

Scenario-Based Forecasts in Support of Regional Coastal Management: Concepts of Operation

Prepared for

NOAA/NOS National Centers for Coastal Ocean Science

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EXECUTIVE SUMMARY

Background

The use of computational models to provide forecasts and scenarios of how aquatic ecosystems may respond to changes in human and natural drivers has a long history and has been a central element of environmental management. These computer models may be used to diagnose environmental problems (i.e., assess what happened), examine causes and precursor conditions (i.e., why it happened) of events that have taken place, or forecast outcomes and future events (i.e., what will happen). In a management and operational context, decision makers need to project the ecosystem consequences of different potential climatic or environmental conditions, management scenarios, and/or population trends. These scenario-type forecasts are critical for enabling coastal decision-making to move from a reactive to a proactive mode.

For scenario-type ecosystem-based forecasts, there is often no clear pathway for transitioning the models to “operational” application following research and development, nor objective parameters for judging when a model becomes sufficient for its intended application. This has slowed the development and availability of these forecasts for critical coastal, ocean, and Great Lakes management decisions and policies. Nevertheless, modeling and forecasting of ecological processes is a priority with many state agencies and regional governance entities as a critical tool to achieve regional ecosystem-based management goals.

NOAA’s Center for Sponsored Coastal Ocean Research (CSCOR) has been a leader in the development of marine, coastal, and Great Lakes ecological forecasts. The development of ecological forecasts and predictive capacity has been the driving force behind CSCOR’s ecosystem research and that of its predecessor, the Coastal Ocean Program, for over 20 years. Recently, NOAA developed an Ecological Forecasting Roadmap. The vision for this Roadmap is for NOAA to “deliver accurate, relevant, timely, and reliable ecological forecast products and services to directly fulfill its mandates and roles in protection of life, property, human health and well-being, the environment, and coastal and marine stewardship. Further, these forecast products and services will build on NOAA’s and partners’ investments in scientific understanding of aquatic ecosystem structure, dynamics and functioning; advances in observational, modeling and computational infrastructure; and experience in operational forecasting.”

To facilitate implementing this Roadmap, NOAA provided funding for this project to gather and synthesize information concerning:

- the current and future needs for ecosystem forecast models for coastal and Great Lakes managers,
- the existing use of various ecosystem forecast models to inform natural resource managers,
- the existing procedures being used by various federal, state, academic, private, and non-profit entities to develop the modeling and predictive capabilities required for ecosystem-based management,

- the identification of requirements and procedures to transition research-based models into operational forecast models, and
- the identification roles that NOAA and other Federal partners can play in the development of an infrastructure appropriate to achieve NOAA's Roadmap for ecological forecasting.

Needs Survey

To gather the required information, we conducted a survey to characterize the environmental issues faced by the management community across multiple regions, characterize the current use of models in management, and potentially assess the cost and benefits of using models to make scenario-based forecasts. The survey was sent out to over 100 targeted individuals in July 2013. Responses were gathered from 61 respondents, of whom 40 were self-described as managers and 21 were self-described as technical staff. Respondents came from a broad geographical cross section of the Great Lakes and coastal waters. The survey results indicated that the top three environmental issues were: eutrophication, hypoxia/anoxia, and harmful algal blooms (HABs). Wetlands were also identified as another environmental issue faced by managers. A large number of respondents indicated they already used models to inform environmental decision making with about 75% of the respondents indicating that they used a mix of statistical and process based models. Although a large number of respondents did not know the costs associated with implementation of the management scenarios, about 20% estimated the cost of management implementation was expected to be in excess of \$100 million. Therefore, given the expected costs for some coastal or Great Lakes systems, managers may consider models to be important in exploring the potential benefits of different management alternatives and in selecting the most cost effective solution.

Workshop

We conducted a day and a half workshop for coastal and Great Lakes managers and modelers to:

- discuss their experience with ecosystem modeling for informing policy and management decisions and to describe the extent to which these models were accepted by invested stakeholders,
- discuss what is meant by "operational" for ecosystem models,
- gain insights from existing operational modeling centers and systems,
- discuss the resources required to develop and apply these ecosystem models, including monitoring data and field studies required to support model calibration,
- assess protocols for model-data requirements, model refinements, and model skill assessment,
- consider project funding required to bring these models into an operational mode, and
- discuss the role that NOAA and other agencies might play in supporting these models and applying them in ecosystem-based management.

The key findings derived from the workshop participants are summarized in the following three areas:

- (1) Managers and decision makers are looking to understand how various drivers affect a system and how should they respond to or prevent adverse changes. They also want models that are understandable. That is, that the model framework, its assumptions, limitations, and outputs can be quickly assimilated by key decision makers and that can be presented to their non-

technical stakeholders and the general public in a simple and straightforward manner. Managers also want models that define or capture uncertainty about their forecasts or predictions. If a model can define its limits of uncertainty, then managers may be better informed of the potential outcomes of various management actions and lay out a plan for adaptive management, which in the long-term achieves the desired management goals in the most cost-effective way.

(2) Workshop participants clearly recognized that, in general, “operational forecast” is a “weather” phrase and that operational scenario-based ecosystems forecast models are fundamentally different. However, despite those differences it was agreed that to be operational, a model must:

- meet decision makers or management needs and be agreed to as salient and credible by all affected stakeholders,
- provide accurate and reliable results in the context of its use,
- be kept operational and available by maintaining and updating when new data and knowledge are available,
- have a demonstrated record of skill assessment, and
- be “certified”/peer-reviewed and well documented.

(3) Workshop participants discussed a number of ways in which NOAA and other Federal agencies could contribute to the development of operational aquatic system models. These included:

- build upon the existing NOAA National Centers for Coastal Ocean Science (NCCOS) research programs that are conducting research programs for hypoxia, pathogens, HABs and climate impacts
- use information available from NOAA National Ocean Service (NOS) and National Weather Service (NWS) operational products such as the NOS Operational Forecast System regional hydrodynamic models, the NOS Integrated Ocean Observing System (IOOS) for access to regional observational and modeling capabilities, the NWS Climate Forecast System that includes both atmospheric and ocean forecast models, and the NWS Regional River Forecasting Centers that can provide information on precipitation, river observations and water level forecasts
- Consider working with the USEPA to develop a national modeling center of excellence
- Consider developing a national modeling center to provide support for model review, certification, training, and support for regional modeling centers that develop and apply the models on a site-specific operational basis .

Recommendations

In developing recommendations for implementing the Ecological Forecasting Roadmap, we considered:

- the needs for short-term and scenario-based operational aquatic ecosystem modeling systems based on the survey
- information gathered and discussions held at the workshop
- existing resources and infrastructure within NOAA and other potential Federal partners
- the Project Team’s experience in hydrodynamic, water quality and ecosystem modeling

- existing resources and infrastructure, which exists within NOAA's current system of National Weather Service's and National Ocean Service's operational centers

A number of different configurations were considered and the following is the recommended structure and staffing:

- a National Laboratory, and
- four to five Regional Facilities.

The **National Laboratory** would be the central facility that coordinates the NOAA effort in operational aquatic ecosystem modeling with a particular emphasis on water quality modeling. It is anticipated that there will be a need for some hydrodynamic modeling expertise as well, but this could be facilitated with support from hydrodynamic modelers already staffing the NOS Operational Forecast System regional models. The National Laboratory would be the home of the in-house models and modelers. It would be the location where some research and development would take place, and where interactions with academic researchers would occur. New models, either developed by NOAA personnel or obtained from outside sources (academics institutions or consulting firms) would be checked, tested, validated, and brought on-line. The laboratory would maintain a series of test beds, similar to the NOAA IOOS Coastal and Ocean Modeling Testbed (COMT) program, that would be used to evaluate the performance of new models relative to those previously available. The National Laboratory would also provide documentation for the models and training in their use. It would also provide the institutional memory that is critical to maintaining a viable technology.

The **Regional Facilities** would provide links between the National Laboratory and the local users and developers. Personnel employed at these facilities would interact directly with the clients that are charged with applying the models for management needs of specific aquatic systems within the region. The Regional Facility personnel would suggest the appropriate model type and level of complexity that match the problem being addressed and the available data. They would provide direct assistance and, if necessary, training during the model's operational application, and they would also recommend any monitoring and research programs necessary to support the model's skill-assessment. Finally, they would implement operational application, including peer-review of the model's calibration/ and of results scenario-based applications at appropriate points in the modeling process. Since these facilities would be regional, they would have a more intimate connection and experience with the problems at issue and the habitat being investigated (e.g. marine or freshwater, coastal or inland). In cases where ongoing, operational modeling is required as part of an "adaptive management" process, the Regional Facilities personnel would be responsible for developing and implementing that process.

SECTION 1. BACKGROUND/INTRODUCTION

The use of computational models to provide simulated forecasts and scenarios of how aquatic ecosystems may respond to changes in human and natural drivers has a long history and has been a central element of environmental management. While concepts have become more sophisticated and expansive in recent decades (e.g., CENR, 2001; Clark et al., 2001; Peterson et al., 2003; Valette-Silver and Scavia; 2003; Sandifer et al. 2012), the use of numerical models to forecast ecosystem responses date back almost 100 years when Streeter and Phelps (1925) developed a model to estimate the amount of organic matter that could be discharged into rivers and protect oxygen levels. In the intervening years, hundreds of models have been applied to establish waste load allocations, TMDLs, habitat conditions, fishery stocking and harvesting, and many other applications (e.g., Bierman et al., 1984; Thomann, 1988; Lorenzen, 1995; Reckow et al. 2001; Chapra, 2003; Post et al., 2003; USEPA, 2009). The diversity of models with different structures, variables, and simulation skills used for these simulations is vast, as is the range of experience of individuals conducting these modeling analyses. While many of these model applications involve or establish management strategies and tactics that represent tens and hundreds of million dollars, there are few established protocols for identifying, evaluating, and certifying models as appropriate for “operations”. In the USA, NOAA, EPA and other federal agencies have demonstrated interest in establishing such protocols (NOAA, 2001, 2003, 2010; USEPA 1980, 2009; USACE, 2005, 2011; Levin et al, 2011, 2013).

Here, we define “operational” as:

Any site-specific model is considered to be operational if it has been sufficiently well-calibrated to observations (preferably both state variables and process rates) and deemed necessary and useful by environmental managers and decision-makers. Such models must meet certain evaluation criteria, including but not limited to: (1) application for conditions outside the calibration regime; (2) incorporation into a management plan for ongoing refinement and application; and (3) documented such that simulations can be replicated.

While this definition includes models that can be owned and operated by agencies, it also includes those that are developed and applied by academics, NGOs, and consultants. What is critical is the identification and application of criteria required to establish the model’s credentials as framed above, and outlined in the following sections.

While there are several definitions for ecological forecasting in the literature, NOAA currently defines ecological forecasting as follows.

“Ecological forecasts predict likely changes in ecosystems and ecosystem components in response to environmental drivers (e.g., climate variability, extreme events and hazards, pollution, habitat change) and resulting impacts to people, economies and communities that depend on coastal ecosystem services. Ecological forecasts provide early warnings of the possible effects of ecosystem changes on coastal systems and on human health and well-being with sufficient lead time to allow corrective actions to be taken or mitigation strategies to be developed.”

It is also important to make the distinction between scenario-based versus forecast-based models as follows.

- Forecasts are predictions of the impacts of known or predicted driving forces. For example, forecasting the time and location of landfall of a harmful algal bloom based on movement of an observed bloom, or forecasting the extent of hypoxia based on observed nutrient loads. That is, “given known conditions A, this operational model predicts responses B”.
- Scenarios, on the other hand, provide estimates of how a system might respond to potential management or natural (i.e., climate) changes in the system drivers. For example, developing a response curve that relates changes in phytoplankton biomass or bottom water dissolved oxygen to different potential nutrient loading. That is, the scenario simulation model is used to explore the relationships between management options A and target environmental endpoints B.

While the two types of modeling efforts (scenarios and forecasts) are related, their scale, scope, and applications – and therefore their requirements to be considered “operational” -- can differ considerably. An appropriate analogy would be the different operational requirements between weather or hurricane forecasts that are driven from known conditions, including real-time data acquisition and data assimilation, that are used for relatively short periods, versus climate change scenarios that are explorations of how the long-term climate might shift under different scenarios for population growth and greenhouse gas emissions.

NOAA is uniquely positioned to provide regular ecological forecasting products and services. The agency is already tasked to forecast weather, climate, tides, fishery stocks, and recovery of protected species and, as such, has a long history of forecasting dating back to the beginning of NOAA’s Ocean and Weather Services. For the past decade, several NOAA offices have been involved in research focusing on ecological processes and developing ecological forecasts for a variety of ecosystem components (e.g., harmful algal blooms, pathogens, hypoxia, sea nettles, sea level rise, and ocean acidification). However, NOAA has lacked a formal program or policy for ecological forecasting. The agency has thus embarked on development of an *Ecological Forecasting Roadmap* for a NOAA-wide ecological forecasting capability that is more effective and parsimonious that calls for an agency-wide approach for coordinating NOAA's existing capabilities and operational centers and service delivery infrastructures.

The purpose of this report is to provide input to implementation of that “Roadmap” by integrating results of (1) a survey with model producers and users who have been developing and applying ecosystem models along all four coasts, with (2) proceedings of a workshop held to share experiences and provide recommendations on potential pathways forward. In particular, our report will consider that an *Operational Aquatic Ecosystem Model* (OAEM) can either be a “forecasting” model, or a “scenario” model, or both.

The report has been divided into the following sections:

- Section 2 provides a summary of the information gathered from a quantitative email survey concerning environmental concerns and issues by regional areas of the country, including: (1) needs for ecosystem-based operational models, (2) use and acceptance of existing models, (3) costs associated with existing models and (4) costs associated with

implementation of management scenarios required to address site specific environmental issues.

- Section 3 provides a summary of the key findings from the 1.5 day workshop conducted as part of this project. A summary of the presentations and discussions held following each presentation are contained in Appendix B.
- Section 4 provides more detail concerning the definition and characteristics of an Operational Aquatic Ecological Model (*OAEM*), the required components of such a model, challenges in developing an *OAEM*, and examples of existing operational modeling centers. This section builds upon the information gathered from the survey and from the workshop, but goes into a greater level of detail and reflects the thoughts of the Project Team and discussions held during the course of the project with the NOAA Project Manager and the Project Steering Committee.
- Section 5 provides recommendations as to how NOAA could support the development and application of *OAEMs*.

SECTION 2.

QUESTIONNAIRE RESULTS

To assess the modeling needs of the environmental management community for scenario-based forecasting tools, we conducted a survey designed with significant input from the project's steering committee. The environmental management community is loosely defined as individuals who influence or make decisions pertaining to protection, restoration and enhancement of coastal environments. The survey was designed to characterize the environmental issues faced by the management community across multiple regions, characterize the current use of models in management, and potentially assess the cost and benefits of using models to make scenario based forecasts.

It was assumed that most federal and state agencies and non-governmental organizations would have personnel with varying degrees of technical expertise in developing, validating, and running models. Therefore, the survey was split into two tracks: (1) the "manager survey track" was assumed to target individuals familiar enough with models to interpret results, budget modeling time and effort, transmit modeling results to stakeholders, and direct more technical staff or consultants regarding modeling goals and (2) the "technical staff survey track" was designed to target those individuals with direct experience developing, implementing and refining models. The survey included approximately 19 questions for managers and 19 questions for technical staff. Both groups were invited to provide additional comments and whether they wanted to be kept up to date with survey results. The list of managers was constructed first by consulting the project team and the project steering committee for their contacts in management in regions across the U.S. This list was subsequently updated to include individuals suggested by respondents and through web-based research into coastal and Great Lakes states environmental management agencies and organizations. The survey was approved by the OMB (for compliance with the federal Paperwork Reduction Act) and NOAA management in July 2013 and was sent to over 100 targeted individuals. Those individuals were encouraged to forward the survey to other individuals who they felt could better assess their organization's modeling needs and infrastructure. Ultimately, there were 61 respondents to the survey, 40 were self-described as managers and 21 were self-described as technical staff.

The spatial distribution of respondents was sufficiently broad to be confident that a wide set of coastal issues (e.g., eutrophication, HAB's, fisheries) would be addressed by the survey (Figure 2-1). As Figure 2-1 demonstrates, the top states for respondents location include the southeast (FL), Gulf Coast (TX), the Great Lakes (MI), the west coast (OR and CA), and the northeast (DE, ME, NY, PA, MD). Subsequent efforts are still ongoing to fill in areas that may be under-sampled. We believe the respondents represent a reasonable cross section of the Great Lakes and coastal managers; every region has been addressed by at least six managers and in most regions more than six.

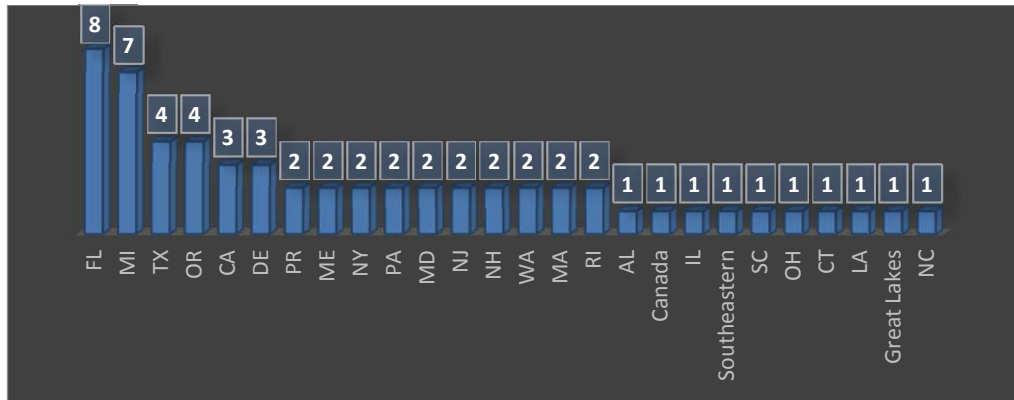


Figure 2-1. Distribution of respondents across states and regions.

Manager track respondents were roughly split between those self-identifying as Regulatory/Policy Managers (60%) and Natural Resource Managers (40%). Respondents were asked to describe their spatial domain of decision making and answers ranged from very general, such as “Tropical estuary and associated ecological communities such as mangrove forest, seagrass beds, etc.” to very specific, “Morro Bay” or “Indian River Lagoon Estuaries – Mosquito Bay, Banana River Lagoon, and Indian River Lagoon”. When asked to rank the issues they were concerned with, respondents indicated that Eutrophication, Hypoxia/Anoxia, and HAB’s were their top three issues (Figure 2-2). However, if one includes the respondents 4th highest ranked concern, Wetlands were also considered in the list of top issues for the managers surveyed in this study.

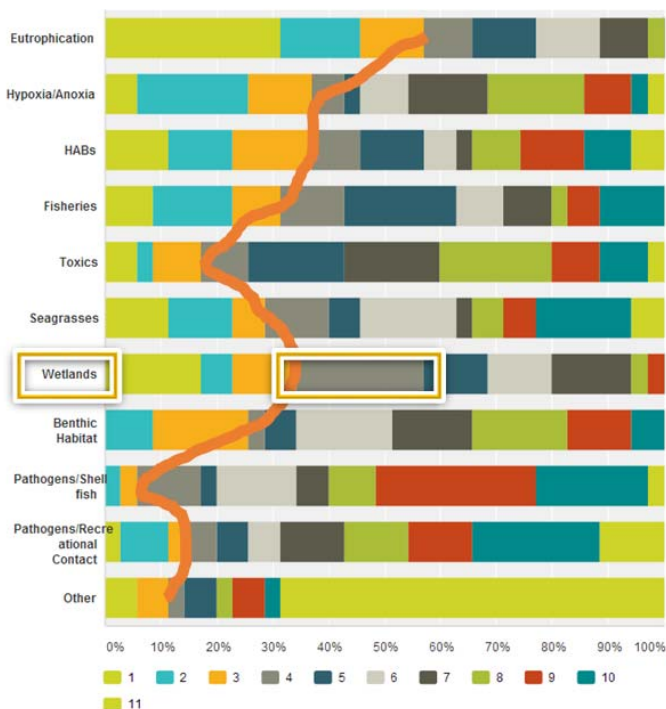


Figure 2-2. Respondents ranking (top 11 issues) they were concerned with. The orange line tracks the top three ranking across the issues.

As a follow up to the issues of concern, respondents were asked to list any indicators or end-points that tend to drive their decisions. The top choices among the respondents were

“Regulatory Drivers (e.g., TMDL, Water Quality Standards)”, Submerged Aquatic Vegetation”, Benthic Abundance/Diversity”, and Fisheries Catch/Yield” (Figure 2-3).

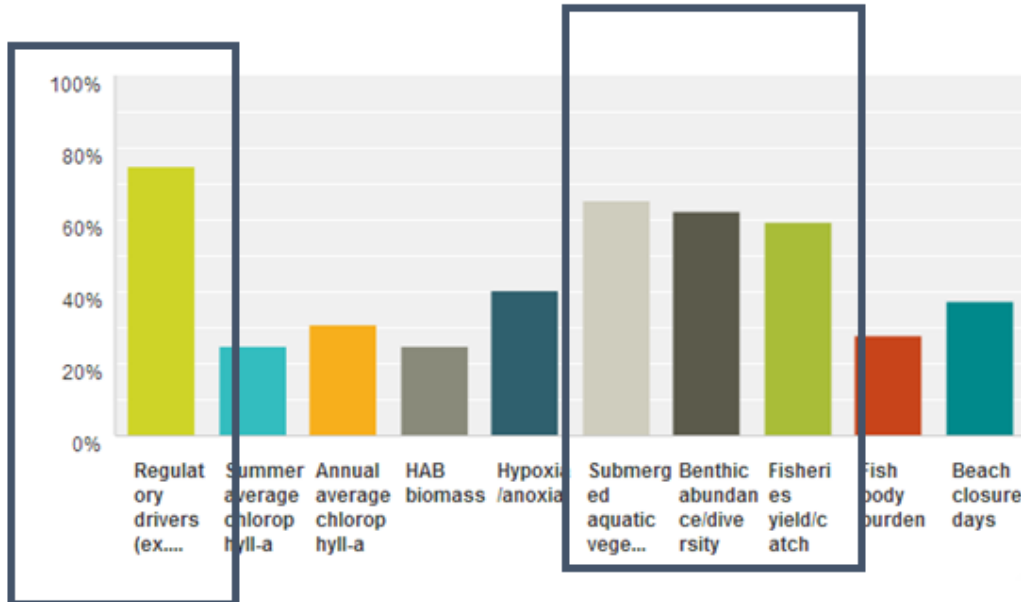


Figure 2-2. Summary of indicators or end points that respondents determined to influence their decision making

Respondents were also asked to indicate what stakeholders were influenced by their decisions. The top three answers were “Other Government Regulators and Planners”, “Municipalities/Counties (NPDES)”, and “Municipalities”, with “Landowners” coming in fourth (Figure 2-4).

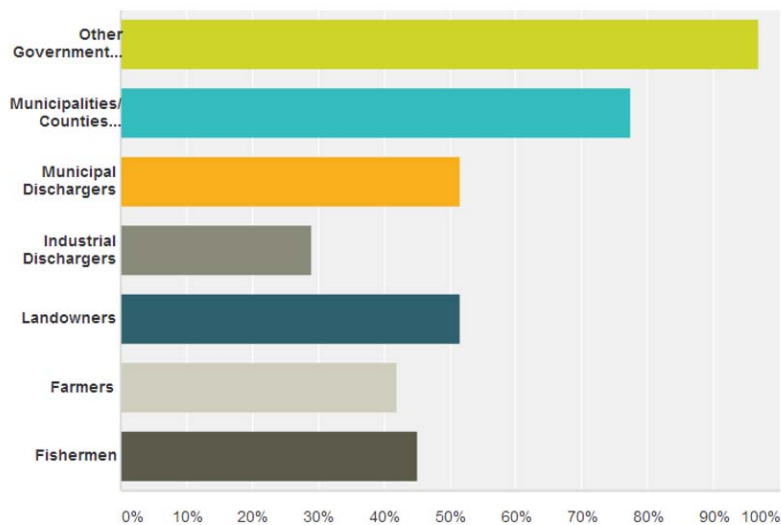


Figure 2-3. Percentage of respondents indicating what stakeholders are influenced by their decisions. Respondents were allowed to indicate multiple stakeholders.

To further determine the mechanism of manager decision effects, the respondents were asked “how are these different people or groups affected by the decisions you make?” The top two answers, above 50%, were “TMDL” and “Permitting or Permit Limits” (Figure 2-4).

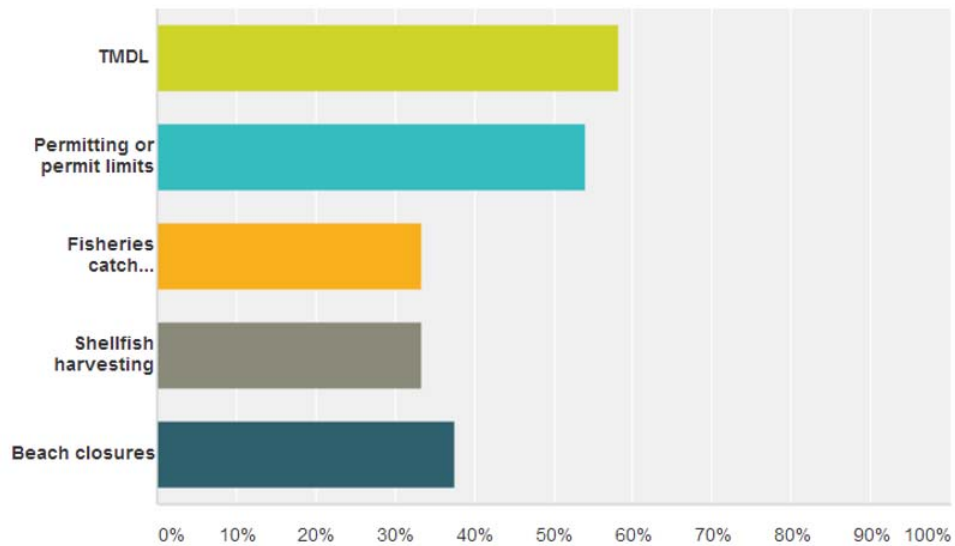


Figure 2-4. Percentage of respondents indicating how the decisions influence stakeholders

The temporal and spatial scale of their decision sphere was mostly defined as “annual” and “regional” (Figure 2-5). As the temporal scale of decreased, the number of respondents indicating this was an important time frame for their decisions decreased. The exception to this correlation was that over 20% of respondents indicated that their decision time frame was “daily”. When parsing the group that answered daily from the rest of the respondents, the only distinguishing characteristic was that this group tended to indicate that their decisions were on the “local” spatial scale. Most respondents answered that their region of influence was regional, presumably for the most part related to a single water body. Those that answered “Multi-jurisdictional” added some description of how this process works: “We have mediated cross-boundary issues between the States of GA and SC to develop consistent water quality standards and to develop a robust water quality model for TMDL purposes” and “comparable data must be collected by the various jurisdictions”.

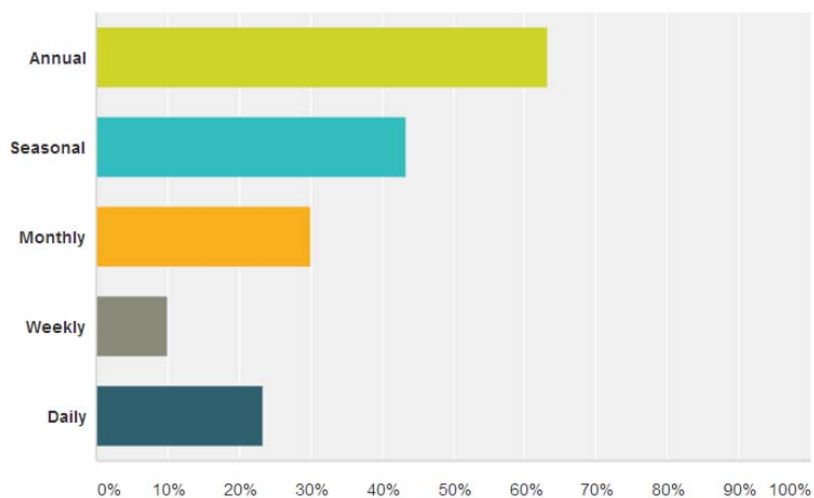


Figure 2-5a. The temporal scales that influence decision making.

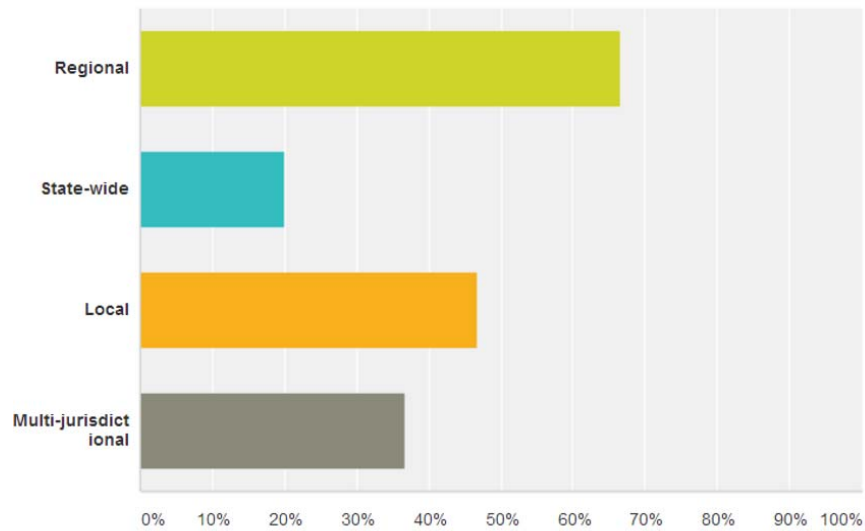


Figure 2-5b. The spatial scales that influence decision making.

When asked about what factors are used to inform decision making, unsurprisingly, all managers agreed that monitoring data was a strong factor. Perhaps more interesting was that ‘Climate Change’ was cited as a factor by 60% of respondents.

The next set of questions attempted to characterize the current use of models in the manager’s decision making process. Over 80% of those surveyed indicated that they currently use models to make decisions for their region. Additional descriptive answers give insight into how these models are typically used. Example comments include the following. (1) “Models [were] initially developed for TMDLs, but states are interested in other management techniques and will be running model scenarios themselves.” (2) “Models [were] used primarily to develop broad conceptual understanding of system dynamics to help inform selection of alternative actions, primarily outside of a regulatory context.” (3) “Coastwise stock assessment models or region specific models – {e.g., EcoPath) were used. ” (4) “We have used models in our work (suspended sediment monitoring for example), but this approach has not been adopted by decision makers. In some cases, decision makers do use modeling to determine TMDLs, etc.” Results of this analysis reveal that 75% of those surveyed indicated that use a mix of statistical and process based models (Figure 2-6).

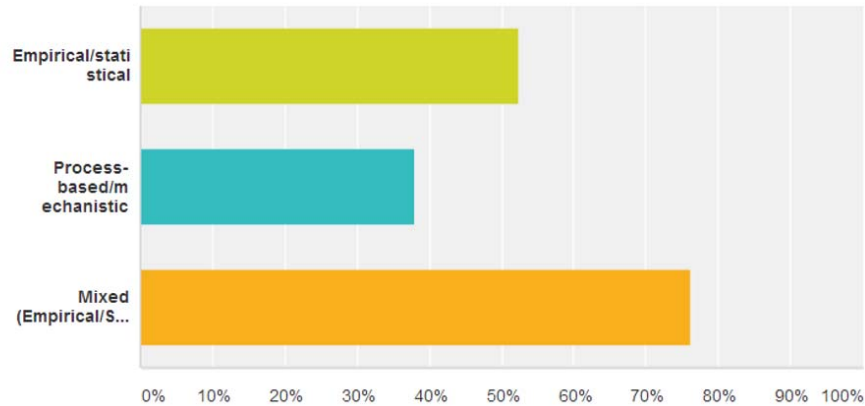


Figure 2-6. Utilization of various model types by managers.

While it was clear that models are used in the decision making process by managers, what was less clear was the costs and benefits of this approach, particularly in relation to the costs and benefits of monitoring programs (Figure 2-7). When asked what level of funding was required for model development, it was clear that there was a large degree of uncertainty (slightly higher for model development than monitoring). Additionally, on average, managers that did respond with costing information indicated that monitoring costs were higher than required costs for model development, with half the managers answering that monitoring costs were greater than \$500,000.

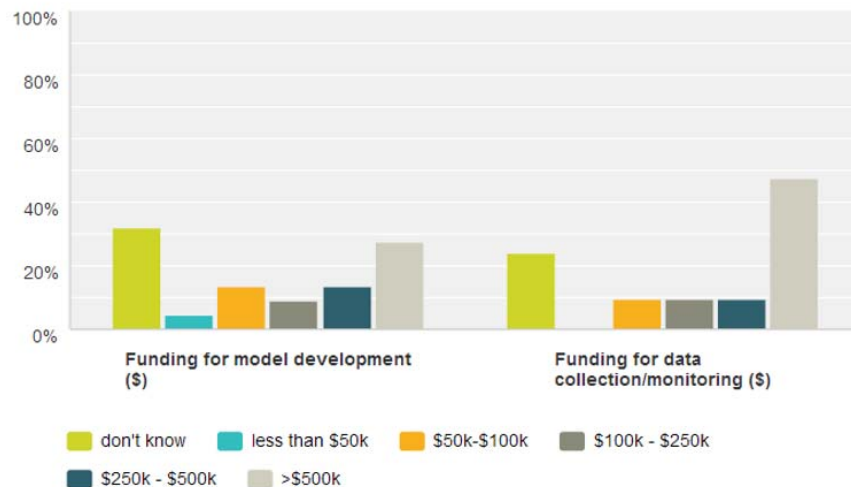


Figure 2-7. Level of funding required to model and monitor for the purposes of making environmentally related decisions.

When asked follow up questions regarding how the costs of implementation differed from the costs of model and scenario development, uncertainty increased. For instance, half the managers would not estimate the cost of scenario generation. For those that did, no manager indicated it would cost more than \$1-10 million. When asked about the cost of implementation of the scenario being generated, uncertainty was still high, but of those that did estimate the cost, most managers estimated the cost would be greater than \$1,000,000, with 20% indicating the costs could be greater than \$100,000,000 (Figure 2-8).

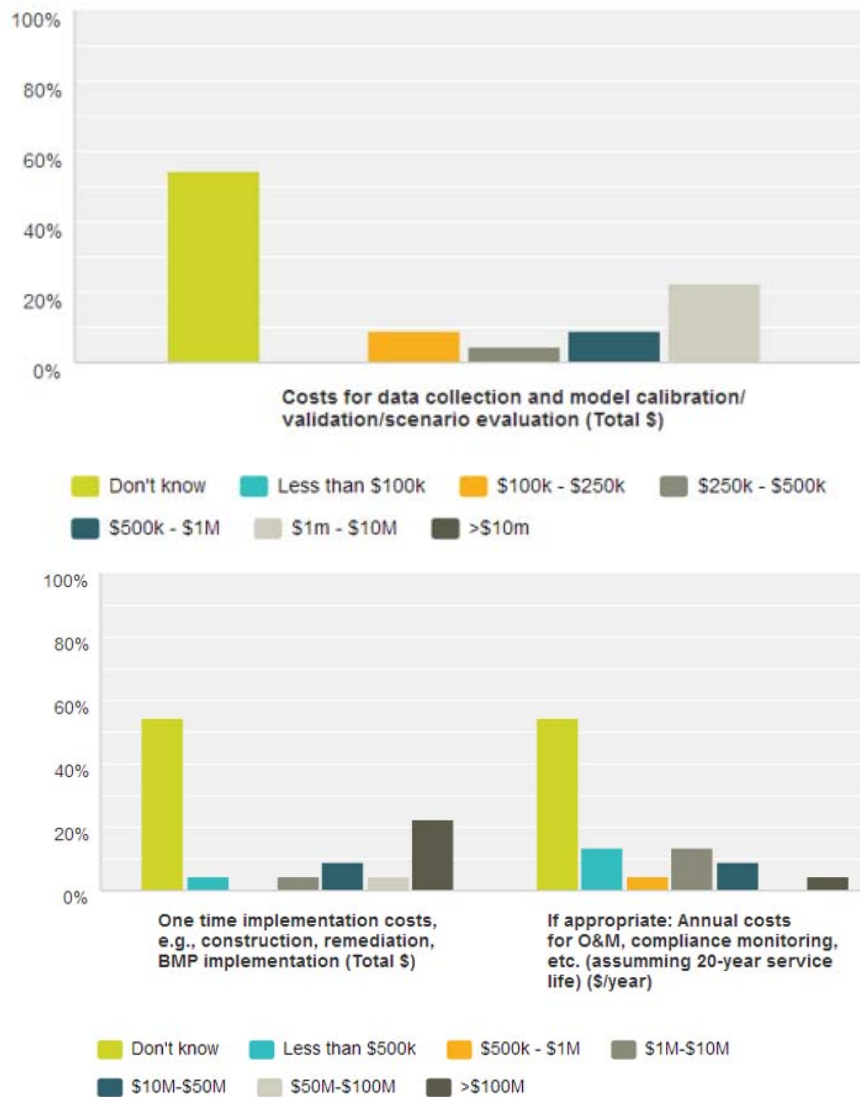


Figure 2-8. Costs of scenario generation, implementation and maintenance of decision as estimated by managers

Uncertainty did not decline when managers were asked to describe the current level of funding allocated to modeling activities (Figure 2-9). However, for those managers that did estimate these costs, most chose between \$50,000-\$100,000 for model execution and over \$250,000 for monitoring. When asked where models are being executed, the most dominant answer was in house on desktop computers. The second most common answer involved outside consultants running models. Many fewer targeted individuals, self-identified as technical staff and therefore many of the more technical questions were answered by fewer respondents. However, some of their answers may be germane to NOAA's efforts to understand the role they can play in scenario generation. For instance, most answered that data was collected for 1-2 years to calibrate their models with some indicating the data collection was closer to 3-5 years. 60% of respondents indicated that their models are run adaptively (that is, models are being re-executed with new information). Most also said that their model could be run in another similar

system, but they are unaware of this type of a cross-system application occurring with their model.



Figure 2-9. Estimated costs to run current models and monitoring programs

Overall, the survey suggests that modeling is much cheaper than monitoring, perhaps by a very significant margin. Perhaps more importantly, there is a fairly high amount of uncertainty in estimating the cost of model development and scenario generation, but also in implementation of the selected management practice. From a modeling perspective, a mix of modeling techniques is the preferred option although, the respondents are somewhat equivocal. In-house capabilities have almost certainly allowed more modeling to take place within organizations and agencies, however, consultant- and academic-based modeling is still a significant fraction of the modeling effort occurring in these locations (35% indicating that and outside consultant runs their model). Finally, Climate Change appears to factor into current decision making which may argue more for the need for scenario-based modeling.

SECTION 3. WORKSHOP RESULTS

Workshop Introduction

Having gathered information concerning the perceived needs for Operational Forecast Models from coastal and Great Lakes resource managers, the next step was to conduct a 1 1/2-day workshop. The purpose of the workshop was to bring together federal, state and regional resource managers and federal, academic and consultant modelers to:

- discuss their experience in ecosystem modeling in informing policy and management decisions and to describe the extent to which these models were accepted by invested stakeholders,
- discuss what is meant by “operational” for ecosystem models,
- gain insights from existing operational modeling centers and systems,
- discuss the resources required to develop and apply these ecosystem models, including monitoring data and field studies required to support model calibration,
- assess protocols for model-data requirements, model refinements, and model skill assessment,
- discuss project funding required to bring these models into an operational mode, and
- discuss the role that NOAA and other agencies might play in supporting these models and applying them in ecosystem-based management.

The workshop was held on April 29th and 30th, 2014 at the University of Maryland’s Center for Environmental Science (UMCES) Horn Point Laboratory in Cambridge, MD.

Workshop Day 1

The first day, meeting participants from NOAA CSCOR, the USEPA, the regulated community and academic and consultant community (Appendix A), were provided with an introduction to the workshop. The introduction, by Dr. Beth Turner (NOAA CSCOR Project Manager) included information concerning the project background and workshop goals. She explained how scenario-based and forecasting-based ecosystem modeling differed from the real-time, event driven forecasting that NOAA performs as part of its more traditional roles in weather forecasting (National Weather Service) and hydrodynamic modeling for navigation and emergency response (National Ocean Services/Center for Operations Oceanographic Products and Services). Differences between the two types of forecasting centered on differences in the time-scales of interest; on the order of hours to a few days for weather/navigation versus seasonal to yearly to multi-years for scenario-based ecosystem forecasting. Data requirements can also be significantly different between the two types of forecasting with scenario-based forecasting perhaps requiring more and varied types and sources of data. Both types of forecasting should include skill assessment and estimates of uncertainty in model predictions.

The different ways in which models are used were also discussed. Tactical models are used to determine what needs to be done now and for “immediate action” management, while strategic models are used for “selecting the best course of action” in management. Models can also be used in hindcast simulations to understand why something happened. Finally models can be used in a conceptual or heuristic mode to help managers understand how a system works and what are the main drivers and interactions. In general, real-time, event-driven models probably fit into the tactical category, while scenario-based models probably fit into the strategic category. Both types of models can be used in hindcast applications and in conceptual/heuristic applications.

Dr. Turner also contrasted two types of scenario-based forecast models –statistical and deterministic – and their strengths and weaknesses. In reality, the issue is not as much about the model or types of models themselves, but rather it is about how the models can be transitioned to become operational. Turner also discussed the challenges that need to be faced and addressed in making a model operational. These include:

- archiving and assessing the model simulations and forecasts when dealing with a 5-7 year adaptive management cycle
- documenting the model’s theoretical foundation, mathematical framework, assumptions and limitations, data inputs (drivers, boundaries and initial conditions) and model outputs (simulations),
- performance of model skill assessment and model uncertainty, and
- maintaining and improving the model.

Finally Dr. Turner presented a series of questions that participants were asked to consider as they listened to presentations on Day 1 and to be ready to discuss in the break-out sessions on Day 2. These questions included the following: (1) “What is or should be the definition of ‘operational’ for scenario-based or forecast-based ecosystem models?”, (2) “What is required for a model to become operational?” and (3) “What does it take to keep a model operational” and (4) “What support could the Federal government provide for these types of forecasts?”

Following the introduction, a synthesis of the results obtained from the Need for Scenario Based Ecosystem Forecast Models Survey was presented by Dr. Damian Brady (Co-PI, University of Maine). The results of the questionnaire indicated that the key issues of concern for coastal and Great Lakes managers were (in order of importance): eutrophication, hypoxia, HABs, fisheries, toxics and seagrasses/wetlands. Respondents indicated that they used statistical models about 50% of the time, deterministic models about 40% of the time and mixed statistical/deterministic modeling approaches about 75% of the time to help inform their management decisions to solve environmental issues. The survey also identified that most responders did not know the costs for model development, nor did they know the costs for data collection to support model calibration, nor the costs for implementing management alternatives. Details of these survey results have been presented in Section 2 of this report.

These first two presentations were in turn followed by a series of presentations with follow up discussion, which are summarized in Appendix B (the presentations themselves are presented in Appendix C). The discussions centered about many topics including:

- existing operational forecast systems/centers,

- examples of some regional eutrophication/hypoxia modeling applications,
- state-of-the-science for contaminant fate and transport models, HABs and fisheries modeling,
- requirements for making research models operational, and
- other Federal agencies perspectives on environmental modeling and modeling certification.

Setting the Stage for Day 2

The two concluding presentations for the first day were focused on setting the stage for the discussions and break-out sessions for the next day. Dr. Beth Tuner presented an overview of: what NOAA's goals were for operational ecological modeling; a roadmap as to how NOAA planned to get there and; a brief overview of what an operational ecological modeling framework might look like. The last presentation was by Dr. Dominic DiToro, who provided a perspective on why scenario-based models are needed and put into perspective the relative costs for ecosystem modeling relative to the costs for implementation of management scenarios to address environmental problems; the main point being that model development and application are a small fraction of expected implementation costs.

Since there was time and interest at the end of the day, the participants had some initial discussions concerning the definition of "operational" for scenario-based forecast modeling, relative to NOAA's definition of operational as it is applied in its more traditional roles of weather forecasting and hydrodynamic modeling for navigation and emergency response.

Day 2

The second day of the workshop began with a summary of the findings of the first day. These findings are presented in Appendix D.

Definition of Operational

The attendees then moved on to developing a definition of "operational." Our definition follows: *Any site-specific model is considered to be operational if it has been sufficiently well-calibrated to observations (preferably both state variables and process rates) and deemed necessary and useful by environmental managers and decision-makers. Such models must meet certain evaluation criteria, including but not limited to: (1) application for conditions outside the calibration regime; (2) incorporation into a management plan for ongoing refinement and application; and (3) documented such that simulations can be replicated.* However, this general definition was augmented by specific comments made by workshop participants, which included the following:

- it should be recognized that the definition of operational for scenario-based or forecast-based ecosystem models is going to be different than that used by the NWS and NOS,
- an operational model need not be running 24/7 but does need to include timeliness, accuracy, reliability, and periodic repetitive application,
- needs to capture uncertainty, managers need to know the uncertainty/variance around the estimate,
- needs to have its definition broadened to include strategic models,
- is a system that regularly produces hindcasts, nowcasts, and forecasts that regularly contributes to management decisions,

- needs to distinguish between prognostic and predictive simulations, emphasizing the fact that we are trying to understand the system behavior,
- needs to ensure that everything is running well, in that model and data are well matched, and if not, it needs to be diagnosed, revised and recalibrated,
- must have a sustained budget, e.g., line item in federal budget,
- needs to have model certification and must be well documented,
- needs to be trusted and reliable, sustainable, and robust, and
- must meet the needs of managers.

Following the group's discussions on the definition of operational, the attendees broke up into two break-out groups to discuss "the role that NOAA and other federal agencies might play to support these models and apply them in ecosystem-based management." The following provides a summary of the resulting thoughts and questions :

- Should the operational center be collocated with CO-OPS?
- Getting the data to the models is key and IOOS has regional data centers .
- Should there be regional centers that are collocated with the IOOS data centers?
- It was noted, however, that we are interested in more than just hydrodynamic models and, therefore, collocating with IOOS is not essential.
- Possibly, there should be a national center, where models are reviewed and the models are then developed and applied regionally.
- There was consensus that NOAA's role should not be the definer or certifier of the model codes. Instead NOAA would have a role in reviewing model codes and would be the one to run the operational model codes.
- It was suggested that NOAA consider academics/consultant firms to develop/maintain models, Rutgers/ROMS and Texas A&M/SWAT given as examples.
- NOAA should consider interagency partnering, as many of the environmental problems that have been identified by managers are also of interest to USEPA.
- NCCOS already supports science, but a new center could be focused on operation.
- A new center should be able to address TMDL-related issues as well as fisheries-related issues.
- A national center is a workable idea, where it would review and certify, regional centers would implement, which could be collocated with IOOS or Fisheries Science Center, close to universities or other researchers; interagency cooperation is worth exploring – Geophysical Fluid Dynamics Laboratory (NOAA/USEPA) given as an example. This Center could be part of a national model vetting process similar to the USACE COP's certification program.
- Discussions suggested that involvement of academics would improve model quality, with cooperative agreements rather than only as grants to the academics.
- It was noted that multiple agencies have coastal roles (CREM/NCCOS).
- Biogeochemical modeling would be a central focus of this Center.

Summaries of the break-out sessions were presented and further discussed with a rough consensus that NOAA should explore the concept of a national center with regional hubs and that NOAA should consider partnering with other federal agencies, the USEPA in particular, to provide support to scenario-based ecosystem forecast models. These discussions also recognized the differences between existing model codes, such as the USACE CE-QUAL-ICM and the

USEPA WASP, and site-specific applications of those or other models, with appropriate site-specific modifications, to address the management needs of a specific water body or system, with the site-specific application being the model that ultimately becomes the OAEM (See Section 4).

Key Workshop Findings

The workshop results are summarized in three areas:

1. What Do Managers/Decision Makers Want?

There was a broad consensus, particularly from the decision makers themselves, that managers and decision makers are looking to understand how various drivers affect a system and how to respond to or prevent adverse changes. Having an understanding of a system and the drivers that affect that system can help inform managers and decisions makers about the potential benefits that may result from a management action. Having a management tool, such as a model can help managers avoid technology driven management (e.g., 85% removal or reduction of BOD₅ to address violations of dissolved oxygen standards as was the general practice in the early days of the Clean Water Act).

Workshop attendees also stated that managers wanted models that were understandable (i.e., that the model framework's, assumptions and limitations and its outputs could be quickly assimilated by key decision makers and that could be presented to their non-technical stakeholders and the general public in a simple and straightforward manner). Managers also want these models to be readily accessible and not require long development times when a decision needs to be made in a relatively short period of time. This requirement can lend itself to adaptive management, where models need to be continuously maintained and updated with new scientific research and information, including new site-specific data.

Managers also want models that define their uncertainties. If a model can define its uncertainty, then managers may be better informed of the potential outcomes of various management actions and lay out a plan of adaptive management, which in the long-term achieves the desired management goals in the most cost-effective way. Workshop participants also offered that managers should realize that modeling is often less than 2-5% of cost to implement a remedial action and, therefore, should consider the use of modeling to address most environmental issues.

2. Operational Forecasting

A key focus of the workshop was to arrive at consensus as to the meaning of operational. It was clear that workshop participants clearly recognized that, in general, forecast is a "weather" word and that operational scenario-based ecosystem models are much different. The initial development of a scenario-based ecosystem model is driven by the environmental question or issue that a resource manager or regulatory agency needs to address. The model development process involves selection of a model or the development of a new model, as well as involving the collection and assembly of data for model inputs as well as for model calibration/validation and skill assessment. Once a model has undergone development, validation and skill assessment and ensures that a set of procedures are in place to synthesize/review model outputs and convey them in a readily understandable format for the manager/user community and that it has demonstrated its utility in informing management decisions, it can be considered a candidate for

operationalization. This process may, in fact, require an iterative process to ensure that the model fully performs all of these functions and meets the needs of the managers and decision makers.

Operational scenario-based ecosystem modeling can also be used in an adaptive management process. This process involves:

- application of a scenario-based ecosystem model to determine the appropriate management scenario(s) to address an environmental problem,
- design of management actions to meet an environmental or ecosystem goal,
- implementation of the management actions, including monitoring of pollutant loadings and system response,
- conducting a post-audit to compare observed ecosystem response to model predictions, and
- if necessary, develop new alternative management scenarios, which are then re-evaluated using the operational model.

It is also important to consider how the operational model may need to be maintained and updated in response to new research and process data, which together with new monitoring data (inputs and receiving water data) can be used to revise and re-calibrate the model and feed into the management scenario evaluation process. In addition, results from the post-audit can be used to identify model uncertainties and focus research and data collection to improve the performance of the operational model. These actions can act to inform and improve the reliability of model forecast or predictions.

To recognize the difference between “weather” forecasting versus scenario-based forecasting, there was a recommendation that NOAA consider replacing the word “forecast” when describing scenario-based ecosystem forecasting with one of the following words: prediction, assessment, projection or prognostic analysis, based perhaps on the lexicon developed in the National Climate Assessment and IPCC reports. However, despite this sidebar recommendation, the attendees agreed that an operational model should include the following features or requirements:

- meets decision makers or management needs – operational models need to address site-specific environmental issues and support managers in making informed decisions,
- sign off by all – the use of an operational model to help inform management decisions should be agreed to by all affected parties and stakeholders. Perhaps an ensemble modeling approach can also be used to help guide these decisions and help define the uncertainty bounds of the management action, but again agreement to utilize such an approach should be a universal decision by all affected parties and stakeholders.
- timeliness, accuracy, reliability, skill assessment – an operational model needs to provide managers with information to guide their decision making process in a timely fashion. This would require an operational model to be maintained and updated on a regular cycle (perhaps 3-5 years), rather than “sit on the shelf” and require a significant effort to update and re-calibrate just when it is needed by the decision makers. The model must provide accurate and reliable results. This also requires that the operational model be maintained and evaluated against new field or monitoring data so as to identify any systemic errors in the model framework before it

is re-applied to address or understand a change in ecosystem function. Finally, the model should have a demonstrated record of skill assessment, so as to provide a greater degree of confidence in the reliability of the model to inform management decisions.

- revisit/update every several years – while this point was addressed under the previous bullet, the workshop participants re-emphasized the importance of keeping an operational model up to date with new science and data so that the model is ready when required to help inform managers in their decision making deliberations.
- keep it operational – collaborative approaches –recognize the importance of academics/consultants in performing model development and documentation in support of the operational modeling centers.
- certified/peer-reviewed – the workshop participants emphasized the need for having operational model codes certified and peer-reviewed. While there was some discussion as to whether or not this should be a central role for NOAA, it was strongly recommended that NOAA be part of this process. It was also a consensus recommendation that operational models be well documented, including a clear definition of the biogeochemical processes that the ecosystem model was attempting to simulate, the model's underlying assumptions and limitations, and clearly defined data needs and computational results.

3. What Can NOAA Provide?

A wide-ranging discussion by the participants led to the following items that NOAA and its Federal partners could offer in support of developing OAEMs (see Section 4):

- There was a strong recommendation that NOAA consider a National Center. There were two types of models for such a Center. The first would be based on: (1) a GFDL-type of center, where models are developed and used to address environmental problems and (2) a center that certifies and evaluates models for the user community.
- It was also recommended that NOAA consider both having Regional Centers as well as a National Center. The Regional Centers could possibly be co-located with the IOOS regional data centers.
- Consider collaboration with the USEPA, since both NOAA and the EPA share many of the same water quality concerns (eutrophication, hypoxia/anoxia, and HABs).

SECTION 4.

OPERATIONAL AQUATIC ECOSYSTEM MODELING – DEFINITIONS, NEEDS AND CHALLENGES

With the information gathered from the survey (Section 2) and with input from the workshop participants (Section 3) as a basis, we developed the following section to more clearly define the characteristics of an operational ecosystem forecast model or more specifically an operational aquatic ecological model (OAEM). We also present more detail as to the components and challenges faced in developing OAEMs, relying in part on information presented and discussions held at the April workshop, but also based on our collective modeling experience. Finally, we present a number of examples of existing operational modeling centers throughout the country as examples of where success has been achieved.

Definition and Characteristics of an Operational Aquatic Ecological Model

As stated in the introduction, this paper investigates the process of establishing a roadmap for the development and implementation of Operational Aquatic Ecosystem Models (OAEM) for large aquatic ecosystem across the U.S. We have defined OAEM as modeling that predicts likely changes in ecosystems and ecosystem components in response to anticipated environmental drivers, whether those predicted changes are produced as a forecast of actual measured or predicted stressors or are produced as scenarios of potential stressor alterations from either management or natural changes in system drivers.

We distinguish between forecast and scenario applications of OAEM. OAEM can also be applied at a range of time scales, from relatively short daily predictions of, for example, bacterial contamination of beaches to multi-decadal projections of response to, for example, climate change forecasts. There also may be a range of complexity from relatively simple statistical models to highly complex process-based models. Typically, the desired complexity of a model is determined by the question/s being addressed and the available data. The model complexity, as defined by its spatial and temporal resolution, and its kinetic complexity, must be compatible with the complexity of the problem definition and the data available to calibrate and confirm and apply a model with that complexity. This concept is thoroughly discussed in EPA's guidance on regulatory environmental modeling (EPA, 2009).

Another distinction should be made between a generic code (e.g., RCA, CE-QUAL-ICM) which can be applied to any number of similar aquatic systems and a site-specific application of that code to a specific aquatic system. Site-specific application of an aquatic ecosystem model inevitably requires site-specific refinements of the code to address the problem definition for the system under investigation. For example, a generic aquatic ecosystem model such as RCA may require the addition of a sub-model for Dreissenid bioenergetics and/or Cladophora growth to be applied effectively to address establishing a nutrient loading target for a lake in which those components contribute significantly to nutrient cycling and primary production.

Regardless of the complexity and type of application, an operational model is designed for ongoing application for a specific system. During the workshop, Batiuk provided a definition of what constituted "operational" by suggesting that for the Chesapeake Bay modeling system "operational" meant that there was universal sign-off by the Chesapeake Bay Partnership (six effected states, multiple federal agencies, academics, etc.) for its use in management

applications. Other concepts for defining "operational" that were raised during discussion at the workshop included:

- recognition that the definition of operational for either scenario-based or forecast-based ecosystem models is going to be different than that used by the NWS and NOS,
- an operational model need not be running 24/7, but does need to include timeliness, accuracy, reliability, and periodic repetitive application;
- the data needed to support an operational model must be collected on the time scale for which the model is being applied;
- an operational model needs to capture uncertainty, managers need to know the uncertainty/variability around the estimate;
- an operational a modeling system should regularly produces hindcasts, nowcasts, and forecasts that regularly contributes to management decisions;
- an operational model should be both predictive and prognostic- emphasizes the fact that we are trying to figure out why a system changed as well as how it is changing;
- an operational model needs to be continually checked that everything is running well, i.e., that it matches the observed data, if not it needs to be diagnosed, revised and recalibrated;
- an operational model must have a sustained budget (e.g., line item in management agency budget);
- an operational model needs to have model certification and must be well documented; and
- an operational model must be trusted and reliable, sustainable, and robust, and meets the needs of managers.

Also during the workshop both DePinto and Turner offered concepts of how OAEM could be used in an Adaptive Management process. The concepts are presented diagrammatically in figures 4-1 and 4-2 below. These processes require periodic, site-specific application of an operational model for adaptive management as well as ongoing model refinement and uncertainty reduction.

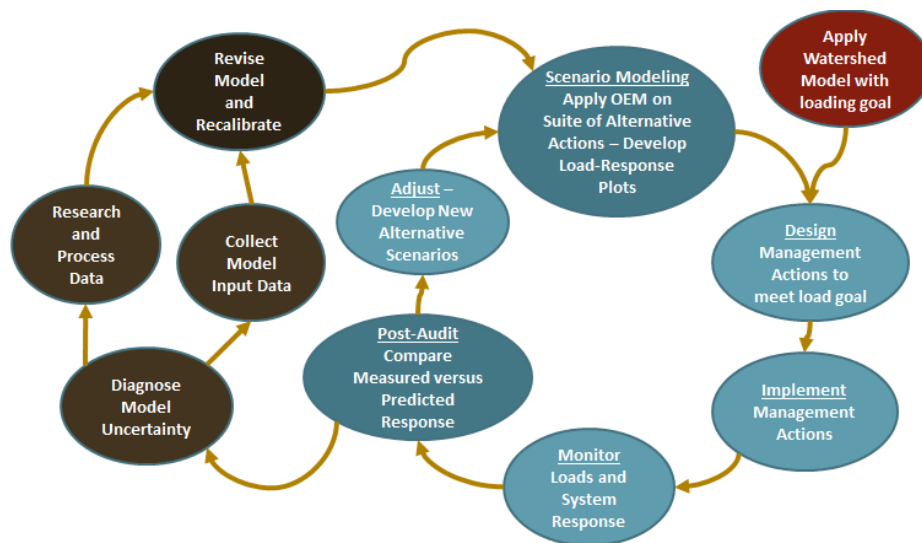


Figure 4-1. Periodic application of an operational model within an adaptive management process, allowing refinement and uncertainty reduction by post-auditing the model (from DePinto, 2013).

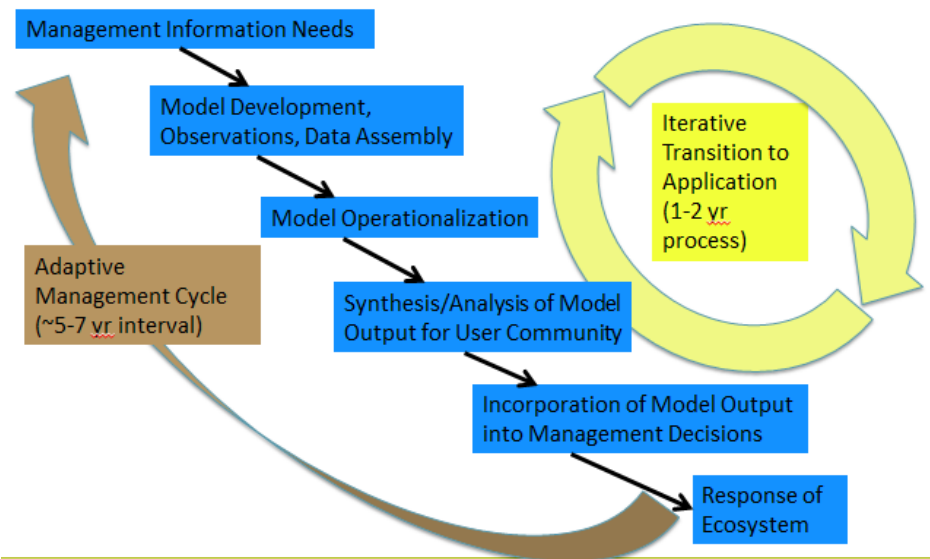


Figure 4-2. Process for periodic application of an operational model to support management decisions.

Required Components for an OAEM

Based on the above characterization of OAEM, we can diagrammatically present the flow of information for a site-specific model support process as shown in Figure 4-3. The blue boxes present the full process and associated components of an operational application of an aquatic ecosystem model and the black arrows indicate the flow of data/information from the model-data integration to the end users and stakeholders. The diagram also indicates how R&D and prototype/test bed applications can contribute to the development of the system. Each one of these components is needed for an OAEM to provide management support for a given aquatic ecosystem. The specific complexity and sophistication of each of the components will, as stated above, depend on the questions being addressed and the resources available to build and operate the system.

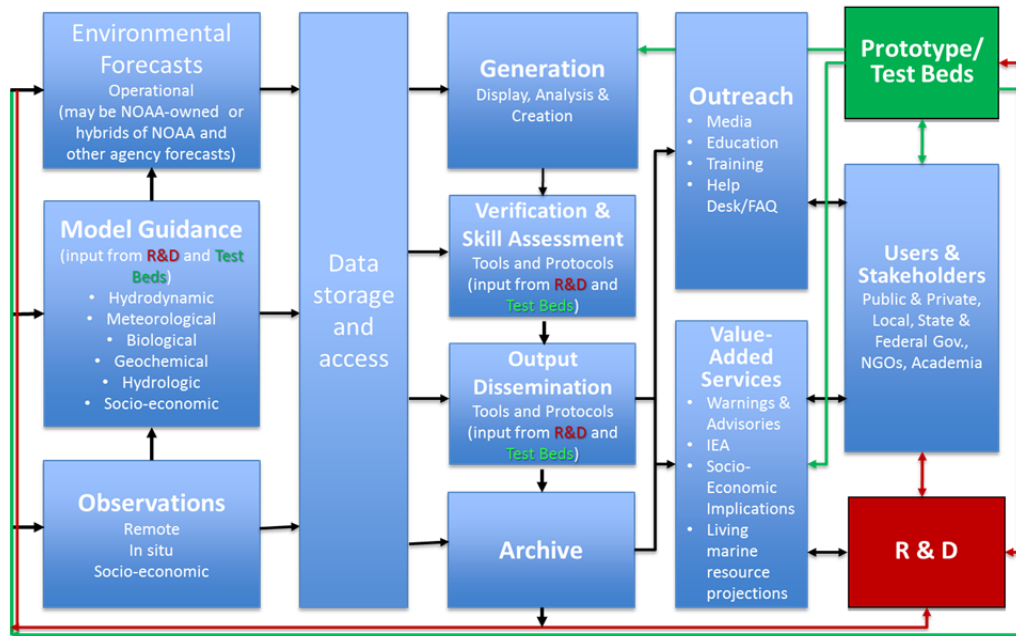


Figure 4-3. Components and flow of data/information for an Operational Aquatic Ecosystem Model, including how research and development and prototype/test beds can be used in developing the system.

Perhaps the best way to identify the challenges of making an aquatic ecosystem model operational is to lay out the steps needed to convert what may have been either a research model or a one-time management decision model into a modeling system that is operational at a given site. Based on our project team and input during the workshop, the following steps are necessary to develop and apply a site-specific OAEM:

1. Select, formulate, and/or revise an existing model to support the following needs for a specific water body being managed:
 - a. User needs and management questions
 - b. Geomorphological, hydrological, and biological characteristics of the system
 - c. Programmatic constraints
 - d. Desired level of model uncertainty - leads to adaptive improvement cycles
2. Develop and implement a strategy to calibrate and confirm the model
 - a. Collect coherent data sets for the calibration and confirmation process, preferably data sets representing a wide range of forcing/environmental conditions
 - b. Perform the calibration/confirmation process
 - c. Assess model skill and compare with desired level of uncertainty
3. Develop model operation plan that includes:
 - a. Routine data needs and model operation/application process
 - b. Output analysis and visualization

- c. Management and communication of model and observation results to users and user support
 - d. Adaptive model refinement plan and incorporation into an overall adaptive management process
4. Plan for data and model output storage, archiving, and documentation
 5. Develop institutional home for model and funding plan for model operation

We recognize there are many options and detailed decisions to make in to undertaking this process. However, those decisions will depend on the site-specific problem definition and the resources available. Therein are the challenges in developing an OAEM.

Challenges in Developing an OAEM

The purpose of this section is to briefly present and discuss some of the challenges associated with each component of an OAEM process. A number of these challenges were discussed by Turner in her presentation to the workshop attendees but are revisited here and include:

- Aquatic ecosystem models must link physical transport processes with biochemical transformation process. It is therefore important that biophysical models be developed jointly by physicists and biologists. While this will provide some challenges in terms of providing appropriate levels of resources and in developing continuous communications between both groups of modelers, it is important to developing biophysical models that are based on the best available science, that include the proper description of how physical and biological processes interact, that are robust and that can pass scientific peer review.
- There is a need for infrastructure and a common data structure for archiving and assessing the model and model forecasts, especially when dealing with a 5-7 year adaptive management cycle for scenario-based OAEMs. Fortunately, the costs for off-line and on-line storage continue to decrease and there are common data structures such as Net-CDF, which are available and provide an approach for data/model archiving. It will also be necessary to develop common protocols, infrastructure and pre- and post-processing tools, so that models can readily obtain the requisite data to generate forecasts, can "talk" to one another, can manage and document model applications, and can provide information to end-users for informed decision making.
- It will be necessary to develop documentation of model theory, computational framework, assumptions and limitations, model inputs and model outputs, and model evaluation results for each OAEM that is supported within NOAA's library of models. The documentation must be complete enough so that the model practitioner fully understands the underlying principles or framework of the model and the end-users of the model fully understand the model's assumptions and limitations. Fortunately, with the advent of the Internet and HTML, documentation of OAEMs can be made available on-line and updated on-line by the developers and "keepers" of the code. These on-line websites can be set up a "wiki" pages and can include information concerning technical documentation (i.e., model theory), user guides (i.e., descriptions of model inputs/outputs, tutorials, frequently asked questions, installation procedures, etc.), examples and applications, including test cases with sample model input and output files.

An example of such a website is available for the Regional Ocean Modeling System or ROMS (https://www.myroms.org/wiki/index.php/Documentation_Portal)

- Procedures and standards should be developed for performance of model skill assessment and model uncertainty. While model skill assessment procedures and metrics have been developed and applied by NOAA's NOS for its operational hydrodynamic forecast systems (Hess et al., 2003; Zhang et al., 2010) and by other researchers for many hydrodynamic modeling systems (ex. Dingman et al., 1986; Vested et al, 1995; Warner et al., 2005; Georgas and Blumberg, 2010; Haidvogel et al., 2008; Hetland and DiMarco, 2012), there are fewer examples of standardized approaches for performing skill assessment for complex biogeochemical and for aquatic ecosystem models in general. Stumpf et al. (2009) provides a skill assessment of a harmful algal bloom operational model used in southwest Florida. Arhonditsis and Brett (2004) reported on a meta-analysis of 153 mechanistic biogeochemical or ecosystem models and summarized model skill for these models based on relative error and the coefficient of determination or the regression coefficients (r^2). Also a special issue of the Journal of Marine Systems (Lynch et al., 2009) focused on skill assessment for coupled biological/physical models of marine systems and would provide a good starting point for developing a standardized approach for performing skill assessment of OAEMs. Furthermore, it may be a bigger challenge to evaluate the skill of the model practitioner. Without a significant amount of modeling experience by the model practitioner, models can often be misapplied yet conventional model skill assessment may not always be able to identify when a model has been misapplied.
- Another challenge to be addressed is how to translate model outputs into forecast and/or projection information needed by resource managers and interested stakeholders. Again there is considerable experience within NOAA's NWS and NOS in taking information concerning hurricanes, tidal elevations and currents, HAB forecasts and providing that information in a format required by managers, stakeholders and the general public. However, this will need to be expanded and built upon for scenario-based OAEMs. For example, in the Chesapeake Bay there are spatially and time-variable water quality standards for dissolved oxygen, which require site specific post-processing software to determine whether a management scenario achieves compliance with these standards. Another example is phytoplankton chlorophyll-a standards for the tidal James River estuary, which vary by season (spring vs. summer) and salinity regime (freshwater, oligohaline, mesohaline and polyhaline). Again site-specific post-processing software is required to determine whether a nutrient management scenario results in attainment of these water quality standards. Such software has been developed and applied on a site-specific basis (DePinto, 2010) and is being generalized to support many different modeling codes.
- Infrastructure should be provided for maintaining and improving the model. A yearly operational budget should be provided for maintaining and improving model codes. This need not necessarily be performed by NOAA staff and may in fact be more cost-effective to be left to academic, federal and/or consulting firms, who initially developed and continue to refine hydrodynamic codes (such as ROMS – Rutgers and FVCOM – UMass-Dartmouth), ecosystem modeling codes (such as CE-QUAL-ICM – USACE ERDC, and WASP – USEPA) with support for model documentation and training provided by NOAA.

- There needs to be sign-off or agreement by both the scientific and user community that the model is “correct” (verification that model is free of process formulation and software errors), functional and operational. This can be accomplished by performing peer reviews of the models, using such procedures as employed by the USACE in their Community of Practice for certifying models or via the peer-reviewed literature and/or by model evaluation groups (MEGs) again with potential support from NOAA.
- In order to help contain costs, consideration should be given to developing, maintaining and applying OAEMs across multiple systems or coastal and Great Lakes environments. This will provide it own sets of challenges, as each waterbody or ecosystem may have its own unique sets of environmental parameters that need to be considered. Therefore, developing or adapting generalized ecosystem modeling codes should be given a high priority. The generalized open-source modeling system, DELFT3D developed by Deltares (formerly Delft Hydraulics Laboratory) is an example of such a generalized system.
- Another challenge to be addressed is how to provide funding for OAEM. Funding will be required for people, computational clusters, data sources, etc. and regular improvements/updates to the models that incorporate research advances are necessary to keep a model or group of models operational. Funding requirements should be met through congressional authorization/appropriation and not grants.
- A final challenge to be addressed is to determine how outputs from the central and regional models will be used to guide or impact regulatory decisions. Among the options are (1) a multi-agency memorandum of understanding (MOU) that says that all of the affected agencies (e.g. NOAA, USEPA, USFWS, individual state agencies, etc.) will use the modeling center outcomes as the basis for their individual regulatory determinations, or (2) a case-by-case decision to go the modeling center route or (3) is the center more an academic exercise that may be used by those agencies that deem it relevant for big, difficult questions – similar to a National Research Council report.

Examples of Operational Modeling Centers

- Two examples of Operational Modeling Centers that have been existence for over 50 years are the Geophysical Fluid Dynamics Laboratory (GFDL), established in 1955 by NOAA and located at Princeton University and National Center for Atmospheric Research (NCAR), established in 1956 by the National Academy of Sciences and located in Boulder, CO. NCAR and university scientists work together on research topics in atmospheric chemistry, climate, cloud physics and storms, weather hazards to aviation, and developing models capable of predicting the evolution of the climate system. Major funding for NCAR is provided by the National Science Foundation with significant additional support provided by other Federal agencies, as well as other national governments and the private sector. GFDL is a NOAA laboratory that develops and uses models and computer simulations to improve understanding and prediction of the behavior of the atmosphere and ocean, hurricane research and prediction, seasonal forecasting, and understanding and projecting climate change. GFDL is entirely funded by the federal government.
- NOAA has a number of operational systems, operating out of the National Weather Service (NWS) and the National Ocean Service (NOS). NWS systems include:

- the Real Time Ocean Forecast System (RTOFS), which provides global estimates of sea surface height, temperature and salinity and horizontal velocities, ice cover and ice thickness,
- the Climate Forecast System, which monitors and forecasts short-term climate fluctuations and provides information on the effects climate patterns can have on the nation,
- National Hurricane Center provides forecasts of the movement and strength of tropical weather systems and issues watches and warnings for the U.S. and surrounding areas,
- Ocean Prediction Center issues weather warnings and forecasts out to five days for the Atlantic and Pacific Oceans north of 30 degrees North,
- Storm Prediction Center provides tornado and severe weather watches for the contiguous United States along with a suite of hazardous weather forecasts,
- Weather Prediction Center provides nationwide analysis and forecast guidance products out through seven days, and
- Regional River Forecasting Centers, which provides forecasts and guidance that are used for the protection of life and property associated with flooding.
- NOS systems include:
 - Center for Operational Oceanographic Products and Services (CO-OPS) provides real-time and historical observations. CO-OPS also supports:
 - Physical Oceanographic Real-Time System (PORTS), which provides observations of water levels, currents, salinity, wind, and bridge clearance, all of which help mariners to successfully guide ships into and out of the nation's ports. Additionally, PORTS provides forecast model guidance in several major U.S. ports, which supports informed decision making in advance of transit scheduling and loading operations.
 - Operational Forecast System (OFS) operates a national network of operational nowcast and forecast hydrodynamic model systems, which provide nowcast and short-term (0 hr. - 48 hr.) forecast predictions of pertinent parameters (e.g., water levels, currents, salinity, temperature, waves),
 - Integrated Ocean Observing System (IOOS), which is a set of regional networks that provide ocean observation data for decision making and supports the coastal and ocean modeling testbed (COMT) program,
 - Harmful Algal Bloom Operational Forecast System (HAB-OFS), which has an operational forecast system for the Gulf of Mexico and is in the process of converting the Gulf of Maine research forecast model to an operational system, and supports an experimental Lake Erie HAB bulletin using satellite nowcast plus the Great Lakes Coastal Forecast System hydrodynamic modeled currents to provide a three-day forecast of future bloom location, and
 - the National Centers for Coastal Ocean Science (NCCOS), which conduct research programs on HABs, hypoxia, pathogens and regional ecosystem research.
- South Florida Water Management District operates one of the largest regional water management systems in the world. The system has approximately 2,100 miles of canals and 2,000 miles of levees/berms, 70 pump stations and more than 600 water control structures and 625 project culverts. Engineers, meteorologists and water managers

monitor weather and water levels 24 hours a day. They use data and computer models to determine optimal operation of the hundreds of water control structures throughout the system.

- The California Department of Water Resources and the U.S. Bureau of Reclamation have developed and operate a computer model that simulates much of the water resources infrastructure in the Central Valley and the Delta region of California. The model provides information to resource managers concerning technical and policy issues related to water Engineers, meteorologists and water managers monitor weather and water levels 24 hours a day. They use data and computer models to determine optimal operation of the hundreds of water control structures throughout the system.

Recommendation for a Chesapeake Bay Modeling Center

In a recent report from The National Research Council of the National Academy of Sciences, "Achieving Nutrient and Sediment Reduction Goals in the Chesapeake Bay: An Evaluation of Program Strategies and Implementation", a recommendation was made to establish a Chesapeake Bay Modeling Laboratory for the following reasons:

"Establishing a Chesapeake Bay modeling laboratory would ensure that the Chesapeake Bay Program (CBP) would have access to a suite of models that are state-of-the-art and could be used to build credibility with the scientific, engineering, and management communities. The CBP relies heavily on models for setting goals and evaluating nutrient control strategies; thus, the models are essential management tools that merit substantial investment to ensure that they can fulfill present and future needs. Currently, only a few technical professionals are fully knowledgeable of the details of the models and their development. The models are not widely used outside the CBP and, therefore, are unfamiliar to the broader scientific community. Credibility of the models is essential if the CBP goals and strategies are to be accepted and have widespread support. A Chesapeake Bay modeling laboratory would bring together academic scientists and engineers with CBP modelers to examine various competing models with similar objectives and work to enhance the quality of the simulations. An important component of the work of a modeling laboratory would be the integration of monitoring with modeling efforts. Joint research investigations focused on evaluating the success of the Bay recovery strategies could be centered in the laboratory, such as studies on the role of lag times in the observed pollutant loads and Bay responses. A close association with a research university would bring both critical review and new ideas."

These justifications for establishing a modeling laboratory apply equally well for any water quality problem where operational modeling is part of an adaptive management solution. As a consequence, this recommendation from the NRC would also apply to establishment of a NOAA national facility that could serve as the center for these activities.

SECTION 5. RECOMMENDATIONS

In developing the following recommendations, resources used by the Project Team include:

- the needs for short-term and scenario-based operational aquatic ecosystem modeling systems as developed from an analysis of the survey questionnaire,
- information gathered and discussions held at the workshop,
- existing resources and infrastructure within NOAA and other potential Federal partners, and
- the experience in hydrodynamic, water quality and ecosystem modeling of the Project Team.

Perhaps most important of these are the existing resources and infrastructure, which exist within NOAA's current system of National Weather Service's and National Ocean Service's operational centers. Considerable resources and infrastructure are available and could be used as a foundation from which to build, as NOAA moves forward with its Roadmap.

A number of different configurations have been considered and the following is the recommended structure and staffing:

- A National Laboratory staffed with five to ten full time equivalent personnel, and
- Four to five Regional Facilities staffed with three to five full time equivalent personnel.

The National Laboratory is the central facility that coordinates the NOAA effort in operational aquatic ecosystem modeling with a particular emphasis on water quality modeling. It is anticipated that there will be a need for some hydrodynamic modeling expertise as well, but perhaps this can be coordinated with hydrodynamic modelers already staffing the NOS Operational Forecast System regional models as more and more of these regional models come on-line as operational systems. The National Laboratory would be the home of the in-house models and modelers. It would be the location where research and development would take place, and where interactions with academic researchers would occur. New codes, either developed by NOAA personnel or obtained from outside sources (academics institutions or consultant firms) would be checked, tested, validated, and brought on-line. The laboratory would maintain a series of test beds, similar to the COMT program, that would be used to evaluate the performance of new models relative to those previously available. It would provide documentation for the models and training in their use. It would also provide the institutional memory that is critical to maintaining a viable technology.

The Regional Facilities would provide the link between the National Laboratory and the local users. They would interact directly with the personnel that are charged with applying the models for management needs of specific systems within the region. Facility personnel would suggest the appropriate model type and level of complexity that match the problem being addressed. They would also provide direct assistance and, if necessary, training during the model's operational application, help develop a monitoring and research program tailored to the support of the site-specific model, peer-review the model's calibration/confirmation and results

developed for scenario-based applications at appropriate points in the modeling process. Since these facilities would be regional, they would have a more intimate connection and experience with the problems at issue and the habitat being investigated, e.g. marine or freshwater, coastal or inland. In cases where ongoing, operational modeling is called for as part of an adaptive management process, the Regional Facilities would be responsible for developing and implementing that process.

The establishment of both a National Laboratory and Regional Facilities would insure that there is a clear allocation of responsibilities: the stewards of the available technology– the National Laboratory – and the application of the appropriate technology to the management problem that is being analyzed – the Regional Facility. Having the Regional Facilities near the regional needs will facilitate the development of the relationships between the managers that are tasked with solving the problems, and the NOAA personnel that can directly assist in the analysis. The Regional Facilities will also have relationships with the National Laboratory staff that will insure a smoother path from the selection and application of the technology to the analysis of the specific management questions in the region.

The following table offers some thoughts on the various roles that a National Laboratory and Regional Centers could play.

	National Laboratory	Regional Centers
Model Review and Certification	✓	
Model Documentation and Training	✓	
Model Application		✓
QA/QP of Model Application	✓	✓
Stakeholder Outreach		✓
Computational Resources	✓	✓
Identify Research and Data Needs		✓
Coordinate with Federal Partners	✓	

CONCLUSIONS

Given ongoing population growth along our coastal waters (including the Great Lakes) and the ever-changing climatic conditions, our coastal communities and ecosystems continue to be at risk. In order to help manage and protect these resources, managers need tools that help them understand how population growth and associated land use change, climate change and other environmental stressors affect these valuable ecosystems. Mathematical models are one such tool available to managers to help understand cause and effect relationships between environmental stressors and the living resources of coastal and Great Lakes ecosystems. Academic researchers, along with technical experts in industry and government, who are developing and applying models for these purposes should strive to make these models operational, including everything that that entails.

The results of the project questionnaire/survey provide evidence that coastal managers are already making use of scenario-based and forecast-based aquatic ecosystem models to inform their management decisions. It is also evident that the costs of modeling are a small percentage of the total cost to implement management scenarios needed to resolve complex environmental problems. Also, based on presentations made at the project workshop, it is clear that NOAA is well positioned to take an active role in developing capabilities to support operational models that would deliver accurate, relevant, timely, and reliable ecological forecast products. These technical services would help to fulfill directly NOAA's mandates and roles in protection of life, property, human health and well-being, the environment, and coastal and marine stewardship. In part this positioning derives from NOAA's substantial experience (with NWS and NOS) in the development and operational application of forecast models and observational systems to predict movement and strength of tropical weather systems, forecasts of river flooding, provide guidance for navigation into and out of the nation's ports, supports decision making for transit scheduling and loading operation in several major U.S. ports. In addition, NOAA has developed experience in the forecasting of HABs in the Gulf of Mexico and the Gulf of Maine; the former is already operational and the latter is being transitioned into an operational system. Finally, NOAA's NCCOS research programs on hypoxia/anoxia, HABs, pathogens and regional ecosystem research all represent invaluable experience for NOAA to take a lead role in the supporting the development and application of Operational Aquatic Ecological Models.

References

- Bierman, V.J., D.M. Dolan, R. Kasprzyk and J.L. Clark, 1984. Retrospective analysis of the response of Saginaw Bay, Lake Huron, to reductions in phosphorus loadings. *Environ. Sci. Technol.* 18: 23-31.
- Chapra, S.C., 2003. Engineering water quality models and TMDLs. *J. Water Resour. Plann. Manage.* 129(4):247-256.
- Clark, J.S., S. R. Carpenter, M. Barber, S. Collins, A. Dobson, J. A. Foley, D. M. Lodge, M. Pascual, R. Pielke, Jr., W. Pizer, C. Pringle, W. V. Reid, K. A. Rose, O. Sala, W. H. Schlesinger, D. H. Wall, and D. Wear. 2001. Ecological forecasts: an emerging imperative. *Science* 293:657-660.
- Committee on Environmental and Natural Resources, 2001. *Ecological Forecasting*, Washington, D.C., 12pp.
- DePinto, J.V. "Advances in Integrated Modeling in the Great Lakes." Invited presentation at EPA sponsored symposium entitled "Integrated Modeling for Analysis to Support the Management and Restoration of Large Aquatic Ecosystems." Washington, DC (January 20-21, 2010).
- DePinto, J.V. 2013. Toward operational ecosystem modeling to support adaptive management in the Great Lakes. 56th IAGLR Conference, Purdue University, IN (June 02-13, 2013).
- Dingman, J. S., and K. W. Bedford, 1986. Skill tests and parametric statistics for model evaluation. *Journal of Hydraulic Engineering*, 112, 124 - 141.
- DiToro, D.M., N.A. Thomas, C.E. Herdendorf, R.P. Winfield, and J.P. Connolly, 1987. A post audit of a Lake Erie eutrophication model. *Internat. Assoc. Great Lakes Res. J. Great Lakes Res.* 13(4):801-825.
- Georgas, N. and A.F. Blumerg, 2010. Establishing confidence in marine forecast systems: The design and skill assessment of the New York Harbor Observation and Prediction System, Version 3 (NYHOPS v3). *Estuarine and Coastal Modeling* (2009): pp. 660-685
- Haidvogel, D.B., H. Arango, W.P. Budgell, B.D. Cornuelle, E. Curchitser, E. Di Lorenzo, K. Fennel, W.R. Geyer, A.J. Hermann, L. Lanerolle, J. Levin, J.C. McWilliams, A.J. Miller, A.M. Moore, T.M. Powell, A.F. Shchepetkin, C.R. Sherwood, R.P. Signell, J.C. Warner, J. Wilkin, 2008. Ocean forecasting in terrainfollowing coordinates: formulation and skill assessment of the Regional Ocean Modeling System, *J. Comput. Phys.* 227:3429–3430.
- Hess, K.W., T.F. Gross, R.A. Schmalz, J.G.W. Kelley, F. Aikman, E. Wei and M.S. Vincent, 2003. NOS standards for evaluating operational nowcast and forecast hydrodynamic model systems. NOAA Technical Report NOS CS 17.
- Hetland, R.D. and S.F. DiMarco, 2012. Skill assessment of a hydrodynamic model of circulation over the Texas–Louisiana continental shelf. *Ocean Modelling.* 43-44: 64-76.
- Levin, D., F. Aikman, A. Allen, F. Bub, G. Jacobs, C. Mooers, S. Payne, R. Signell, H. Tolman, 2011. Transition of models to operations (Draft). http://www.ioos.noaa.gov/modeling/reports/model_r2O_drl_2011_05_02.pdf
- Lesht, B.M., T.D. Fontaine, and D.M. Dolan, 1991. Great Lakes total phosphorus model: post audit and regionalized sensitivity analysis. *J. Great Lakes Res.* 17(1): 3-17.

- Levin, P.S., C.R. Kelble, R.L. Shuford, C. Ainsworth, Y. deReynier, R. Dunsmore, M. J. Fogarty, K. Holsman, E.A. Howell, M. E. Monaco, S.A. Oakes, and F. Werner, 2013. Guidance for implementation of intergrated ecosystem assessments: a US perspective. ICES J. Marine Science. doi:10.1093/icesjms/fst112.
- Lorenzen, K., 1995. Population dynamics and management of culture-based fisheries. *Fisheries Management and Ecol.* 2:61-73
- Lynch, D.R., D.J. McGillicuddy, Jr. and F.E. Werner, 2009. Skill assessment for coupled biological/physical models of marine systems. Special Issue. Lynch, McGillicuddy, and Werner (Eds.). *J. Mar. Syst.* 76(1-2): 250 pp.
- NOAA, 2001. Implementation of advanced hydrological prediction service. NOAA National Weather Service. Office of Hydrologic Development
- NOAA, 2003. NOS Procedures for developing and implementing operational nowcast and forecast hydrodynamic model systems. NOAA Technical Report NOS CO-OPS 39. Silver Spring, MD.
- NOAA, 2010. Transition of innovation and research to operations. National Weather Service Policy Directive 80-8. <http://www.nws.noaa.gov/directives/080/pd08008a.pdf>
- Obenour, D.R. A.D. Gronewold, C.A. Stow, and D. Scavia (in press). [Using a Bayesian hierarchical model with a gamma error distribution to improve Lake Erie cyanobacteria bloom forecasts](#). *Water Resources Res.*
- Peterson, G.D., G.S. Cumming, and S.R. Carpenter, 2003. Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology* 17(2):358-366.
- Post, J.R., C. Mushens, A. Paul, and M. Sullivan, 2003. Assessment of alternative harvest regulations for sustaining recreational fisheries: model development and application to bull trout. *North Amer. J. of Fisheries Management.* 23: 22-34.
- Reckow, K., A. Donigian, J. Karr, J. Mandrp-Poulsen, S. McDonald, V. Novothy, R. Smith, and C. Yoder. 2001. Assessing the TMDL approach to water quality management. National Academy Press, Washington, DC.
- Sandifer, P. A., T. K Collier, and J. M. Trtanj. 2012. Coastal ecosystems, sustainable management. *Encyclopedia of Sustainability Science and Technology.* Meyers, R.A. (Ed.) Springer
- Streeter H. W. and E.B. Phelps. 1925. A Study of the pollution and natural purification of the Ohio river. III. Factors concerned in the phenomena of oxidation and reaeration, *Public Health Bulletin no. 146*, Reprinted by U.S. Department of Health, Education and Welfare, Public Health Service, 1958, ISBN B001BP4GZI, <http://dspace.udel.edu:8080/dspace/bitstream/handle/19716/1590/C%26EE148.pdf?sequence=2>
- Stumpf, R.P., M.C. Tomlinson, J.A. Calkins, B. Kirkpatrick, K. Fisher, K. Nierenberg, R. Currier, and T.T. Wynne, 2009. Skill assessment for an operational algal bloom forecast system. *J. Mar. Syst.* 76(1-2): 151-161.
- Thomann, R.V., 1988. The future "Golden Age" of predictive models for surface water quality and ecosystem management. *J. Environ. Eng.* 124(2):94-103.
- USACE, 2005. Planning models improvement program: model certification. Engineer Circular No. 1105-2-407. Washington, D.C.

- USACE, 2011. Assuring quality of planning models. Engineer Circular No. 1105-2-412. Washington, D.C.
- USEPA , 1980. Workshop on verification of water quality models. Thomann, R.V. and T.O. Barnwell (Editors). EPA-600/9-80-016.
- USEPA, 2009. Guidance on the development, evaluation and application of environmental model. Office of the Science Advisor. CREM. EPA/100/K-09/003. 90pp.
- Valette-Silver, N.J. and D. Scavia. 2003. Ecological Forecasting: New Tools for Coastal and Ecosystem Management. NOAA Technical Memorandum NOS NCCOS 1. 116 pp.
- Vested, H. J., J.W. Nielsen, H.R. Jensen, and K.H. Kristensen, 1995. Skill assessment of an operational hydrodynamic forecast system for the North Sea and Danish Belts. In Quantitative skill assessment for coastal ocean models, 373-396.
- Warner, J.C., W.R. Geyer, and J.A. Lerczak, 2005. Numerical modeling of an estuary: A comprehensive skill assessment. J. Geophys. Res. Oceans. 110(5).
- Zhang, A., K.W. Hess, and F. Aikman, 2010. User-based skill assessment techniques for operational hydrodynamic forecast systems. J. Operational Oceanogr. 3(2): 11-24.

APPENDIX A. WORKSHOP PARTICIPANTS

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APPENDIX B.

SUMMARY OF WORKSHOP PRESENTATIONS

This Appendix presents brief summaries of the key points made by the presenters together with follow on discussions by the workshop participants.

Burke: NOAA NOS CO-OPS Program Overview

Dr. Pat Burke (NOAA NOS/CO-OPS) presented an overview of NOAA's Center for Operations Oceanographic Products and Services (CO-OPS) program. The mission for NOAA's CO-OPS is to develop a national network of operational hydrodynamic models that perform 24-hr nowcasts and 48-hr short-term forecasts. The primary motivation for this effort is to support safe and efficient navigation (water levels for ship clearance, currents for maneuverability and temperature and salinity for density and vessel loading). This Center also provides for emergency response (search and rescue, HAZMAT and homeland security), and it is also developing ecological forecasting to support environment management of the coastal zone, an example of which is HAB modeling in the Gulf of Maine.

Dr. Burke identified the following issues as being key in developing the CO-OPS operational modeling system.

- It must meet 'client' needs.
- It must be operational continuously (24/7), with automated product generation, and it should account for redundancy both of computer platforms performing the forecasting runs, but also redundancy of inputs to run the model.
- It must have QA/QC continuously monitored.
- It must have ongoing maintenance, support and planned product development.
- It must provide for accuracy, timeliness and reliability of results.

Currently, the CO-OPS program has a staff of four modelers that support 15 regional models. The number of modeling codes being supported is fairly limited (six computational codes) with two of the codes, FVCOM and ROMS, being the main codes used to generate regional forecasts. NOAA depends mainly on academic colleagues from Rutgers (ROMS) and UMass-Dartmouth (FVCOM) for model development and support. The CO-OPS program also has a well defined set of skill assessment metrics with defined error criteria that the modelers strive to meet. The initial motivation for development of the CO-OPS program came from the navigation/shipping community. The navigation team also strives to operate like National Weather Service (NWS), in terms of accuracy, timeliness and reliability of results. The CO-OPS program is also supported by the NWS, which provides some of the data required to run the hydrodynamic models (networks of water-level sensors, current meters, and wind anemometers).

Key Points and Conclusions: Models should meet client needs and expectations, including passing QA/QC and skill assessment metrics, recognizing the need for ongoing maintenance, support and development, and providing reliable results.

Batiuk: Chesapeake Bay Modeling System

Rich Batiuk (USEPA Chesapeake Bay Program) presented an overview of the Chesapeake Bay integrated modeling system. The modeling system is composed of linked models that include (1) an airshed model, used to generate precipitation and atmospheric deposition of nutrients to (2) a land-use based watershed model, which provides runoff water flows to (3) a hydrodynamic model and pollutant nutrient loads to (4) a water quality model. The hydrodynamic model provides information concerning pollutant transport and sediment resuspension and transport to the water quality model and the water quality models accounts for the linkages between nutrients, phytoplankton biomass and primary production and dissolved oxygen, and light availability to submerged seagrasses. The water quality model also includes (5) a sediment oxygen demand and nutrient flux submodel and (6) a benthic filter-feeder submodel.

Given the size and complexity of the Chesapeake Bay catchment, the watershed model is the key component and workhorse of the integrated modeling system, since that is how waste load allocations (WLAs) are assigned and evaluated in order to determine whether the Bay total maximum daily load (TMDL) is meeting the Bay's water quality standards and designated uses. The USEPA also developed the Chesapeake Assessment Scenario Tool (CAST) to manage the 100's of scenarios (involving millions of people, hundreds of point/non-point source urban discharges, thousands of farms, etc.) that need to be evaluated to meet the TMDL.

Batiuk also provided his definition of what operational meant for the Chesapeake Bay modeling system. What makes this system operational is that there was universal sign-off by the Chesapeake Bay Partnership (6 states, multiple federal agencies, academics, etc.) for its use in management applications. Keeping it operational has been accomplished by a collaborative decision making process among representatives of the partnership, and it is important to recognize that the Bay Program's modeling system is undergoing constant development and re-calibration as the science and understanding of the Bay increases over time. Batiuk concluded his presentation by mentioning that the Bay Program is moving towards use of multiple models to inform the decision making process.

In follow-up questions and discussion on the Bay Program's moving towards the use of multiple models, Batiuk said that the EPA does not see a problem with the use of multiple models, but acknowledged that it does present some challenges from a legal/regulatory point of view. However, he concluded with the comment that making everything available or accessible for review should help to minimize that concern.

Key Points and Conclusions: There has been a sign-off and agreement by user community, recognizing the need for and plan for ongoing refinement and development and considering the utility of multiple or ensemble models.

DePinto: Lake Erie HAB Modeling

Dr. Joe DePinto (LTI) presented an overview of eutrophication and HAB modeling in Lake Erie. He began his presentation with an overview of the history of how ensemble modeling was applied to establish target phosphorus (P) loads for the Great Lakes. These models included a range of complexity from the empirical model of Vollenweider, to the simple mass balance model of Chapra, to the more complex process-based models of Thomann, DiToro and Bierman. The initial mechanistic models were strong on processes but weak on spatial resolution, but P target loads were developed for the Great Lakes using these models. The target load for Lake Erie was attained in the early 1980's. However, while many of the models were successfully

post-audited (DiToro et al., 1987; Lesht et al., 1991), efforts to continue to compile loads and continue with modeling pretty much ceased in the early 1990s.

Dr. DePinto pointed out that these water quality models did not remain active because (1) modelers moved away, (2) the eutrophication had been "solved" and (3) toxics moved to the forefront. However, in late 1990's blooms of the harmful alga *Microcystis* reoccurred and hypoxia returned to Lake Erie. But since the monitoring and modeling had not been maintained in an operational sense, the management community did not know whether the re-eutrophication was the result of increased nutrient loading or changes in the ecosystem structure and function (e.g., introduction of Dreissenid mussels). Subsequently, eutrophication modeling became active again with finer spatial resolution and updated ecosystem function and structure. Since about 2007, there has been a large re-eutrophication assessment initiative, and currently there is an effort to apply a multiple or ensemble modeling approach to revise the target nutrient loads to Lake Erie. Also, there has been consideration of the use of adaptive management, which involves assessing the problem, designing and implementing a solution, monitoring and evaluating for change and/or improvement, adjust target and goals and performing those tasks in an iterative process until the goals and waterbody uses were obtained. The Lake Erie resource management and modeling community now desires to have ongoing operational model development that considers multiple drivers and multiple endpoints.

Key points and Conclusions: Recognize that for models to be operational they cannot be used and put on the shelf, and they need to undergo periodic updating and revision; consideration of multiple or ensemble modeling. It should be further recognized that there is need for an institutional home for the model(s) with an adequate operational budget.

Kreis: Lake Michigan and Great Lakes Operational Ecosystem Modeling

Dr. Russ Kreis (USEPA-ORD) presented an overview of Great Lakes water quality scenario models and the Lake Michigan mass balance models, in particular. There are a number of environmental issues in the Lake Michigan that benefit from the use of models to inform management decisions. These include: nutrients/eutrophication; toxicants, including atrazine, PCBs, and mercury; mass balance nutrient/contaminant modeling: nutrients and eutrophication and contaminants, including atrazine, PCBs and total Hg. The Federal government has provided about \$1M each for model development, calibration and application of models to address each of these environmental concerns and has used multiple linked models (hydrodynamics, water quality-eutrophication, contaminant fate and transport and food webs). These models are complex and time-consuming due to the need to run decadal scenario-based forecasts. Dr. Kreis emphasized the importance of post-audit modeling and the need to recognize ecosystem change. In Lake Michigan these changes include: introduction of invasive species, such as zebra and quagga mussels and goby fish; alteration of planktonic communities and biomass; the extirpation of the benthic invertebrate, *Diporeia*; and alteration of forage and predatory fish diets.

Dr. Kreis posited that water quality monitoring is more expensive than maintaining models and provided some rough costs relative to operational feasibility. They are:

- routine maintenance - \$5-10k
- transfer model to different computer system/platform - \$100k
- new field studies/laboratory analyses
 - watershed loads - \$750k
 - water column data - \$250k
 - diet study - \$400k
 - biological analysis - \$500k
- model recalibration and application - \$300k

Key points and Conclusions: Environmental models are complex and often multi-faceted; some may require decadal scenario-based simulations. Supporting data for model inputs and model calibration are often considerably more than the cost of the model application and maintenance.

Scavia: Gulf of Mexico – Multiple Modeling Approaches

Dr. Don Scavia presented an overview of results from an ensemble of models developed to assess initiation of hypoxia (early 70's) and to target nutrient reduction goals to reduce the spatial extent of hypoxia in the Gulf of Mexico (GOM). The models ranged from statistical/regression models (Turner) to simple ecology models with varying spatial domains (Justic, Scavia, and Obenour) to complex ecological models with quasi-3D resolution (Bierman). Two of the models (Turner's and Scavia's) also provided a measure of the uncertainty around the nutrient reduction goals estimated by respective models. The ensemble of models provided somewhat consistent target nutrient reductions to achieve hypoxia goals, demonstrating the power in ensemble modeling when they tell you roughly the same thing.

Dr. Scavia pointed out that for each of these models there was a relatively modest level of funding for model development/calibration relative to the costs of data collection and generating estimates of nutrient loading rates to the Gulf.

Key points and Conclusions: These current GOM models are not complex and do not need to be run by "operational agencies"; there is strength in ensemble modeling when the models provide roughly comparable advice; there was agreement that simple models can be used to help determine and assess "driver-response" behavior and inform the public, and that more spatially refined models and possibly "ecosystem" refined models can provide more detailed responses once better developed, tested, and confirmed .

Kidwell: State-of-the-Science Modeling in the Gulf of Mexico

Dr. David Kidwell presented an overview of the next level of mathematical modeling in the Gulf of Mexico meant to provide greater insights in the spatial and temporal response of GOM hypoxia to nutrient loadings and physical forcing such as hurricanes and large storm events. Dr. Kidwell reviewed the suite of models being developed by the USEPA and a model being developed by Rob Hetland (Texas A&M) and Katja Fennel (Dalhousie U.). All of these models are based on a greater level of biogeochemical understanding of nutrient dynamics and interactions with phytoplankton and hypoxia, and they will provide greater spatial and temporal resolution of the physical factors that affect hypoxia. These models are, however, still undergoing development and calibration.

Dr. Kidwell also described the findings of a 2013 workshop and technical panel that evaluated the existing models in terms of their ability to address key management questions and their

readiness for transition to operational status. He stated that the existing statistical models have a demonstrated track record for informing nutrient management and are ready for transition to an operational framework, but, while deterministic models have advanced significantly in the past few years, they are not quite ready for operational use because they need additional calibration/validation. So the decision, for now, is to stay with statistical models to set nutrient reductions goals, but NOAA expects to continue moving toward deterministic modeling approaches as they become better calibrated.

Key Points and Conclusions: Simple scenario forecast models still have relevance to address environmental problems, but the expectation is that more complex, deterministic models may be better able to provide spatial assessments of hypoxia response to nutrient management, as well as better seasonal and short-term forecasts. More detailed, mechanistic models may also provide for better coupling with ecosystem and living resource models.

Friedrichs: IOOS Testbed Support for Scenario-based Ecological Forecasts

Dr. Marjorie Friedrichs presented an overview of the benefits that the U.S. IOOS Coastal Ocean Modeling Testbed (COMT) provides in supporting scenario-based ecological forecasts. These benefits include:

- the development of tools to simplify access to data, to support models and to simplify access to model outputs,
- the advancement of common infrastructure and more rapid deployment from research to operational mode,
- the advancement of “skill metrics” used to evaluate model performance, and
- progress in prototyping and testing of models.

While there are five COMT teams, Dr. Friedrichs focused her presentation on the work being performed by the Chesapeake Bay Estuarine Hypoxia Forecasting team and a discussion of ensemble modeling and associated skill assessment.

Key Points and Conclusions: Dr. Friedrichs provided a definition of operational for the COMT models – it is a system that regularly produces hindcasts/nowcasts/forecasts that satisfy a management need, ideally with uncertainty estimates. Promoting the idea of simulation models becoming operational will benefit from considering the use of multiple models, the use of hindcasting, which identifies models with greatest skill and identifies errors in models. The use of multiple models in forecasting can provide uncertainty estimates. Funding for people, computational clusters, and data management, and regular model refinements that incorporate research advances, is necessary to keep a model or group of models operational.

Rose: Fisheries Modeling - Challenges Faced

Dr. Kenny Rose (LSU) provided viewpoints of what the state-of-the-science is in fisheries modeling and what challenges there are to operational fisheries modeling. He referred to the strict definition of operational being more like NOAA's NOS national operational coastal modeling program's definition as presented by Dr. Burke versus a looser definition that might be appropriate for fisheries models. For example, a fisheries model that has been highly calibrated to long-term monitoring datasets might be considered operational. He also stated that if a model is being used for tactical fisheries management decision making, then it is already operational.

He provided several examples of where fishery models are being used to inform management decisions including fish stock rebuilding plans in the U.S., modeling of river diversions in Breton Sound. These might include modeling fish movement and habitat issues, as well as model scenario evaluation involving multispecies fisheries management and conservation. He also provided a brief description of an end-to-end operational modeling framework that simulated anchovy and sardine in the California Current. It included a 3-D hydrodynamic model for physics, a NPZ model to provide estimates of phytoplankton biomass as a food source for the anchovy and sardine, a multi-species IBM for fish and a fourth model of fishing fleet dynamics for estimating harvesting losses. He also mentioned two other end to end fisheries modeling frameworks: Atlantis and IEA.

Key Points and Conclusions: Operational models should be coupled – physics to fish; physicists and biologists should jointly develop biophysical models; operational models need to account for multiple spatial resolutions and should be time-dependent; suggestion for a center for ecological modeling and forecasting with the following roles: workshops for training and conveying lessons learned; model development; testing and inter-comparison of models; develop next generation models.

Townsend: NOAA Fisheries/Ecological Modeling

Dr. Howard Townsend (NOAA NMFS/CBPO) described various levels of marine ecosystem management and a fisheries management process. He also discussed heuristic vs. strategic vs. tactical models used to inform fisheries management. Dr. Townsend pointed out that lots of models are available from statistical models to stock assessment models to multi-species models to biomass dynamics models to true ecosystem models. These models differ on their linking of spatial and temporal scales and habitat data.

Key Points and Conclusions: There are many models to choose from depending upon the fisheries question being addressed. There is potential for collaboration with oceanographic data collection. Infrastructure gaps exist in the ability to deliver ocean and forecast model output to ecological models; habitat data are spatially and temporally patchy, and there is a need to work on handling and evaluating model uncertainty and model coupling (i.e., ocean to ecological).

Stumpf: NOAA HAB Forecasting

Dr. Richard Stumpf (NOAA NCCOS) provided an overview of the nation's coastal and Great Lakes HAB issues and described work that NOAA is doing to build an integrated system that deals with a national problem but focuses on regional ecology. NOAA has spent between \$10 M/year and \$20M/year over the past 10 years in researching HABs and working towards building operational HAB forecast models. The models Stumpf presented are not scenario-based forecast models, but rather are more similar to the NWS forecast systems. More recent developments by Stumpf and others (e.g., Obenour et al. in press) have produced similar models that are also useful in scenario mode.

Key Points and Conclusions: Dr. Stumpf provided some background on his definition of operational as it relates to HAB forecasts, which included the following points. Forecasts are analyses, models are guidance, interpretations are forecasts (this is standard for weather forecasts). Operational HAB forecasts should be scheduled – produced as scheduled (daily to weekly), with model guidance produced as scheduled before forecasts. The system has to be

reliable and operational on a 5 (or 7) day week with model operators available to fix problems before forecasters see them. Institutional requirements include the fact that operational systems or centers should be base-funded not grant-funded. They should have standard operational procedures (SOPs), there should be user training, and there should be annual assessment and evaluation of the models. He also identified challenges or needs for HAB forecast models, which included better data on bloom initiation/location with which to initialize the model and data with which to validate the models. Finally, Dr. Stumpf described some criteria for an operational forecast model, which included: that the model must be scientifically vetted or peer reviewed, and it must also be user vetted, where the vetted forecasts are useful (for managers not researchers). The model must be transferable, in that its capability should not depend on one expert or computer, and it must meet the operational definition, i having SOPs, training materials, skill assessment criteria, and a strategy to provide required resources. Scenario-based models have similar requirements, although not including near real-time dimensions.

Leo: Massachusetts Bay

Wendy Leo presented an overview of the Massachusetts Bay Eutrophication Model, its uses, operational challenges and lessons learned. The model was initially developed to address concerns about dissolved oxygen depletion and buildup of organic material in the vicinity of the outfall before the implementation of secondary treatment as well as to address concerns over bay-wide eutrophication due to nutrient enrichment. The model, which is now based on the FVCOM hydrodynamic model and the RCA water quality model is built into MWRA NPDES permit, which requires that the model be updated, maintained and ran every year to support decisions about the need for nutrient limits. The model is considered to be semi-operational and is reviewed by a Model Evaluation Team.

Key Points and Conclusions: For MWRA, the term operational means that the model meets the requirements of its NPDES permit. To keep it operational requires ongoing monitoring as a source to specify boundary conditions, and it needs to be continually checked that it is "still working." By working, we mean that it is reproducing the key trends and features of the bay-wide compliance monitoring program. There must be easy access to modeling results as well as archiving model results for each year. The operational model has potential utility to other dischargers besides MWRA. Federal support could include providing funding for continuous monitoring, e.g., the IOOS buoys and for sponsoring and helping to staff a "model evaluation group" to peer review the model.

Connor: San Francisco Estuary Management Perspective

Dr. Mike Connor (East Bay Dischargers Authority) provided an overview of model integration needs for the San Francisco Bay Estuary and for building user capacity for the Estuary's decision-makers. The SFB Estuary is faced with five manageable ecosystem stressors, as well as changing ecosystems that are responding or have responded to invasive species. The management community spends about \$50M each year in data collection. There are several available models, mostly hydrodynamic models and a few ecosystem models, but there is little

integration and funding for modeling (\$10 million on modeling with \$200 million in data monitoring/research). Environmental managers are facing multi-billion dollar decisions (water rights/management, wetlands restoration, nutrient reduction, toxics) and realize that operational models are something to improve decision making and something that all parties have to sign off on.

Key Points and Conclusions: Given interactions among all major stressors, there is a need to make data streaming between different models operational. There is also a need to integrate models for evaluating tradeoffs among ecosystem services and perhaps apply gaming technologies. Models should be able to address what kind of ecosystem services do we want and where, and they should be able to provide a picture of the past, present and desired future. Furthermore, models, supported by data, should be able to assess whether goals/targets are being met and if not what needs to be done to adjust them or manage differently.

Fitzpatrick: USACE Community of Practice

James Fitzpatrick (HDR) presented an overview of the USACE Community of Practice (COP), its purpose and what it takes to get a model certified. By the late 1990's the USACE was becoming concerned with the large number of models used in water resource projects and the decentralized approach towards model development which had costs, maintenance and training implications, and a desire to eliminate "home-grown" models.

Key Points and Conclusions: In developing the COP the USACE came up with the following goals: (1) develop planning centers of expertise to provide confidence and transparency in models; (2) developed certification goals and a process to ensure that models are theoretically sound, computationally accurate, transparent and that fully describe assumptions and limitations, i.e., well documented. Thus, USACE described a procedure for model testing before the model is certified for use. However, what is not covered in the COP is the skill set of those that utilize and run the models.

Kremer: CREM and Modeling at the USEPA

Janet Kremer presented an overview of the USEPA's Council for Regulatory Environmental Modeling (CREM) and a description of CREM's purpose and objectives. These include: (1) to promote scientific integrity and defensibility in modeling principles, practices, and guidance; (2) to encourage quality practices and principles in modeling; (3) to serve as a dynamic forum, actively-sought source of expertise, and central point of contact; and (4) to coordinate with internal and external stakeholders. As a result of the complexity of modern environmental problems and decisions, it has required EPA scientists to consider the environment in a holistic manner and focus on end points of concern and develop an integrated environmental modeling approach to address environmental problems.

Key Points and Conclusions: A primary objective of all models is communication. CREM and IEM goals are to provide access to experts, access model documentation and archiving applications and get information and models into a position to succeed.

The two concluding presentations for the first day discussed (1) what NOAA could offer in support of scenario-based ecosystem modeling and (2) a perspective on why scenario-based models are needed. The latter also provided a brief discussion of the goals for the break-out

sessions planned for the morning of the second day of the workshop. A brief overview of these presentations follows.

Turner: What can NOAA provide?

Dr. Beth Turner stated that one of the goals of the NOAA Administrator is for NOAA to provide information and services to make communities more resilient to severe environmental events. This can be accomplished through “Environmental Intelligence,” which includes observations, monitoring, assessment, modeling and forecast and products. NOAA has developed an Operational Ecological Modeling Roadmap, a plan that combines capabilities across the agency into one framework and delivers coordinated, accurate, and resource-efficient ecological forecast products. While NOAA has a long history in environmental forecasting, as of now it has no holistic plan to accomplish its Operational Ecological Modeling Roadmap. NOAA has ecological teams that are developing experimental forecasts for HABs, pathogens, hypoxia, species distribution change and habitat and ocean acidification, but wants to take the next step forward in developing the Roadmap; hence the purpose of this project, the workshop and white paper. Dr. Turner presented an overview of the Operational Ecological Modeling Roadmap, which essentially provides a general pathway for the transition of a scenario based forecast model from research to operations. However, she pointed out that the transition would probably be a continually iterative process with a potentially long time frame and many feedback loops.

Dr. Turner then provided a brief overview of what an operational ecological modeling framework might look like. She pointed out, that while there are many components to be developed for any type of forecast or scenario model, there are many components that are relatively common among the types of forecast models that may need to be developed.

It was also recognized that not all forecast models would use all the boxes in the same way. Some forecast models might have a greater need for certain boxes, e.g. weather models requiring remote and *in situ* observations, than others, and some might be able to ignore certain boxes, perhaps requiring little or no archiving of previous results. The thought or hope is that this diagram captures the basic things that need to be in place for an operational ecological forecast.

Dr. Turner then provided a list of the current operational forecasts run by NOAA. These included the following:

- National Weather Services systems: the Real Time Ocean Forecast System (RTOFS), the Climate Forecast System, and Regional River Forecasting Centers,
- National Ocean Service CO-OPS systems: Tides and Water Levels, HABs (GOM forecasts with other locations in development), Operational Forecast System (OFS), Integrated Ocean Observing System (IOOS), Office of Response and Restoration (ORR), and the National Centers for Coastal Ocean Science (NCCOS) research programs on HABs, hypoxia, pathogens and regional ecosystem research, and
- National Marine Fisheries Service (NMFS): Regional Science Centers.

Key Points, Conclusions and Discussion: There may be a need to consider linking to or working with other agencies or institutions. To develop such an operational system, there will be a need to leverage existing resources, both within and outside of NOAA and to get a handle on budget requirements at different levels of connectivity. Perhaps, one strategy would be to pick a specific environmental concern and develop a roadmap based on that concern and learn the lessons to be learned, work to improve the process and

expand to other environmental concerns. One lesson learned from the EPA and the regulatory community is that TMDL models are often incorrectly applied, in some cases due to the choice or limitations of the model and sometimes due to the lack of skill of the modeler. Can this be “fixed” with a national modeling center of excellence? Given that there is a programmatic hammer, the Clean Water Act that permits enforcement, and given that monitoring/modeling is 2-5% of the cost of implementation of a management action, one would think that obtaining based-funding to support a national or regional modeling centers would be possible. Economic arguments are necessary – cost-benefits to fisheries, drinking water, habitat, recreation. It is noted that EPA may have lost its reputation/identity as the lead agency for environmental modeling.

DiToro: Assessing the Need for Operational Modeling and Setting the Stage for Day 2

Dominic DiToro’s presentation focused on the need for operational modeling, making note of the following points.

- Water quality issues arise as new or recurring problems.
- Historically, these problems have been dealt with in an ad hoc manner (negotiated settlements, uniform treatment, using simplified/inappropriate/incorrect analysis, nutrient criteria, TMDL modeling).
- There is a significant contrast between Superfund (detailed/expensive/small regions) and water quality (less detailed/larger areas/less resources) investigations.
- In water quality and even in Superfund the costs of study/solution are much less than costs associated with NASA, DOD and other engineering projects.
- Constructing modern water quality models is a major undertaking requiring specialized resources and personnel.
- Once a water quality problem is “solved” all too often, the model is no longer needed and gets put on the shelf – this is an operational issue.

Dr. DiToro raised the following questions concerning the need for operational models.

- Is there a need (diagnosis, planning, regulatory)?
- How uniform are the requirements/needs – do they require a common basis i.e., data inputs, coastal and Great Lakes hydrodynamic models, etc.?
- What are the scales that need to be addressed – local/regional/national?
- Where do model codes come from?
- What are the required frameworks: hydrodynamics + mass transport + kinetics?
- What types of data are needed: calibration/validation, hindcasts, inputs, etc.
- What about model maintenance: how does it get accomplished?

Key Points, Conclusions and Discussion: There is a need for operational models to help inform multi-million dollar decisions. Modeling related costs are relatively cheap compared to implementation costs. Models need to go through life-cycles, and there is need for continuous updating based on new scientific data and knowledge. Funding needs to be through congressional authorization/appropriation and not grants. Options for NOAA to consider include: (1) a centralized national center; (2) a centralized organization with regional partners; (3) fully regionalized offices; and/or (4) academic and environmental consultants. Currently we are spending \$100 billion on restoration activities (reference?) – can it be better spent? How do we account for climate change

impacts on restoration? We also need to recognize the importance of data and science not just modeling.

