. 1990's

Jamaica Bay, NY – Expert Panel member
Restoration of Jamaica Bay salt marshes for National Park Service, 2002 – 2005.

NRC Committee on Use of Dispersants on Oil Spills – Biogeochemist
Participated in NRC committee meetings and composition of reports on use of dispersants for treating oil spills in marine waters, 1988.

Scientific Advisory Committee, Outer Continental Shelf program of U.S. Mineral Management Service – Marine Ecologist and Biogeochemist
Participated in meeting advising MMS on suitable scientific studies for elucidating effects of oil production activities on outer continental shelf, 1979-1981, 1984-1990, Chair 1987-1989

Publications

Author and or co-author of:

- More than 160 peer-reviewed scientific papers
- Ten articles in popular publications
- Four encyclopedia articles
- Six children's articles on oceanography
- Four trade books:

  Portrait of an Island, Athenaeum and Univ. GA. Press

  Life and Death of a Salt Marsh, Atlantic-Little Brown and Ballantine

  Pigeons and People, Atlantic-Little Brown

  The Sargasso Sea, Atlantic-Little Brown

Complete bibliography available on request

Qualifications Summary

- More than 25 years academic and consulting experience in hydrodynamics, sediment transport, and coastal processes
- Expertise in design and interpretation of field measurements for understanding coastal systems and evaluating and improving models
- Strong written and verbal communication skills

JOHN H. TROWBRIDGE, Sc.D.

Senior Coastal Scientist

Fields of Expertise

Research on coastal hydrodynamics and sediment transport. Design of oceanographic measurement programs for evaluation and improvement of models of coastal waves, currents, and sediment transport. Interpretation of measurements and model simulations. Development of simplified conceptual and analytical approaches to provide preliminary estimates, facilitate feasibility studies, and design complex measurement programs and model implementations. Development of analysis methods for extraction of robust statistics from measurements.

Employment

1987-Present Woods Hole Oceanographic Institution –
Assistant, Associate and Senior Scientist
1983-1987 University of Delaware, Department of Civil
Engineering – Assistant Professor
1977-1983 Massachusetts Institute of Technology (MIT),
Department of Civil Engineering –
Graduate
Research and Teaching Assistant
1979-1980 Woods Hole Oceanographic Institution,
Department of Geology and Geophysics –
Research Assistant

Higher Education

Sc.D., Oceanographic Engineering – Massachusetts
Institute of Technology and Woods Hole
Oceanographic Institution (1983)
S.M., Civil Engineering-Massachusetts Institute of Technology
(1979)
B.S., Civil Engineering-University of Washington (1977)

Key Projects

Measurement and analysis of turbulence statistics and characteristics of suspended sediments during the Coastal Mixing & Optics experiment on the New England shelf.

Measurement and interpretation of turbulent stresses in the surf zone during the SandyDuck experiment in Duck, North Carolina.

Development of a theoretical model for the development and maintenance of shore-oblique sand ridges on the east coast of the United States.

Development of measurement and analysis methods for determining turbulence statistics in the presence of energetic waves.

Development of analytical modeling approaches for prediction of the fate and transport of a spill of tetra-ethyl lead off Venezuela.

Development of a code for computer simulation of coastal wave-driver currents, sediment transport, and patterns of erosion and accretion.

Publications (A Selection of 10)

Trowbridge, J. H., W. R. Geyer, M. M. Bowen, and A. J. Williams, 1999. Near-bottom turbulence measurements in a partially mixed estuary: turbulent energy balance, velocity structure, and along-channel momentum balance. Journal of Physical Oceanography, 29, 3056-3072.

Shaw, W. J., J. H Trowbridge and A. J. Williams, 2001. Budgets of turbulent kinetic energy and scalar variance in the continental shelf bottom boundary layer. Journal of Geophysical Research, 106, 9551-9564.

Trowbridge, J. H. and S. Elgar, 2001. Turbulence measurements in the surf zone. Journal of Physical Oceanography, 31, 2403-2417.

Trowbridge, J. H. and S. Elgar, 2003. Spatial scales of stress-carrying nearshore turbulence. Journal of Physical Oceanography, 33, 1122-1128.

Fries, S. J. and J. H. Trowbridge, 2003. Flume observations of enhanced fine particle deposition to permeable sediment beds. Limnology and Oceanography, 48, 802-812.

Trowbridge, J. H. and Y. Agrawal, 2004. A two-spot sensor for measurement of dissipation by means of laser-Doppler velocimetry. Journal of Atmospheric and Oceanic Technology, 21, 1104-1111.

Feddersen, F. and J. H. Trowbridge, 2005. The effect of wave breaking on surfzone turbulence and alongshore currents: a modeling study. Journal of Physical Oceanography, 35, 2187-2203.

Feddersen, F., J. H. Trowbridge and A. J. Williams, 2007. Vertical structure of dissipation in the nearshore. Journal of Physical Oceanography, 37, 1764-1776.

Gerbi, G. P., J. H. Trowbridge, J. B. Edson, A. J. Plueddemann, E. A. Terray and J. J. Fredericks, 2008. Measurements of momentum and heat transfer across the air-sea interface. Journal of Physical Oceanography, 38, 1054-1072.

Publications (continued)

Gerbi, G. P., J. H. Trowbridge, E. A. Terray, A. J. Plueddemann and T. Kukulka, 2009. Observations of turbulence in the ocean surface boundary layer: energetics and diffusivity. Journal of Physical Oceanography, in press.

Lee L. Weishar, Ph.D., M.S., B.S., P.W.S.

Senior Scientist/Coastal Engineer

Qualifications Summary

- More than 30 years experience in the fields of oceanography, coastal engineering, sediment transport, and nearshore processes
- Strong written and verbal skills. Excels in presenting complex information and concepts to non-technical audiences
- Specializes in developing and implementing complex data collection efforts, which require solving detailed and often-diverse logistic problems such as marsh restoration and sediment transport projects
- Excellent project management skills. Excels at managing large projects with multi-discipline investigators
- Specializes in collection, analysis/interpretation, and integration of field data into project design. This includes the design of field studies/programs to measure waves, currents, water levels, and suspended sediment transport at tidal inlets, nearshore, and in estuaries in MA, DE, NC, VA, FL, AL, NY, and Caribbean
- Managed projects which designed and completed investigations to determine the optimum offshore borrow site locations, which maximize grain size, and quantities of borrow material while minimizing project environmental impacts
- Managed and completed longshore sediment transport and examined shoreline response at numerous tidal inlets along the eastern coast of the U.S. Designed and completed large-scale field investigations to examine wave interaction on ebb and flood tidal shoals
- Managed and completed numerical and physical modeling studies for the design of shore protection facilities. Numerical model simulations, water elevations during storms, and shoaling effects of nearshore bathymetry were integrated to determine shore protection design criteria. The model and field data including the shoaling affects of nearshore bathymetry were integrated to develop shore protection design criteria. Cost optimization of the shore protection design resulted in significant cost savings to this phase of the project

Professional Affiliations

Sigma Xi
American Association for the Advancement of Science
American Geophysical Union
Society of Economic Paleontologists and Mineralogists
American Society of Engineers
Society of Wetland Scientist
Estuarine Research Federation
ASCE Wetlands & Sediment Management Committee
Chairman of ASCE Wetlands Engineering Guidelines Subcommittee
Certified as Professional Wetlands Scientist

Fields of Expertise

Scientific consulting in marsh ecology and the tidal hydraulics of wetlands. Salt marsh restoration as mitigation for power plant intake impacts (e.g., 316(b) restoration measures), and NRDA. Engineering consulting on the effects of tidal inlet and shore protection structures, longshore sediment transport, shoreline response, marsh hydrology and restoration. Conducted numerical model studies of channel stability, shoaling, and tidal flushing at tidal inlets. Designed field studies and performed numerical and physical modeling of waves, currents, water levels, and suspended sediment transport at tidal inlets. Field collection of oceanographic and geotechnical data. Designed and supervised several large beach nourishment projects requiring dune and beach design, construction oversight, and field monitoring.

Higher Education

Ph.D., Physical Oceanography-Purdue University (1982)
M.S., Geophysical Oceanography-Virginia Institute of Marine Science and College of William and Mary (1976)
B.S., Mechanical Engineering-Michigan State Univ. (1973)

Employment History

1989-Present	Woods Hole Group, Inc.
1983-1989	U.S. Army Corps of Engineers
1973-1982	Purdue University (Research Coordinator, Research Fellow, Research Instructor)
1972-1973	F.W. Amend Company
1969-1972	Michigan State University (Research Assistant)

Key Projects

Evaluation of Wetland Remediation Techniques in an Arid Environment – Project Manager
Dr. Weishar was the project manager for this large remediation project and led the remediation efforts within the Kingdom of Saudi Arabia. This field study extends along the 750 Km of the Kingdom of Saudi Arabia Arabian Gulf shore from the Kuwait border to the industrial city of Al-Jubail. This complex shoreline is composed of an interlaced series of tide flats, beaches, embayments, lagoons, and salt marshes. Much of these ecosystems remain severely impacted from the oil spill. The year-long remediation demonstration project tested remediation technologies at the field scale for these arid ecosystems. The project demonstrated that large-scale marsh restoration was feasible through construction of a marsh remediation project. The project also demonstrated restoration of the other affected biotypes was feasible using indigenous equipment.

Restoration of a Restricted Tidal Marsh: South Cape Beach, MA – Project Manager
South Cape Beach is a high marsh that has been isolated from the tidal source waters by culverts and artificial ditches. The installation of the ditches has muted the tidal range on the marsh plain and as a result *Phragmites* has begun to invade the marsh from the upland fringes. Dr. Weishar led the numerical modeling of the effort that formed the foundation for deriving marsh restoration designs that will help restore tidal circulation and prevent *Phragmites* encroachment onto the marsh plain.

Restoration of a Restricted Tidal Marsh: Nonquitt, MA – Project Manager
Dr. Weishar was the project manager for this project and worked with the Woods Hole group team to develop restoration design alternatives. Nonquitt marsh has been isolated from tidal source waters of Buzzards Bay from approximately 40 years. The isolated pipe leading to the Bay mutes the tidal range from several feet to several inches. As a result the marsh sediments are highly saturated and a fresh water upland community has developed around the marsh perimeter. The preferred restoration alternative incorporated establishing a new tidal inlet in its historical footprint. Restoration design alternatives addressed large-scale marsh plain erosion, impacts to the adjacent wetlands, and increased flooding potential.

Monitoring Marsh Restoration in Delaware River Estuary, Public Service Electric and Gas Company –Project Manager
Dr. Weishar is the adaptive management evaluation team leader responsible for an ongoing project evaluating restoration plans, developing and implementing corrective mitigation strategies, required to insure the successful restoration of 20,000 acres of salt marsh in the

Key Projects (continued)

Delaware River Estuary. This project requires evaluation and dissemination of complex data to the public regulatory community and scientists.

Marsh Restoration and Estuary Enhancement in Southern New Jersey, Hancock's Bridge, NJ, Public Service Electric and Gas Company - Oceanographer/Project Manager
As part of permit-required mitigation for nuclear facility with a once-through cooling system, Dr. Weishar reviewed feasibility of a program to restore 10,000 acres of degraded salt marshes through on-site visits and analytical analyses. Performed critical investigation using hydraulic modeling, resource area evaluations, design review of marsh channel and tidal inlet design, and investigation and quantification of restoration effects on ground water, septic systems, and private drinking wells. The success of this project required close interaction between Woods Hole Group, Inc., NJ State environmental agencies, NJ Attorney Generals Office, National Fish and Wildlife, US Army Corps of Engineers, National Marine Fisheries, and concerned citizens.

Beach Nourishment Design for Spectacle Island Massachusetts, Boston Harbor, MA, Massachusetts Water Resources Authority - Oceanographer/Project Manager
Completed a detailed beach nourishment design for the shorelines of Spectacle Island. Used refraction/diffraction model, REF/DIF1, to predict transformation of waves in areas where the bathymetry was irregular and diffraction was important. Used wave height results as input to longshore and cross-shore sediment transport models. These models were employed to simulate the performance of several different beach fill designs.

Design and Environmental Permitting for Pier and Dock Reconstruction at US Coast Guard Facility, Provincetown, MA, United States Coast Guard - Oceanographer/Project Manager
Performed coastal engineering analysis for the redesign and rehabilitation of a pier and dock facility and wave barrier for the US Coast Guard Station. Calculated design wave criteria for average and storm-induced conditions.

Beach Nourishment Design and Monitoring for the Southern Shore of Cape Cod, Cape Cod, MA, Great Island, Long Beach, and Dead Neck Homeowners Associations - Oceanographer/Project Manager
Performed shoreline change studies to evaluate rate of erosion and sediment loss for three different sites. Designed and participated in collection of high-resolution bathymetry, vibra cores, beach profiles, and sediment grain size data at each site. Developed and implemented beach nourishment plans for each site. Performed on-site topographic and bathymetric surveying before and after nourishment projects.

Environmental Impact Report (EIR) for Shore Protection Structures Between Aunt Lydia's Cove and Morris Island, Chatham, MA, Town of Chatham - Oceanographer/Project Manager
Prepared EIR to address impacts of revetments and other shore protection structures built to protect the Chatham mainland following the formation of the new inlet through the Nauset barrier, January 1987. Analyzed geologic history of the area, and studied evolution of Nauset barrier and tidal inlet system using historical maps, charts, and aerial photographs. Used a

Key Projects (continued)

combination of existing studies and numerical analysis to quantify wave, tidal, storm surge and sediment transport processes. Prepared a plan of short-term action, long-term action, and short-term optional management alternatives for the Town of Chatham, property owners, and permitting agencies.

Numerical Model Analysis of Wave Climatology and Storm Surge for Seawall Design, Deer Island, MA, Massachusetts Water Resources Authority via Metcalf and Eddy, Inc. - Oceanography/Project Manager
Conducted numerical and physical model analyses of wave climatology, storm water levels, and wave run-up so that an effective and cost efficient shore protection plan could be developed for the island. Results from models runs were used to predict nearshore wave heights and water levels for 5-, 10-, 25-, 50-, and 100-year storm events and to optimize seawall design specifications. Two-dimensional physical modeling of the seawall design was performed using a test facility to evaluate the proposed structural design.

Bathymetric and Side Scan Surveys of Fort Point Channel, Boston Harbor, MA, BSC Group, Oceanographer/Project Manager
Performed bathymetric and side scan sonar survey for part of the Central Artery/Tunnel Project. Bathymetry was plotted on the area basemap to ensure water depths were adequate for floating construction barges into the channel. Side scan data were reviewed for possible bottom debris or hazards. During the survey, field operations were restricted due to bridges crossing the channel, and barge and boat activity within the channel. Despite the navigational problems, full coverage of the channel was obtained.

Directional Wave and Current Meter Installation and Data Analysis, Townsend and Absecon Inlets, NJ, Offshore & Coastal Technologies, Inc. - Oceanographer/Project Manager
Collected wave and current data at the entrances to and nearshore region downdrift of the Townsend and Absecon inlets. Analyzed data for directional spectral parameters including significant wave height, wave direction, mean water depth, and the variance of water surface elevation.

Particle Tracking Analysis at the Salem Nuclear Generating Station, Hancock's Bridge, NJ, Public Service Electric and Gas Company - Oceanographer/Project Manager
Evaluated near- and far-field impacts to a nuclear generating station's intake basin using a particle tracking numerical model. Identified portions of the estuary providing potential detritus sources to the intake basin and evaluated the migration of detritus cleaned from the intake screens and dumped back into the estuary. Results of the particle tracking were collected in an effort to design a program to reduce and eliminate the detritus problem.

Bathymetry, Geophysical Survey, and Wave Refraction Analysis for Sand Borrow Site Analysis, Siasconset, MA, Town of Nantucket - Oceanographer/Project Manager
Completed a reconnaissance survey and analysis of two offshore sand borrow sites for a proposed beach nourishment project. Collected regional bathymetry, coring, beach sediment sampling, side-scan sonar, sub-bottom profiling, and magnetometer surveys. Modeled the wave

Key Projects (continued)

climatology using collected data. Used model results to calculate sediment transport potentials and gradients in sediment transport to determine dredging from the proposed borrow sites.

Sub-bottom Investigations and Detrital Flux Analysis at the Salem and Hope Creek Nuclear Power Plant, Hancock's Bridge, NJ, Public Service Electric and Gas Company - Oceanographer/Project Manager
Designed a phased field data collection program to evaluate potential causes of detrital loading at the Salem and Hope Creek Nuclear Power Plant after detrital loading had forced the operating plant to shut down. Collected bathymetric data, conducted a sub-bottom survey, and monitored physical conditions: temperature, conductivity and current profile at the power plant. Conducted additional surveys to the north and south of the power plant to identify potential sources of the detritus.

Data Collection and Analysis of Tidal Current Characteristics at St. Lucie Inlet and Adjacent Waterways, Martin County, FL, Coastal Technologies Corporation - Oceanographer/Project Manager
Designed a survey to obtained high-resolution measurements of tidal current velocities and to map temporal variations in the spatial structure of flow through the Inlet and waterway cross sections. Calibrated a numerical model of Inlet dynamics using survey results. Quantified the effect of Inlet geometry on the spatial structure of tidal flow and explained sediment accretion/scour characteristics within the Inlet.

Publications and Presentations: 100

Presentations	**41**
Publications	**59**