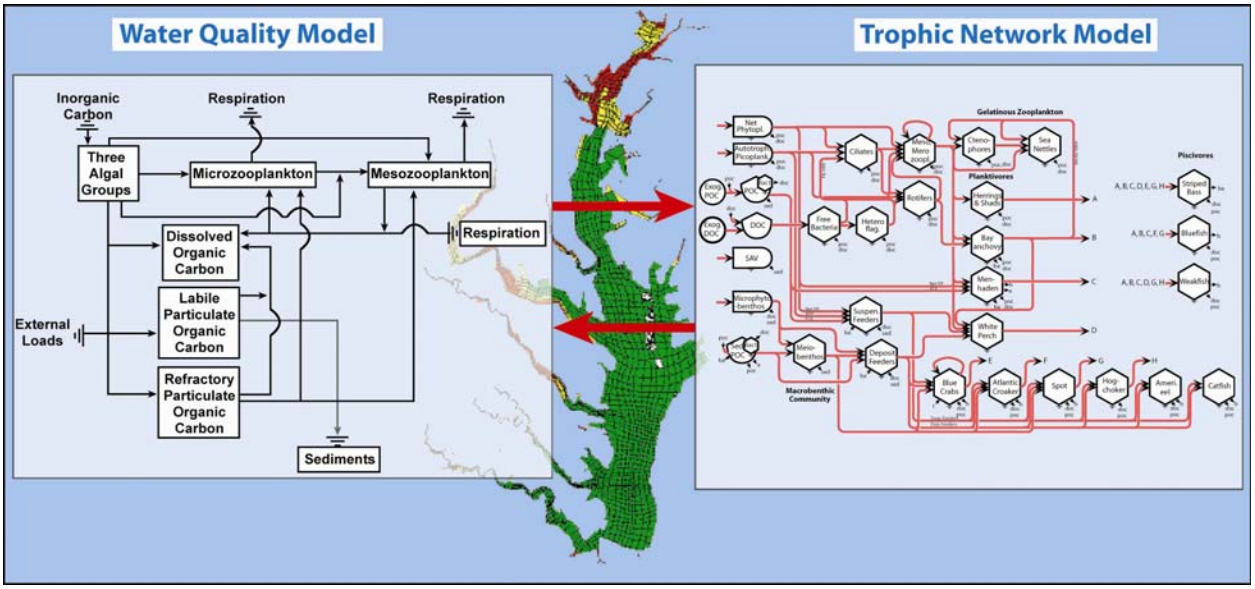
Coupling Water Quality and Upper Trophic Level Models for Chesapeake Bay: A Planning Workshop



US EPA Chesapeake Bay Program
Annapolis, Maryland
January 8-9, 2004

Sponsored by the Chesapeake Bay Program's
Scientific and Technical Advisory Committee

March 2005
STAC Publication 05-002

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The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program on measures to restore and protect the Chesapeake Bay. As an advisory committee, STAC reports quarterly to the Implementation Committee and annually to the Executive Council

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Introduction

Background

Recent publications of the *Chesapeake 2000* agreement (C2K) and the *Fisheries Ecosystem Plan* reflect the growing interest in integrated management of water quality and fisheries. Together, these two directives call for a combination of: (1) ecosystem-based fisheries management, (2) water quality improvements to restore key fish habitats, and (3) management of populations at lower trophic levels for water quality benefits. The US EPA Chesapeake Bay Program (CBP) has invested in a variety of numerical modeling approaches to address issues related to management of the estuary. The Chesapeake Bay Water Quality Model (*CBWQM*) has been a primary tool used to simulate estuarine ecosystem responses to alternative nutrient and sediment watershed management policies. Although this model includes variables related to food supply at lower trophic levels (phytoplankton, zooplankton, benthic macrofauna) and related to benthic habitat conditions (dissolved oxygen, water clarity, seagrass), it does not simulate fish populations. The NOAA Chesapeake Bay Office (NCBO) has sponsored development of a fisheries-oriented trophic network model for the Bay using a widely applied software package (*Ecopath with Ecosim,* or *EwE*).

Members of the CBP Scientific and Technical Advisory Committee (STAC), working with the CBP Modeling Subcommittee and NCBO, organized a meeting in Annapolis, MD on January 8-9, 2004 to examine the potential for coupling these two modeling approaches (*CBWQM* and *EwE*) to address questions pertaining to integrated management of water quality and fisheries. The workshop was structured around a series of presentations that described existing models and previous efforts to couple similar models of ecosystems, water quality, food webs and fisheries.

Motivating Questions

As indicated above, there were a range of scientific and management objectives that motivated the organization of this workshop. The following two management questions served to focus the structure of this workshop.

(1) How important are interactions among estuarine water quality, habitat condition, and exploited animal populations at upper trophic levels?
(2) What are the key mechanisms by which interactions occur, and what is the relative importance of both “bottom-up” and “top-down” processes?

Although these questions provided a starting point for organizing the workshop, it was recognized at the outset that there were key technical questions that would determine the feasibility, cost and strategy for the proposed model linkage. These include the following.

(1) What are optimal temporal and spatial scales for coupling *CBWQM* and *EwE* for Chesapeake Bay?
(2) What information would be passed between the coupled models?

(3) What are reasonable performance measures for a coupled model?
(4) How can we use available data to optimize model calibration and testing (e.g., parameter optimization, data assimilation)?
(5) How can upper trophic level models deal with trophic complexity, population dynamics and spatial interactions?

These management and technical questions set the stage for the workshop and led to a modest set of workshop objectives.

Workshop Goals

Given the limited resources and time-frame for organizing this meeting, the overall workshop goals were purposely designed to be simple and focused. We anticipated that this meeting would help us address the following goals:

(1) To assess capabilities and limitations of *CBWQM* and *EwE* for addressing interactions between water quality, habitat condition, food availability, and fisheries population dynamics;
(2) To identify possible mechanisms by which these two models could interact via direct or indirect coupling;
(3) To consider alternative modeling approaches for simulating dynamic interactions between exploited animal populations and the ecosystems that they inhabit.

This workshop was organized by combining individuals both from within and outside the Chesapeake Bay region with expertise and interest to produce a list of knowledgeable and talented participants. We were pleased to have been able to assemble such a diverse and informed group of participants (see attached table). The workshop was intended to be a “brainstorming” session to generate a plan for coupling the two models. The meeting was organized to provide ample time for structured but open discussions, which were initiated and punctuated with a series of invited technical presentations. These presentations were designed to illustrate previous uses of models to address questions that cross the boundaries between water quality and fisheries population dynamics. The following pages describe the proceedings of this workshop.

Summary of Workshop Presentations

The meeting began with a review of management questions related to C2K. Specifically, what are the relationships between nutrient loadings, water quality and filter/suspension feeders. The issue of "top down" (primary producers controlled by consumers) controls on water quality was introduced with the question of "can we improve water quality by changing fisheries management?" In addition, the issues of water quality effects on animal habitat, trophic efficiencies and population dynamics were considered with the question, “how will nutrient reduction affect production of fish and other important consumer organisms?” Following a brief introduction, the morning session focused on the current modeling efforts described briefly in the following paragraphs. Files (pdf) containing these presentations are available from the STAC website (http://www.chesapeake.org/stac/workshop.html).

The first two presentations provided overviews of two existing Chesapeake Bay models that were the primary focus of this workshop. Carl Cerco of the U.S. Army Corps of Engineers discussed development of the CBP Water Quality Model (*CBWQM*) while Alasdair Beattie of NCBO provided insight into *Ecopath* with *Ecosim* (*EwE*). Both focused on the workshop technical and management questions. Equation structures, functional relationships, boundary conditions, coefficient parameterizations, and scaling options were presented for both models. It became apparent there are some fundamental differences between the two modeling approaches. These issues are outlined later in this report.

After describing the spatial and temporal domain and basic structure of *CBWQM*, Carl Cerco presented a summary of simulated effects of nutrient reduction on benthic macrofauna. In general, model simulations suggest that nutrient reduction causes an overall reduction in benthic fauna. The presentation indicated that the model predicted non-linear impacts of grazers on nutrient cycling and primary production. While base-run model output calibrated reasonably well with observations for most invertebrate grazers, there were some inconsistencies, with the caveat that simulating benthic and planktonic invertebrate communities was not the primary focus of this water quality model.

An introduction to the *EwE* approach to modeling set the stage for a brief description of the Chesapeake Bay *Ecosim* model. Considerable emphasis was placed on the nature of modeled predator prey interactions using "arena foraging" theory. The ability of *EwE* to detect top-down versus bottom-up (nutrient control on consumer populations) trophic relationships was emphasized, along with the availability of "mediation functions" to portray effects of habitat and primary production. The presentation noted that effective coupling of *CBWQM* and *EwE* would probably require that the latter model be modified to include seasonal and spatial (regional) articulation, as well as incorporation of nutrient cycling processes and key mediation functions that relate water and habitat quality to fish production.

An example was presented describing how *EwE* was currently being linked to physical circulation and water quality simulations in a coupled model developed for Tampa Bay to examine eutrophication effects on fish. Alasdair Beattie provided a brief description of this project for Steve Martell, who was unable to attend the workshop. This Florida Ecosystem Model (*FLEM*) involves *Ecopath*, *Ecosim* and *Ecospace*, connected to a nutrient loading and mixing model using a series of regression equations relating nutrients to habitat and food. The model relationships include nutrient effects on seagrasses and seagrass habitat effects on fish. Modeled fish populations provide a better fit to data when primary productivity and habitat are included. The workshop participants were keenly interested in this model application, but a bit frustrated by an inability to get details of the overall *FLEM* structure and dynamics. Nevertheless, this approach seemed promising, and model development continues.

Two presentations on the afternoon of the first day described a number of alternative approaches for integrated analysis of water quality, ecosystem functions, and fish dynamics. Kenny Rose of LSU described three examples of fish models linked or embedded into ecosystem computations. The first example involved a spatially-explicit plankton ecosystem model including state variables for three nutrients, two algal groups, three detrital groups, and three zooplankton groups. This ecosystem model was driven by a physical circulation model and was also linked to a stage-specific bioenergentic model for herring. Results showed direct effects on herring population dynamics resulting from changes in nutrient inputs to the system. The second example used an individual-based stage-specific model for brown shrimp to examine its dependence on marsh, seagrass and open-water habitats. Model results illustrated that optimal shrimp recruitment and production resulted from a balanced mix of habitats. The third example involved an individual-based, food-web model for Lake Mendota that included six fish species, and full life-cycles for zooplankton and benthic forage species. The model was structured into three lake regions (littoral, epilimnion, hypolimnion). This model was indirectly coupled to output from a water quality model that predicted effects of global warming on lake temperature and dissolved oxygen. Simulation experiments showed how different food-web linkages lead to very different model predictions, and this study thus served as an excellent example of indirect linkage between water quality and food-web models.

The second of these presentations, by Denise Breitburg of SERC, described how output from a suite of models for the Patuxent River estuary watershed, estuarine circulation and water quality can be coupled indirectly with individual-based larval fish and food web models. Detailed descriptions of the watershed and the water quality modeling approaches were provided. The combination of these models was used to relate nutrient loading to habitat conditions that drive fish production, and predation mortality of early life stages of estuarine fishes. These results illustrate how trophic relationships and fish growth could be affected by nutrient enrichment.

Although two presentations were scheduled for the second day of the workshop to address the problem of simulating pristine conditions in the Chesapeake Bay, one was cancelled. Jim Hagy, from EPA Gulf Breeze Laboratory, presented results of a recent study combining *Ecopath* with a series of empirical functions to estimate food web structure and fish production for the mesohaline region of a “restored” Bay. This presentation illustrated a straight forward method for estimated trophic relationships in the estuary restored to water quality conditions approximating those of the 1950s. It also showed how static calculations with *Ecopath* (without *Ecosim*) could be used as a valuable tool to assess the consequences for food-webs and “potential fish production” resulting from changes in water quality and habitat conditions associated with Bay restoration. Although this analysis used empirical functions from comparative data analyses to generate restoration scenarios, it was suggested that improved relationships could be derived from the *CBWQM*. *Ecopath* does not consider effects on recruitment, mortality or other aspects of fish population dynamics, but *EwE* simulations could be run for the same scenarios to consider relative changes in fish populations that would affect how the *Ecopath* calculation is structured.

Workshop Discussions

During the discussion sessions, it became evident that a number of important technical issues must be addressed when considering the coupling of water quality and trophic fisheries models. Before the group tackled such logistics, however, preliminary discussions focused on a few philosophical differences between approaches to water quality and fisheries modeling. Although interactions between water quality, habitat and fisheries must be considered in developing plans for Bay restoration, *CBWQM* and *EwE* treat these interactions differently. The optimal harvest rate that maximizes fish production is a common concept in fish stock models. In the C2K work projected by the Bay Program, however, the emphasis is on examining the influence harvested filter feeders have on water quality, particularly on the water quality criteria of dissolved oxygen, water clarity, and phytoplankton chlorophyll. These are management questions that will be considered in 2007. The diverse workshop discussions began with an analysis of the nature of key interactions between fish populations and the water quality and habitat conditions of the Bay. Then the workshop considered the current capabilities of *CBWQM* and *EwE* inputs and outputs that are relevant to the objectives of model coupling. The discussion then focused on technical questions of model scale, and approaches for coupling the two models. Based on these discussions, this report develops a list of conclusions and recommendations.

Water Quality, Habitat and Fish Interactions

One impediment to developing integrated analyses of water quality and fisheries management arises from the differences in how scientists working in these two disciplines view key processes and interactions. Water quality researchers and modelers maintain a view that ecosystem dynamics are dominated by physiological and biogeochemical processes and their associated kinetic and mass-balance relationships. Fisheries scientists, however, tend to view fish population dynamics as being dominated by organism life cycles and behaviors that are constrained by fishing mortality. Researchers and modelers in both fields agree, however, that physical environmental conditions (e.g., temperature, water circulation) are important drivers for the dynamics of populations and ecosystems. In either case, it is essential that researchers, modelers and managers recognize the important mechanisms by which fish interact with habitat and water quality. Several examples were identified and considered in the workshop discussions.

(1) Bottom water hypoxia, which is partially driven by nutrient loading, has Negative effects on benthic food-chains and demersal fish, as well on pelagic fish that use sub-pycnocline waters for thermal refuge. Hypoxia may also affect trophic interactions that involve fish and invertebrate populations.
(2) The distribution and abundance of submerged aquatic vegetation (SAV) are regulated by inputs of nutrients and suspended sediments which, in turn, affect water clarity and growth of planktonic epiphytic algae. In general, SAV provides important refuge habitat for juvenile and molting animals, as well as nursery habitat for feeding of forage fish. SAV may have critical importance

for recruitment and production of blue crabs in the lower Bay. SAV also enhance trapping and binding of suspended sediments along with retention and efficient use of nutrients, thereby improving their own growth conditions.

(3) The abundance of benthic diatoms is regulated by water clarity, which is affected by nutrient and sediment loading to the Bay. These benthic micro-algae provide the basis for efficient nutrient retention and cycling and efficient demersal food-chains. They also create mats that bind bottom sediments, reducing resuspension and thereby providing feedback control on water clarity.

(4) Nutrient levels and ratios (N:P:Si) regulate the size and taxonomic structure of phytoplankton and zooplankton communities. The species composition and size structure of the plankton community may regulate the efficiency of trophic energy transfer from primary production to planktivorous fish.

(4) Benthic (e.g., oysters) and pelagic (e.g, menhaden) filter feeder animal populations which consume phytoplankton, exert substantial effects on water quality. Direct removal of phytoplankton and other suspended particles tends to increase water clarity, and deposition of fecal and pseudo-fecal material may indirectly enhance nitrogen loss via coupled nitrification-denitrification. Oyster reefs also provide important habitat for many fish and invertebrates.

The structure of *CBWQM* allows many of these mechanisms to be included; however, some of these (e.g., #3 and #4) are not directly included, and others (e.g., #5) have not been fully tested. The water quality model does simulate three-dimensional spatial dynamics on short time-scales (hours to days). As currently configured, the Chesapeake Bay *EwE* model does not include nutrient cycling, primary production or controls on water clarity, and it does not include "mediation functions" that would be needed to simulate SAV and oyster reef effects on fish. Currently, *EwE* has zero spatial dimensions, with the Bay considered as to be single well-mixed water mass; model simulations also generate output averaged over an entire year with no seasonality. Therefore, there are questions regarding the ability of these models to capture these ecological mechanisms that relate water quality to dynamics of key fisheries populations.

Current Model Simulations

As indicated earlier, presentations by Carl Cerco and Alasdair Beattie provided descriptions of current versions of the water quality and trophic fisheries models for Chesapeake Bay. Here we focus on key insights regarding the structure and behavior of these models in relation to the potential for them to be linked. The primary processes and information that might be exchanged from *CBWQM* to *EwE* are: (1) phytoplankton and benthic micro-algae biomass, production and quality, (2) zooplankton and benthic macrofauna biomass, production and quality, (3) SAV abundance, cover and habitat condition, (4) deep bottom water habitat O_2 and temperature conditions. The most important processes and information that might be exchanged from *EwE* to *CBWQM* are: (1) grazing rates on primary producers (phytoplankton, benthic micro-algae), (2) predation rates on herbivorous invertebrate consumers (zooplankton, benthic macrofauna).

Water Quality Model. Simulation scenarios involving changes in nutrient loading forecasted considerable changes in habitat and food available to support fish production. Nutrient reductions result in substantial increases in bottom water dissolved oxygen (O_2) and in abundance of submerged aquatic vegetation. These simulated responses represent important improvements in the quality of deep and shallow habitats, respectively. In addition, nutrient reduction simulations indicated that zooplankton biomass would be enhanced in the mesohaline Bay regions due to increased levels of dissolved oxygen (O_2) and associated habitat in the bottom layer. Nutrient reduction simulations, however, also result in decreased phytoplankton abundance and production, which affects food availability for many consumer groups in the model. For example, simulated nutrient reduction caused mixed effects on benthic animal communities. Benthic macrofauna in deep channel regions were increased due to higher O_2 levels, but animal biomass was predicted to be substantially reduced in the shallower flanks due to reduced availability of phytoplankton food. Because there is evidence that benthic populations in mesohaline region of the Bay (channel and flanks) are not strongly limited by food availability, there is some question about the model's current calibration for benthic feeding in this region (e.g., feeding K_s saturation coefficients, preference for phytoplankton versus benthic micro-algae). Obviously, this calibration might have important effects on benthic responses to water quality scenarios.

The model exhibits interesting non-linear effects of zooplankton grazing rate on phytoplankton production, due to the counter-balancing effects of direct loss of algal biomass, on one hand, and the increased recycling of nutrients, on the other. The same levels of algal biomass can be achieved at low and high levels of productivity with low or high grazing, respectively. Although the model is currently calibrated with intermediate grazing rates, this appears to be a sensitive calibration point that will directly determine zooplankton responses to water quality changes. The grazing effect on phytoplankton biomass in *CBWQM* is described by a quadratic predation function, related to the square of the prey biomass. This function adds stability to model behavior, and recent model analyses with similar functions, indicate that the efficiency by which primary productivity is transferred to consumers will exhibit a parabolic response to nutrient loading. This effect is particularly acute under conditions, such as those in Chesapeake Bay, where zooplankton populations are regulated more by predation (top-down) than by food (bottom-up). Benthic suspension feeding might exhibit similar effects on phytoplankton biomass and production. Since the time of this workshop, CBWQM has been calibrated to examine effects of increased benthic filtration associated with oyster restoration in the Bay. Recent model simulations suggest substantial improvements in bottom water O_2 and SAV abundance with increased oyster filtration, although food limitation can limit growth of model oysters.

Ecopath with Ecosim Model. An analysis of how well various fish population dynamics are simulated with *EwE* might provide insights on the relative dependence of different species on water quality and habitat conditions. The idea is that interannual variability of fish populations, for which there is good match between model and data, is probably controlled largely by fishing mortality. For species that are poorly simulated by the current model, food and habitat might be more important. In the latest simulations for the 1950's to the present, there appeared to be reasonable matches between simulated and observed populations of striped bass, bluefish, and oysters. This indicates that, for species with well represented fishing pressure, the *EwE* simulation does well. However, the model does less well for fish and invertebrate populations that are not subjected to relatively high fishing pressure. These species are more likely to benefit from improved habitat conditions resulting from nutrient input management. However, the current version of the Bay's *EwE* does not include "mediation functions" that would allow for such improved habitat conditions to change fish production. A caveat that should be considered in comparing *EwE* model fit among fish species is that there tends to be strong co-variance among species because similar physical environmental conditions regulate diverse populations (although often via different mechanisms).

The current Chesapeake Bay version of *EwE* models the estuary as a single volume with no seasonality in organism growth and metabolic rates. This limits the ability of spatially and temporally explicit output from *CBWQM* to be used to drive *EwE*, because of the strong regional and seasonal variations in primary production and habitat quality. Physiological rates in *EwE* are related to organism size and biomass turnover ratios, and these rates are normalized to organism biomass. Therefore, any changes in food turnover or food quality simulated from *CBWQM* would need to be noted with an associated adjustment in *EwE* physiological rates. This feature would need to be addressed if *EwE* were to be used alone to guide potential management decisions which influence water quality through fisheries management.

Alternative Approaches for Coupling *EwE* and *CBWQM*

There are several ways in which the *CBWQM* and *EwE* models might be coupled. These alternative approaches are constrained in different ways and each has potential advantages and disadvantages. One approach is *indirect coupling*, in which information from one model (e.g., simulation ouput) drives another model, with the modelers serving as the interface between the models. On the other hand, *direct coupling* involves the simultaneous running of both models, with information being passed back and forth continuously between models at each time-step. Problems with incompatible time and space scales make direct coupling impossible with the current versions of *CBWQM* and *EwE*. A third and simple option for examining compatibility of two models for linkage involves comparing forecasted outputs for variables included in different models.

Scales of Coupling* CBWQM *and* EwE *Models. It is important to consider the time and space scales at which the respective models currently run, and any constraints on modifying these scales. As with any numerical modeling, there is a need to match temporal and spatial scales of analysis. Landscape ecologists use the term "grain" to refer to the resolution scale. The temporal grain of a numerical model is indicated by the time-step of integration, while the spatial grain is represented by the grid size. Similarly, the term "extent" is used to refer to the temporal or spatial domain of the analysis. The duration of a simulation (e.g., 1, 10, 50 years) can be considered its temporal "extent" scale, while the spatial boundaries of the computation (e.g., whole Bay with tributaries, mainstem only, region only) define its spatial "extent." Any kind of coupled (direct or indirect) simulation would require both models use the same time and space scales. If coupling is indirect, output of a higher resolution model can be collapsed or aggregated to produce inputs for a coarser grain model. The spatial and temporal extents of current versions of both models are similar, with the whole Bay defining the spatial domains, and annual-to-decadal scales typically used for the temporal domains. The temporal and spatial grains are much finer for the current water quality model than for *EwE*. While the current time-step for integration of *EwE* is on the order of a day, this could be reduced for compatibility with *CBWQM*. A spatial version of *EwE* (*Ecospace*) could be developed with cell size defined at regional scales (10-50 km), which is still coarse compared to the current grid scale of *CBWQM* (500-1000 m by 1-5 m).

Direct Interactive Coupling. Direct coupling would require a new initiative, combining the two model codes into a single executable program with information exchanged in both directions between the two models at each time step over the course of the simulation duration. The primary advantage of this approach is that it allows for feedback effects between upper and lower trophic levels or between water/habitat quality and fish. Such feedback effects include: a) predation affecting both consumer and prey populations, b) benthic filter feeders affecting phytoplankton abundance but also being affected by plankton deposition and hypoxia, c) water clarity affecting benthic micro-algal production and associated benthic food-chains, but benthic bioturbation decreasing water clarity. Disadvantages include the cost of modifying respective model codes to accommodate required spatial/temporal scales and currencies of exchange. Developing a directly coupled interactive modeling system may require a substantial investment of time and resources.

Indirect (One-Way) Coupling. This option would involve running one model and saving that model's output into files that would be used to drive a simulation run for the second model. Because the time/space scales of this output and input need to match, there would probably be a need to aggregate from finer scale output to coarser scale input. This coupling can be done in either direction. For example, effects of changes in menhaden fishing on water clarity and hypoxia could be analyzed starting with an *EwE* simulation that considers changes in chlorophyll-*a* grazing rates, and this *EwE* output would be used to guide a *CBWQM* scenario simulation. Conversely, the effects of nutrient reduction on demersal fish production could be analyzed be running scenarios with the *CBWQM* to produce changes in bottom [O_2] and SAV abundance, which would be used as inputs to *EwE* simulations, including the appropriate "mediation functions" that relate bottom benthic habitat and SAV abundance to fish recruitment, production and mortality.

The major advantage of this approach is that it would require very little modification of current model capabilities to initiate indirect coupled simulations. Indeed, it was suggested that there would be (at least some) utility in using the current whole Bay *EwE* model to compute trophic and fisheries consequences of water quality management scenarios. It would be difficult, however, to run indirectly coupled simulations in the other direction from *EwE* to *CBWQM* without spatial disaggregation. Many participants agreed that ecological characteristics of major Bay regions vary too dramatically in terms of water quality, habitats and fish abundance for a whole Bay approach to be of much value. The need to develop an *Ecospace* version of the model would, however, tend to undermine the major advantage of indirect coupling (it can be done soon, with little additional investments). Another disadvantage of this approach is that it would accommodate limited applications. There was some concern that this might be an inefficient compromise level of investment, providing few of the benefits of the direct coupling but most of the cost.

Non-Coupled Model Comparisons. This approach does not really involve quantitative exchange of information between models, but rather it involves comparative analysis of the structures and behaviors of the two models from which information can be derived to improve interpretation of each model. Non-coupled comparison is relatively cheap and easy, and it would likely start with comparative analysis of parameter values and functional relationships used in *EwE* and *WQM*. A limited number of variables were identified that are contained in both models, including phytoplankton, zooplankton, SAV, benthic suspension-feeders, benthic deposit feeders. This approach would compare scenario simulations (such as nutrient reductions) run with *EwE* and *CBWQM* in terms of key variables and process that both models have in common, and it would involve subsequent analysis and interpretation of the variables and processes that do not match between the two models.

Major Conclusions

The workshop discussions led to several tentative conclusions regarding model coupling and recommendations for future action. There was strong consensus among workshop participants that, in the long-run, there is a need to develop a suite of linked models that simulate water quality, habitat condition, trophic interactions, and fish population dynamics. Invited presentations made it clear that there is a variety of potentially effective approaches. Although many felt that it would be useful to pursue linkages among several relevant models, the focus of this workshop was coupling water quality and trophic network models. There are several technical questions that need to be resolved; however, the workshop participants expressed a general optimism for developing a simple and effective comparisons and coupling of *CBWQM* and *EwE* for Chesapeake Bay.

Although substantial work has gone into calibration of *CBWQM* to field data, a parallel effort is needed for calibration and testing of *EwE* in relation to the observed data. This may already be part of the current NCBO work plan for *EwE* development. It is an essential step that must be completed before attempting to couple this model with *CBWQM*. There are several additional areas in which *EwE* needs further development prior to coupling with *CBWQM*. For example, the current version of *EwE* for Chesapeake Bay does not have any “mediation functions” or comparable non-trophic mechanisms that would generate fish responses to simulated or forced changes in water quality or habitat conditions. Without such mechanisms built into the model, changes in habitat cover or quality cannot forecast associated responses in fish abundance, production or harvest. Spatial and temporal scaling issues must also be considered.

Any kind of coupled (direct or indirect) simulation would require both models to use similar time and space scales. If coupling is indirect, output of a higher resolution model can be collapsed or aggregated to produce inputs for a coarser grain model. It is problematic, however, to adjust output from a coarser-scale model as input to a finer-scale model. After a lengthy discussion, there was a strong sentiment among workshop participants that effective linkage would require that the *EwE* model be simulated at monthly time-scales to produce seasonal patterns. This would require monthly forcing functions for primary production and other drivers including temperature, salinity and hydrodynamic transport. It was also recommended that the minimal spatial "grain" scales for an *Ecospace* (i.e., the spatial version of *EwE*) model would involve 3-5 main-stem regions, along with a single region for each of the major tributaries. For coupled simulations, the *CBWQM* would need to be either run in a regional scale mode or run in a full-grid simulation with results collapsed to an appropriate regional scale.

One conclusion that was broadly supported by workshop participants was that the compatibility of current versions of *CBWQM* and *EwE* should be evaluated by a comparative analysis of model outputs for variables and processes common to both model structures. This could be done for base run simulations for specific years or decades and/or for simulated management scenarios. Such a comparison would be inexpensive and could be done soon. In addition, several participants expressed support for another relatively inexpensive analysis using well-calibrated regional and seasonal *Ecopath* models with empirically based transfer functions to produce scenarios that are related to proposed water quality and fisheries management scenarios (e.g, see Jim Hagy's presentation).

Recommended Actions

The workshop participants discussed many philosophical, practical and technical issues that relate to coupling of ecological and fisheries models in general and the Chesapeake Bay water quality and trophic network models specifically. The following recommendations emerged from these discussions.

(1) It was agreed that a first and essential step toward model coupling *EwE* and *BWQM* should be a comparative analysis of simulations for variables common to both models. This step would be relatively inexpensive and would reveal potential problems and strategies for future direct or indirect coupling. This would start with a comparison of parameter values and functional relationships for ecological properties included in both models. The state variables that are contained in both models include phytoplankton, zooplankton, SAV, benthic suspension-feeding invertebrates, and benthic

deposit feeders.

(2) A possible test case for broad indirect coupling was suggested using the "confirmation scenarios" with *CBWQM,* where major reductions in nutrient loading are simulated to produce conditions with no water quality impairments. These simulations should produce large changes in algal production, bottom O_2 and SAV distribution. It is recommended that the *EwE* modeling team use these outputs from the water quality model to examine the responses of striped bass, blue fish, oysters, and other key species to large reductions in nutrient loading. This analysis, which would provide a first-order estimate of how nutrient and algal reduction affect fisheries production, should also be compared to results from Jim Hagy's Ecopath scenario assessment. Analysis of these results would provide a constraining test of model performance, and it might force a reevaluation of expectations regarding nutrient management.

(3) To the extent possible, an initiative to fund the coupling of the two models, either direct or indirect, should be proposed and championed in 2004 with work to begin in 2005. In the long-term, to maintain mass balance between the algal foods and consumer animal populations, the models need to be either directly coupled or indirectly coupled with multiple iterations. For example, nutrient effects on phytoplankton biomass predicted with *CBWQM* should be adjusted based on *EwE* estimates of phytoplankton grazing by zooplankton, menhaden and ctenophores.

(4) Another workshop should be organized by NCBO to set temporal and spatial scales of *EwE* in preparation for its use in the 2007 reevaluation, with a focus on the scales needed to address reasonably the question of water quality effects from enhanced filter feeding. This is a basic question clearly raised in C2K, and it needs to be integrated with proposed fisheries management goals.

(5) Given the timing of this initiative relative to the sequence of goals outlined in C2K, it is recommended that an indirect coupling of *CBWQM* and *EwE* be used to address questions of water quality consequences of alternative scenarios for managing the Bay's menhaden fishery. This will require a special study to improve understanding of trophic interactions and biogeochemical consequences of changes in mortality and age structure for menhaden in the Chesapeake.

In closing the workshop, the organizers and Chesapeake Bay Program representatives expressed resolve to take the next steps needed to carry the goals of this workshop forward and optimism for a useful outcome.

APPENDIX I: List of Meeting Participants and Organizing Committee

Organizing Committee

STAC Representatives:

W. Michael Kemp, UMCES Horn Point Lab
Denise Breitburg, SERC

Chesapeake Bay Program Representatives:

Lewis Linker, US EPA CBO
Arthur Butt, VA Dept Water Quality
Carl Cerco, US Army Corps of Engineers, WES
Alasdair Beattie, NOAA CBO

Meeting Participants

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APPENDIX II:

Coupling Water Quality and Upper Trophic Level Modeling
Workshop Agenda

<u>January 8, 2004</u>

10:00 am Welcome, introductions, logistics, and workshop objectives

1. INTRODUCTION TO CHESAPEAKE BAY'S WQ & FISH MODELS

10:10 am *CBP Water Quality Model Overview* – Carl Cerco
An overview of the Water Quality Model will be presented with a focus on workshop mgmt questions. What water quality management questions could benefit from trophic network modeling? What fisheries management questions could benefit from water quality modeling?

10:40 am *CBP Ecosystem Model Overview* – Alasdair Beattie
An overview of Ecopath with Ecosim Model will be presented with a focus on the workshop management questions. Same questions are posed here as for Carl Cerco's presentation.

11:10 am Moderated Discussion: *What are the relevant Management Questions that would benefit from coupled simulations of WQM and EwE??* – Moderator: Diana Esher
What are the relevant management questions that would benefit from coupled simulations?

12:00 noon *LUNCH*

2. EXAMPLES OF COUPLED WQ-FISH MODELS

1:00 pm *Coupling EwE with Transport and WQ Models in Tampa Bay* - Steve Martell, A. Beatty et al.
This presentation will describe progress and approaches in coupling nutrient inputs, and transport to seagrass ecology models and Ecopath/Ecosim. Examples of the application of this approach will be reviewed for several bays along the SW Florida coast.

1:30 pm Moderated Discussion: *Building the Bridge I* – Moderator: Diana Esher
How should the two models be linked—directly or indirectly? What information should be passed between the two models? Is the information exchange uni- or bi-directional? At what temporal and spatial scales should information be exchanged? Do these issues change for different management questions?

2:30 pm *BREAK*

3. ALTERNATIVE SCHEMES FOR LINKING WQ, ECOSYSTEM & FISH MODELS

3:00 pm *Individual Based Models and Loose Coupling* – Ken Rose
Ken Rose will review concepts of loose coupling approaches in integration of stochastic ecosystem models with deterministic water quality models.

3:30 pm *Water Quality & Fish Population Production: Coupled models for Patuxent* - Denise Breitburg

An example of linked models of watershed runoff, physical circulation, water quality, fish bioenergetics and trophic interactions will be presented here.

4:00 pm Moderated Discussion: *Building the Bridge II* – Moderator: Diana Esher
Should we consider expanding the charge to allow coupling of other existing models in Bay to improve our ability to address key management questions. What other models are available, and how might they be coupled? What are the important, particularly vexing, management questions that would benefit from an expanded perspective of linking models?

5:00 pm Adjourn

<u>January 9, 2004</u>

4. A STRAWMAN PROPOSAL FOR COUPLING WQ & EwE MODELS

9:00 am *The Big Push:* Review of previous day's presentations and discussion and overview of the day's objectives. A Strawman Proposal, incorporating the thoughts of the previous day's discussion, will be reviewed – Presentation: Mike Kemp & company

9:30 am *Discussion of Proposed Coupling of WQ and EwE models* – Moderator: Diana Esher
What details need to be resolved? What are the agency positions? And so on. . . . .

10:20 am BREAK

5. PRISTINE CHESAPEAKE: ALTERNATIVE SCENARIOS

10:40 am *Sensitivity Analysis of the Ecosystem Model* – Rob Latour [Cancelled]
Rob Latour will examine the sensitivity of the Ecopath/Ecosim model to estimated algal biomass under a pristine all-forest condition and under conditions of the C2K allocations.

11:00 am *An EcosPath Model of a Restored Chesapeake* - Jim Hagy
Analysis exploring ecosystem processes in a "1950s-like" Chesapeake will be presented.

11:20 am Discussion: *Simulating a Pristine Chesapeake BaY?* – Moderator: Diana Esher
Revisiting the importance of process. What are the important processes that must be incorporated into water quality and trophic network models to simulate adjustment from a eutrophic plankton-dominated system to an meso- to oligo-trophic benthic dominated system? Would a coupled WQ-EwE model improve our ability to simulate a pristine Bay?

12:20 pm LUNCH

6. CONCLUDING DISCUSSION

1:00 pm The Road to the 2007 Revaluation and a Coupled Water Quality and Ecosystem Model – Moderator: Diana Esher
We'll conclude with a discussion of specific steps to be taken within the timeframe of the completing the coupled simulation system for the 2007 Reevaluation. Specific decisions, approaches, and rough timelines for the proposed work will be outlined. Given the VBASIC and FORTRAN language barrier, what is needed to

couple the codes? Key data gaps and areas needing additional work will be identified. How can we effect a working interaction between EwE, WQM (and other models) in Chesapeake Bay. Do we need a mandate from NOAA and EPA? What is the appropriate timing, and how would the interactions occur? How would this effort be supported $$?

2:00 pm Workshop closure – Concluding remarks and preparation of workshop report.

2:45 pm ADJOURN