Workshop Report

U.S. Environmental Protection Agency
Integrated Modeling for Integrated Environmental Decision Making Workshop

U.S. Environmental Protection Agency
Main Campus, Auditorium A
Research Triangle Park, NC

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EXECUTIVE SUMMARY

JANUARY 30, 2007

INTRODUCTION AND OVERVIEW

The 2007 U.S. Environmental Protection Agency (EPA) Integrated Modeling for Integrated Environmental Decision Making Workshop was held on January 30–February 1, 2007, in Research Triangle Park, North Carolina, and was hosted by the Office of Research and Development (ORD), Council for Regulatory Environmental Modeling (CREM) and the ORD, National Exposure Research Laboratory (NERL). The goal of this workshop was to build a workable vision of and strategy for the future role of integrated modeling in informing EPA's regulatory decision making. This workshop provided an opportunity for EPA offices to share their experiences and perspectives in this area and to address the science and technology approaches and interoperability challenges of integrated modeling. The various definitions of integrated modeling were discussed, and future directions and programmatic priorities of integrated modeling were explored.

Welcome and Introduction

Pasky Pascual, U.S. EPA/ORD/National Center for Environmental Research and CREM

Mr. Pascual welcomed participants to the meeting and recognized participants from Environment Canada (EC) and Europe. The notion of integration is not new. The synthesis of information from different sources across different scales has moved from the theoretical to the applied because of emerging technologies. EPA makes its analysis of integrated assessments transparent by providing sufficient detail to decision makers. The analysis of uncertainty in a single model, and the propagation of uncertainty within linked models, is an important issue to be addressed in integrated modeling efforts. The framework for integrated modeling includes five areas of interest: (1) earth observation systems; (2) earth observation systems linked with environmental and health models; (3) decision-support models; (4) a process for putting information into a framework for decision making; and (5) meta-issues involving data and model evaluation as well as standards and inter-operability. Decision making in the face of uncertainty requires a process for model evaluation that includes scientific panels, peer review, regulatory impact assessments, and model documentation. The goals of this meeting are to develop methods for coherent and transparent meta-analysis, share meta-analyses, and help stakeholders use legal and administrative mechanisms to develop sound analytics and, in turn, sound policy.

OPENING PLENARY SESSION

Relevance of Exposure Science to Decision Making and the Role of Integrated Modeling

Lawrence W. Reiter, U.S. EPA/ORD/NERL

Dr. Reiter discussed the juxtaposition of two concepts—the relevance of exposure science in integrated modeling and the importance of integrated models to exposure science. The distribution of stressor and receptor in space and time affects when and where exposure will occur. In humans, the individual level of biological organization is typically of interest, whereas in ecology, biological organization can occur at the population, community, or ecosystem level. The receptor can be examined at any of these levels of biological organization. Stressors include more than just chemical exposures. In the context of the consequences of exposure on a receptor, integrated models are needed to understand the relationship among points along the continuum. Environmental concentrations are the basis for policies and regulations protecting our public health, and integration is essential to achieve advancements in exposure science, risk assessment, and risk management. Mitigation requirements are determined by risk assessment; therefore, links between concentrations, exposure, and dose affect outcome. Exposure laboratory scientists are beginning to explore how to integrate models to better understand the source-to-exposure relationship. Information from the Community Multiscale Air Quality (CMAQ)/AERMOD model, which predicts ambient concentrations, can be used in the Stochastic Human Exposure and Dose Simulation (SHEDS) model, which uses human activity to predict frequency, intensity, and duration of exposure. This information can in turn be used to link data on air quality emissions and human exposures. Linkages along the source-to-outcome continuum are critical to understanding complex environmental issues and their impact on human and ecosystem health. Major challenges include developing better approaches to facilitate interoperability between systems, improving spatial resolution, and better characterization of model uncertainty, especially as it relates to the manner by which overall uncertainties are affected by integrating individual models.

Integrated Modeling for Environmental Decision Making

Gary Foley, U.S. EPA/ORD/National Center for Environmental Research and CREM

Dr. Foley defined accountability in the evaluation of exposure and public health improvements at NERL. Model development to support air quality protection has been prompted by the requirements of the Clean Air Act (CAA). This task is made more complex by the need to also meet the requirements of the Government Performance and Results Act (GPRA) and to address accountability. The CMAQ model allows the Agency to determine the best control strategy for reducing exposure to air pollutants. After controls are in place, monitoring verifies that the standards have been met. For example, modeling was used to evaluate water quality in the Great Lakes region to determine the concentrations of pollutants entering the air pathway and to estimate nonpoint runoff. The National Oceanic and Atmospheric Administration's (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was effectively used to determine the relative contribution of each county to the deposition of toxic substances in each lake. Integrated modeling also is being used to develop long-term tools linking mercury emissions, aquatic cycling, bioaccumulation, and human exposure. A short-term pilot project on Lake Ontario involved the development of a simplified media-specific model, sensitivity and uncertainty analysis, simulations without dynamic linkage, and integration of compartmental models. In addition, EPA collaborated with EC in an effort to use integrated modeling to predict mercury circulation in the northern hemisphere; this provided an understanding of seasonal changes in mercury concentrations, as well as the locations of major sources of mercury emissions. The goals for this workshop are to obtain a high-level perspective of the drivers for integration—of both models and decision making—and how models inform regulatory decisions.

KEYNOTE PANEL DISCUSSION

Panel Chairperson: Candida West, U.S. EPA/ORD

John Bachmann, U.S. EPA/Office of Air and Radiation (Retired)

Mr. Bachmann discussed the history of modeling in the context of the Office of Air and Radiation's (OAR) mandate to protect public health in the face of uncertainty. Integrated modeling can encompass multiple pollutants in a single medium or across multiple media, the link between fate and transport and effects (or, source to dose), and links between biogeophysical models and social models. Integrated modeling also is defined as the sequencing of multiple modules even for single pollutants, such as in air, emissions, dispersion, and exposure. Conceptually, integrated models should drive policy integration. Integrated modeling must add value, however, by providing intermediate results and demonstrating a logical chain, rather than focusing on cost-benefit and risk analyses. It is important to understand when integrated modeling is simply desirable as opposed to when it is necessary. Air quality management challenges for the 21st century include meeting standards for particulate matter (PM), ozone, and persistent bioaccumulative toxic pollutants; assessing and protecting ecosystem health, ensuring environmental justice, and analyzing climate effects and strategies. These challenges have implications for integrated modeling and decision making. Models that integrate multiple data sources can be used for multi-pollutant “backcasting” to assess models and dynamic changes in emissions. Thus, integrated modeling addresses accountability by assessing the effectiveness of past policies.

Barnes Johnson, U.S. EPA/Office of Solid Waste and Emergency Response

Mr. Johnson presented the perspective of an EPA manager who used integrated modeling to address a regulatory problem requiring a determination of a safe level of waste. This complicated national problem involved multiple pathways and multiple receptors with potential impacts on both human health and ecosystem health. Integration of modeling frameworks and expertise in a number of domains was required. Over a 6- to 8-year period, the Office of Solid Waste and Emergency Response (OSWER) addressed a number of issues related to model structure, computer science and technology, and the “softer side” of model development. In terms of model structure, OSWER addressed problems stemming from the multimedia nature of the problem, differences among models in temporal and spatial scales, and a large number of modules with complex linkages in a modeling system that included close to 1,000 variables. Uncertainty analysis for this model was complex. Because this model was intended to address a regulatory question, quick and accessible results were required. The computer science and technology challenges stemmed in part from the need for greater complexity, which can affect performance, platform, and runtime. Graphical user interfaces (GUIs) were critical to connect model results to decision makers. Issues also arose with respect to version control and the need for software to manage the large code for the model. The regulatory nature of the problem necessitated careful documentation, long-term storage of intermediate results, and model verification and validation. The “softer side” of integrated model development is as critical as the technological issues. This aspect of modeling includes peer review via independent external panels and EPA’s Science

Advisory Board (SAB), documentation and publication, marketing, and project planning. This effort required close collaboration among large, multidisciplinary teams.

Jerry Schnoor, University of Iowa and SAB

Dr. Schnoor discussed the ability of integrated models to link environmental impact assessments with social and behavioral science to aid EPA decision makers. Integrated models are essential to the National Science Foundation's Water and Environmental Research Systems (WATERS) Network, which is intended to help improve detection, prediction, and management of the effects of human activities and natural perturbations on the quantity, distribution, and quality of water in near-real time. Applications that require integrated modeling include linking water quality models with drinking water source models, predicting capabilities for hypoxia, and pathogen modeling. The WATERS Network asks whether integrated models can be used not only to hindcast and analyze problems, but also to forecast and control water quality problems. Through close partnerships with EPA and other agencies, future plans for the WATERS Network include observatories and environmental field facilities that will span the country, connected by high-speed wireless informatics. The latest synthesis and modeling technology will be connected with sensors and measurement facilities to aid decision makers. Observations from sensors will be used in real time to improve sensing and models. First, by employing adaptive sampling, models will run in real time and optimize sensing frequency and position. Second, using data fusion, "smart" models will improve parameter values as they process streaming data from the field.

Jim Laity, Office of Management and Budget, Office of Information and Regulatory Affairs

Mr. Laity talked about the importance of integrated modeling from a decision making and regulatory context, especially for the purpose of providing useful information to the end-consumer of modeling. To be most useful to decision makers and the public, information derived from modeling must be presented clearly, should be standardized across time and applications, and should maximize the quality, utility, objectivity, and integrity of the information. From the perspective of the Office of Management and Budget (OMB), integrated modeling should only be as complex as is necessary to provide needed information. Modelers should identify and focus on the relationships and parameters with the most potential to influence results. In general, an iterative approach should be used to determine the appropriate level and focus of complexity by starting with a simple model and becoming more complex if necessary to meet the needs of decision makers. When good technical and scientific information on policy alternatives is provided, decision makers can balance competing values to make appropriate social choices. It is critical that analysts keep their own values out of the analysis to the extent possible. One of the strengths of the integration of science and economics modeling is that a single metric (dollar amount) can facilitate tradeoffs among dissimilar resources and amenities. Limitations include valuation methods that are rarely transparent to decision makers and the difficulty of quantifying many benefits and some costs. It is important to develop better, standardized methods for quantifying environmental effects, not only in terms of dollars, but also in meaningful physical units (e.g., tons of a contaminant or number of species protected) for decision makers. Understanding uncertainty and effectively communicating this to decision makers is crucial.

Ken Rojas, U.S. Department of Agriculture/Natural Resources Conservation Service

Mr. Rojas addressed integrated modeling from the perspective of the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). The NRCS regularly addresses integration. For example, OMB requested an assessment of the effectiveness of NRCS' conservation programs. In response, NRCS initiated the Conservation Effects Assessment Project (CEAP), in partnership with the Agricultural Research Service (ARS). As part of this effort, NRCS is using integrated modeling, incorporating Natural Resources Inventory data on cropping systems, to evaluate the outcomes of conservation programs. To quantify water quality, the Soil and Water Assessment Tool (SWAT) model and the Agricultural Policy Environmental Extender (APEX) physical process model were used. Another initiative related to integrated modeling is a multimedia environmental modeling memorandum of understanding (MOU) that has been signed by a number of federal agencies, including the Department of Energy, NRCS, ARS, EPA, the U.S. Geological Survey (USGS), and NOAA. The purpose of this MOU is to find ways to better integrate multimedia modeling efforts within and across the agencies. One result of this MOU is the establishment of the Collaborative Software Development Laboratory (CoLab). The purpose of CoLab is to facilitate collaboration within and across agencies in the design and development of software. Through CoLab, NRCS has adopted the Object Modeling System (OMS), through which different models (or codes) can be segregated into reusable components that can be integrated in new modeling systems for new applications. OMS allows for a greater focus on the science underlying the models and facilitates greater interaction between NRCS and ARS. In addition, NRCS has developed a two-part system that includes a source control mechanism and a project management component. This has allowed NRCS to formalize the collaboration among disciplines and regions and provides a way for farmers to interact with model developers. For NRCS, CoLab is benefiting conservation planning as well as science. A future challenge for USDA is to quantify and measure ecosystem services and to make the results understandable to decision makers and the public. Workshops such as this one can lead to new collaborations between agencies, a goal supported by Agriculture Secretary Mike Johanns.

Kathryn Lindsay, EC/Knowledge Integration Strategies Division

Dr. Lindsay presented integrated modeling from a Canadian perspective, as it applies to land and marine management projects. In Canada, the provinces, First Nations, and municipalities are the primary administrators of natural resources. At the federal level, EC pursues regulatory, negotiation, consultation, and stewardship approaches. EC has the tools and technical expertise for integrated modeling but institutional bridges are needed to match needs across political and sectoral boundaries and to increase knowledge among end-users. Integrated modeling has been used by the air and meteorology service and for certain issues in the toxics areas such as acid rain and mercury studies. The water and wildlife areas are now beginning to understand how integrated modeling can be used; however, integrated modeling is not yet used for environmental assessments. The Integrated Landscape Management Modeling (ILMM) is among the integrated modeling approaches EC is using. ILMM is used to study the ecological, economic, social, and cultural components of an area in terms of how they are impacted by changes resulting from policy and land management decisions. A workshop sponsored by Natural Resources Canada recommended the development of ILLM conceptual frameworks. Modeling approaches need to become more useful for decision making and should provide an improved capacity to allow for the integration of information, training, and knowledge transfer. Further recommendations include improving stakeholder engagement processes and leveraging funding over longer timeframes to make initiatives valuable.

David Fortune, Wallingford Software, HR Wallingford Group

Mr. Fortune provided an overview of integrated modeling efforts in Europe and the model interface, OpenMI. Over the last 10 years, an increased awareness of environmental issues and a need for action by decision makers has prompted an integrated, holistic approach to legislation regarding water, urban wastewater, and floods management. An issue now is how European legislation should be implemented nationally. There has been increased pressure for decisions that are sustainable, consider environmental costs and impacts, involve stakeholder participation, and assess uncertainty. For management of river catchments and water quality, single models have proved to be insufficient, especially from an economic standpoint. Competition for scarce resources, the desire for integrated environmental management, and the need for whole catchment models require model linking. Integrated science can improve the regulatory process by allowing a complete analysis of issues from an environmental, social, and economic viewpoint and can improve understanding of the impacts of engineering and social solutions. This, in turn, can allow for the development of best management practices (BMPs) for scarce resources. There is a need to develop technology to build any combination of models cost effectively, using any number of frameworks. In Europe, integrated modeling is viewed as an inevitable, logical progression, and is seen with varying degrees of enthusiasm and concern about the degree of learning required.

PROGRAM AND REGIONAL OFFICE PRESENTATIONS

Panel Chairperson: Gerry Laniak, U.S. EPA/ORD/NERL

Case Study #1: Clean Air Mercury Rule (CAMR) and Clean Air Interstate Rule (CAIR)

Peter Tsirigotis, U.S. EPA/OAR/Sector Policies and Programs Division

Mr. Tsirigotis presented a historical perspective on the use of integrated modeling for the development of CAMR/CAIR and discussed the future of integrated modeling and integrated decision making for sector program development. Historically, modeling has driven the overall direction of the regulatory program development process, informed decisions throughout the development process, and aided in communicating decisions to stakeholders. Model use can drive decisions based on the cost effectiveness and technical feasibility of specific emissions reductions. Models are informational and provide program perspective or context such as determining the portion of total mercury deposition that derives from one industry. In developing CAMR/CAIR, air quality and economic modeling substantially informed program development decisions and provided an important context for communicating projected program results. The kind of program determines whether rigorous modeling is required. For example, if control technologies will be required across the board, then the need for integrated modeling is not high. In contrast, with CAMR/CAIR, more rigorous modeling efforts were required to explain how reductions achieved through emissions trading programs would influence air quality and watershed impacts in specific locations and in the country as a whole. In projecting impacts with CAMR/CAIR, the goal was not only to reduce air pollutants to particular levels, but also to determine whether the costs to industry would be acceptable. CAMR is the first multimedia regulation. To facilitate the decisions that led to CAMR, emissions models were linked with air quality, watershed, and economics models to assess the effects of emissions on water quality. EPA can incorporate integrated decision making into sector program development by understanding regulations' causes and effects, focusing on the initial "big" picture view of sector impacts instead of on piecemeal effects, and by understanding a specific industry's economic drivers and perspectives. The goal is to make as many meaningful reductions as possible while providing industry with as much flexibility as possible.

Discussion

Regarding the relatively complex decision rule involved in regulatory decisions by the OAR, a participant asked about the extent to which equity comes into play. Mr. Tsirigotis responded that transparency regarding the decision making process is crucial. Stakeholders will be better able to assess a decision if they are provided with sufficient description of the science and modeling that informed the decision.

A participant asked whether OAR has engaged in dialogue with ORD and the modeling community to determine the real policy questions and how best to use modeling to answer those questions. Mr. Tsirigotis replied that OAR has attempted to engage in such dialogue in various ways with small successes and small failures. Further dialogue should help bridge the gaps among offices and programs.

Regarding CAIR, a participant asked whether proximity of emission sources to Class 1 areas (i.e., federally designated scenic or protected areas) and nonattainment areas (i.e., areas that do not meet National Ambient Air Quality Standards [NAAQS]) determined which states would be included in the program. Modelers can approach such problems with much greater accuracy by considering more than merely proximity. In particular, the HYSPLIT model may be an appropriate way to model the trajectory of emissions from some sources in areas of concern. Mr. Tsirigotis responded that the maps showing proximity to Class 1 and non-attainment areas were only intended to be informative and that proximity alone did not drive these decisions. He acknowledged, however, that additional air quality components to the modeling efforts would be beneficial. OAR has not used HYSPLIT to model trajectories; decisions regarding the most appropriate models are made by the head of the modeling team.

A participant asked whether the OAR typically presents a class of problem statements or a single problem statement to address via modeling. Mr. Tsirigotis stated that they generally present multiple problem statements regarding multiple issues, some of which are suitable for modeling and others that are not.

Case Study #2: Chesapeake Bay Program

Lewis Linker, U.S. EPA/Chesapeake Bay Program Office

Over the last two decades, the Chesapeake Bay Program Office (CBPO) has used environmental models to inform decision making issues such as the ranking of pollutant sources and cost-effective strategies for pollutant reductions. These questions can only be answered using integrated models tailored to the nature of the decision and to the desired level of analysis. Future models are expected to have increased utility and clarity. In the Chesapeake Bay, eutrophication of estuary waters results in low bottom dissolved oxygen (DO), excessive algae, and poor water quality. The CBPO has integrated a number of models to compare different scenarios for reducing nitrogen pollution. The CBPO's airshed model combines a regression model of wet deposition with CMAQ estimates of dry deposition. The watershed model encompasses 164,000 square miles in six states and is used to assess water quality standards regionally and at the local watershed scale. The estuarine water quality model is the decision model for DO and chlorophyll water quality standards. The water quality model, combined with the sediment transport and filter feeder models, is the decision model for the water clarity standard; achieving the water clarity standard is necessary for restoration of submerged aquatic vegetation. The nutrient allocation decision support system relies on the integration of these models. Because tributaries vary widely in their relative contribution to nitrogen load reaching the Bay, geographic targeting may represent a cost-effective strategy for decreasing the percentage of the Bay that is in non-attainment. Applications of integrated modeling and decision making will increase in the future. Integrated models are most useful when environmental control costs are high, when control measures are complex and involve different media, or when success can only be assured though engagement of all available control measures.

Gary Shenk, U.S. EPA/CBPO

For decision support, the CBPO uses integrated models that include the airshed, watershed, and land use models to characterize the Bay and to establish criteria assessment procedures. The watershed model uses the Hydrologic Simulation Program-Fortran (HSPF) model to run watershed scenarios that take into account factors such as land use acreage and BMPs, as well as hourly values for rainfall, snowfall, temperature, and other measures. In the past 20 years, the models have increased dramatically in complexity, driven by the management community's need to evaluate point sources versus nonpoint sources of nutrients. Model integration themes incorporate internal processes as well as other models and external databases. The CBPO has achieved flexible functionality by using software that includes time varying land use and time varying BMPs. Internal integration of watershed model processes allows for fair allocation of nutrient sources. External integration with other models such as the USGS' Spatially Referenced Regressions on Watershed Attributes (SPARROW) watershed model and ESTIMATOR flux model is a major advance that has been useful in streamlining the river calibration process. By building an online tool to access crop and land use databases, information is available for the watershed model and for state agencies. Decision making is based on multi-state goals, total maximum daily loads (TMDLs), and other users. The integration of management and decision making is difficult, and it is therefore important to develop a model that is credible. The watershed model will have multiple uses and users, and will be a community effort, structured to facilitate cooperation among stakeholders. This integrated modeling effort has been successful because it has incorporated fine segmentation, flexible functionality, high-resolution input data, automated calibration (ensuring even treatment across jurisdictions), transferability (i.e., an open-source model), and user friendliness.

Discussion

A participant asked to what extent the CBPO has outlined alternative strategies for achieving program goals. Such strategies might include alternative vegetation planting along waterways, the use of hybrid vehicles to reduce NOx emissions into water bodies, and other options that may not be classically targeted in emission reduction. Mr. Shenk responded that, once the goals were established in 2003, the program began a multi-year process using modeling to assess tributary strategies (best management practices). A number of the alternative new methods were discussed, but any new strategies or processes must be supported by research. The model is flexible enough, however, to incorporate new alternative strategies that are supported by research.

A participant asked Mr. Shenk to comment on the major data gaps in watershed modeling used by CBPO. Mr. Shenk answered that the data needs of the watershed model are immense; the required data include not only nutrient loads reaching the bay, rainfall, land use, and flow, but also changes resulting from manage-ment practices. The data regarding the effects of management are the most crucial for this model.

Regarding the importance of integrating the organizational structure up front in the Chesapeake Bay Program, a participant remarked that this must have been a daunting process considering the complexity of the model and the many stakeholder participants. What process was used to reach agreement on the complex technical modeling strategy? Mr. Shenk agreed that this was a difficult process. It was important to integrate the organizational structure before asking the states to come to agreement on how to build the model. CBPO was able to take advantage of an existing organizational structure; if it had been necessary to build the organizational structure from scratch, the process would have been much more difficult. Mr. Linker added that it is not what you say that is important, but rather how you say it. It can be helpful to begin by outlining a straw man and then asking participants if there are any objections. In addition, it is important to demonstrate success whenever possible.

A participant commented on highly parameterized models such as HSPF, which has been criticized because it provides multiple solutions. How did CBPO address over-parameterization and why was HSPF chosen rather than the regression-based SPARROW model? Mr. Shenk replied that HSPF was chosen because it was necessary to integrate all sources in the watershed to facilitate decision making and provide managers with realistic management options. SPARROW, which has only recently been considered for scenario analyses, is limited in that it can describe only what has been included in the calibration of the model. In addition, time must be incorporated (as an hourly input) to run the watershed model.

A participant asked whether there is a URL address for the open source watershed model and who are the current users. Mr. Shenk responded that he would provide the URL to those who are interested. Some universities used the previous version of the model; the current version is being used for some small-scale TMDL determinations.

PROGRAM AND REGIONAL OFFICE PANEL DISCUSSION: PAST EXPERIENCE, FUTURE NEEDS IN INTEGRATED MODELING AND DECISION MAKING

Panel Chairperson: Gerry Laniak, U.S. EPA/ORD/NERL

Mr. Laniak stated that the purpose of this panel discussion is to gain the perspective of those who operate at the intersection of science and decision making. This discussion should help to define and delimit integrated modeling and integrated decision making and to develop and prioritize a consolidated list of issues to address within the Agency on integrated modeling in the context of regulatory decision making.

Lester Grant, U.S. EPA/ORD/National Center for Environmental Assessment (retired)

As director of ORD's National Center for Environmental Assessment (NCEA), Research Triangle Park Division, Dr. Grant was responsible for directing assessments of the health and environmental effects of major air pollutants such as PM and ozone; developing and reviewing the NAAQS; and improving methodology such as physiologically based pharmacokinetic modeling to refine assessments for air toxics. NCEA has made significant contributions to the modeling of multimedia impacts of lead exposure on blood lead levels and to evaluations of the associated health effects. These evaluations have been used by many of EPA's program and regional offices to set standards for lead in air, water, soil, and other media. NCEA developed and validated the Integrated Exposure Uptake Biokinetic model, which is now widely used in a number of countries to evaluate lead exposure impacts. A number of insights can be gained from NCEA's experience with controversies in assessing air pollution effects and lead impacts. Lessons learned from NCEA's experiences include the importance of model verification and validation and the quality of data inputs, as these often are at the core of attacks on the credibility of models. In particular, it is important to verify the accuracy of the computer code used to implement a model parameter or calculation as mistakes in the code could seriously affect the results and could ultimately have huge monetary or human health impacts. In addition, it is important to validate the model against observations whenever feasible. The proceedings of a model validation workshop, published in Environmental Health Perspectives in December 1998, could be useful for workshop participants. Quality assurance (QA) and quality control (QC) for data entry (for model inputs) is another crucial component of modeling. Past mistakes in data entry have been sufficient to change the statistical significance of results and have led to major controversies over modeling efforts. With respect to the quality of the original observations, modelers sometimes have a tendency to accept the quality of data provided by external sources or disciplines outside of their own areas of expertise. It is important to determine how the quality of these data was checked and to know in advance, for example, how much of the data, if any, can be estimated or interpolated, as opposed to actual observations.

Cathy Fehrenbacher, U.S. EPA/Office of Prevention, Pesticides, and Toxic Substances/Office of Pollution Prevention and Toxics

Ms. Fehrenbacher described the regulatory programs of EPA's Office of Pollution Prevention and Toxics (OPPT). Problem formulation in OPPT can be complex and is exacerbated by the limited available data. Decisions made by the OPPT range from screening level decisions to more detailed analyses. OPPT is a multimedia office and devotes significant time to coordination with other offices. Models designed and used by OPPT must be transparent such that users and stakeholders understand the limitations and application range of the models. The New Chemicals Program is a unique program in which OPPT must develop a risk assessment and make risk management decisions on new chemicals prior to com-mercialization. Following the submission of a notice by a company, EPA has 90 days to decide whether the company can commercialize the product. The company is not required to conduct testing or provide even basic information on chemical properties and hazard information. Because of the lack of data, screening-level models of physical chemical properties, environmental fate and transport, human and environmental exposure, and hazard effects are crucial to the New Chemicals Program. Approximately 2,000 new chemicals are submitted each year. Therefore, scientists have, on average, only 10-20 minutes per chemical to develop an exposure assessment based on the screening model. OPPT also implements a number of voluntary programs in which the decision making process is developed in an open public process with a great deal of stakeholder input. In addition, OPPT programs build capacity within communities to use OPPT's tools and models to solve their own problems and facilitate the development of safer chemicals by industry. Through its participation in the Organization for Economic Cooperation and Development (OECD), OPPT has been able to share its models with other OECD member countries. OPPT is a multimedia office and, as such, it has always used integrated models. OPPT's increasing use of integrated modeling should help to prioritize resources and analyses and better inform decision making. As OPPT progresses toward greater use of integrated modeling, however, uncertainty is becoming a major consideration. For the New Chemicals Program in particular, it is important to consider the most appropriate type of uncertainty analysis in light of the impact of the decision, the legislative authority under which OPPT is operating, and the type of decision to be made.

David Guinnup, U.S. EPA/OAR

EPA's OAR engages in exposure and risk assessments for hazardous air pollutant sources. OAR routinely performs multimedia and multipollutant analyses for criteria and hazardous air pollutants and uses these analyses to make risk-based decisions. Decision making by OAR includes setting NAAQS for criteria pollutants and examining process standards for industrial sources of hazardous air pollutants. Science and environmental modeling can be powerful in eliciting a regulatory decision, but are generally less effective in dictating the exact level of the regulation. There are, however, exceptions to this rule, such as the 1996 decision to lower the ozone standard. OAR's exposure and risk assessments helped to place judgments regarding adverse health effects resulting from ozone into a broader public health context. Regarding the CAMR, environmental modeling (e.g., models of air deposition and bioaccumulation of mercury in fish tissue) played a central role, despite a lack of localized hotspot modeling. In another important rulemaking, OAR used modeled estimates of exposures and cancer risks associated with a hazardous air pollutant emitted by dry cleaning operations to set process-based standards that will be more effective than the previous technology-based standards. OAR has a history of decision making in the face of clear un-certainties. As scientific knowledge improves, however, uncertainty should be reduced and policy should change incrementally. For example, with respect to standards for PM, strong evidence clearly indicates that adverse health effects occur at PM levels below the earlier standards. However, in setting the new NAAQS for PM, EPA decision makers had to act in the face of considerable uncertainty regarding the specific levels and components of PM that cause these health effects. OAR continues to explore new methods for understanding, quantifying, and communicating its analyses and the associated uncertainties to decision makers in a consistent manner. A common presentation of environmental exposure and risk information could ultimately facilitate a consistent understanding of information by decision makers. The future of integrated modeling by OAR will further advance multipollutant modeling, will benefit from links to modeling in other programs, and will incorporate improvements in scientific understanding.

Zubair Saleem, U.S. EPA/OSWER

Dr. Saleem described modeling used by OSWER in the identification of waste and in determinations such as whether the waste is hazardous. The initial model used by OSWER was very conservative and assumed, for example, that contaminants are infinite in quantity (i.e., steady state) and do not decay or degrade; the model also did not account for metal speciation. In collaboration with ORD, OSWER then developed an improved model that uses a finite source methodology, which assumes that contaminants have a finite mass, allows for degradation or transformation of contaminants, and distinguishes among metal species. OSWER contributed to the development of a framework for a Multimedia, Multipathway, Multireceptor Risk Assessment (3MRA) modeling system as part of an inter-Agency effort. In accordance with a section of the Resource Conservation and Recovery Act statute, OSWER has shifted to a focus on conservation of valuable material and energy resources related to industrial by-products and recyclable materials. OSWER has adapted an integrated solid waste management model that includes source reduction, recycling, waste combustion with energy recovery, waste combustion without energy recovery, and landfilling. OSWER now is required to conduct a comparative evaluation of the environmental, economic, and other advantages and disadvantages of these techniques. To address this, OSWER is using a 3MRA modeling system with an additional highway source term. Further, to determine the acceptable risk from industrial waste materials resulting from highway construction, OSWER uses the Industrial Waste Evaluation model with the added highway term. OSWER also uses lifecycle impact assessments to compare the advantages and disadvantages of different techniques, as well as the use of virgin materials. OSWER is attempting to minimize uncertainty and find ways to verify its models.

Discussion

A participant asked Ms. Fehrenbacher to explain how risk assessments for new chemicals can be made in only 10-20 minutes. Ms. Fehrenbacher explained that OPPT's screening models enable this kind of rapid assessment. OPPT processes new chemical submissions in a standard way that allows a decision to be made within 2 weeks. Approximately 10-50 new chemicals are submitted every week. For each chemical, OPPT must develop a report of the chemistry, human health and ecological endpoints, and environmental fate and transport assessments and must make a decision based on these analyses. Companies are not required to submit data, and few new chemicals are submitted with any data. OPPT's modeling platform incorporates specialized tools with default inputs that are biased toward protectiveness by overestimating exposures.

A participant asked Ms. Fehrenbacher whether OPPT's predictions of new chemical safety have been accurate. Ms. Fehrenbacher replied that OPPT assessments tend to overestimate exposure. When a company contests a decision, OPPT may challenge the company to conduct monitoring and this enables model validation.

A participant reiterated Dr. Grant's concerns regarding code verification and QA/QC procedures. It is important to thoroughly check for mistakes in the code or other aspects of the model before decision making has occurred. If a modeling mistake is discovered late, requiring a reversal or change in the decision, this may give the impression that the Agency was pressured to change its results for political purposes.

A participant asked Ms. Fehrenbacher how OPPT assesses nanomaterials considering that very little is known about these products. Ms. Fehrenbacher responded that OPPT is charged with making decisions despite a lack of data on these materials; however, OPPT has substantial latitude regarding the types of decisions it can make. For example, OPPT can limit or ban the production or use of a chemical until the company conducts testing believed to be necessary. She added that OPPT is collaborating with OECD partners, other agencies, and ORD to determine how best to address permitting the use of nanomaterials.

Regarding the transparency of decision making, a participant asked Dr. Guinnup whether Agency decisions might best be articulated in terms of a "value of information" framework. In this type of framework, the Agency might indicate that the cost of reducing the uncertainty is not exceeded by the cost of the risk believed to be associated with a particular pollutant. Dr. Guinnup agreed that attempts to express uncertainties quantitatively to decision makers are fraught with difficulty. Many decision makers are not comfortable with the concept of uncertainty, especially if it is quantified, because it seems to undermine the decision. It is important to find a consistent and acceptable way to express this kind of information to decision makers.

With respect to transparency in decision making, a participant suggested that there is a tendency to confuse a rational basis for a decision with a scientific basis and that a decision can go against scientific evidence if there is a rational basis for doing so (e.g., the cost of implementation). In such situations, is it worthwhile to convey that uncertainty is being addressed in a rational manner, and not in a political manner? Dr. Guinnup responded that he advocates presenting uncertainty in a rational and systematic way and allowing decisions to be made with a recognition of both the quantitative, logical uncertainty, and the political realities. In some cases, risks are so great that they must be reduced regardless of cost. In other cases, risks appear to be acceptable but substantial uncertainty remains; even under these circumstances, however, political realities often require the Agency to spend money to reduce the risks.

A participant asked the panelists to comment on their experiences in situations in which the variables to which model outcomes are most sensitive have been generated by another office or discipline. Dr. Guinnup replied that, when obtaining monitoring data from another office, for example, it is helpful to know something about the uncertainties in the measurements. Reflecting the uncertainty as a range of values in such cases would be more useful than expressing it as a point estimate.

A participant asked panelists whether anyone has developed a rule of thumb for an acceptable level of uncertainty relative to the size of the decision. Dr. Guinnup answered that this is difficult to do and this will always be subject to the political nuances and realities of the situation. It can be valuable, however, at least to quantify the uncertainty.

A participant commented that uncertainty sometimes is used to justify not taking action or to justify ignoring huge potential risks such as those predicted to occur as a result of climate change. Scientists need to acknowledge the uncertainty and also indicate whether the potential consequences of inaction (or action at the wrong level) are so great that the Agency must act in spite of uncertainty. Similarly, scientists should acknowledge instances in which consequences of inaction are minimal, in which case uncertainty might be sufficient to cause the Agency to decide not to act.

Another participant responded that it is the political decision maker’s job to make the decision; this includes the decision of what to do in the face of uncertainty. The job of modelers and other analysts is to provide options and explain the pros and cons of the options. Although the modeler must find a way to express the level of uncertainty, it is not the modeler’s role to tell decision makers what to do with the uncertainty. Further, it is incorrect to suggest that a decision not to take action represents a lack of a decision.

A participant asked panelists about accountability and whether there is a requirement to monitor the effects of decisions to determine if the modeling was accurate. Panelists responded that it is important to continually revisit the question by checking model results against data in an ongoing, iterative process. When the model’s predictions are not confirmed, one must determine why and what action is required to get back on course.

BREAKOUT DISCUSSION SESSION 1: INTEGRATED MODELING AND DECISION MAKING: DEFINITION, DRIVERS, LIMITATIONS, AND ISSUES

Session Co-Chairs: Jeff Yurk, Lynne Petterson, Robin Dennis, Cathy Fehrenbacher, Brian Caruso, Gary Shenk, Tom Purucker, and Larry Zaragoza

The purpose of this discussion session was to engage workshop participants in an initial consensus building on definitions and program-focused integrated modeling issues.

Question 1: What does integrated environmental modeling mean? Is integration new or simply a concept that is evolving or maturing with respect to environmental decision making?

Defining Characteristics of Integrated Environmental Modeling

A participant suggested stepping back to define modeling before defining integrated modeling. Participants agreed that modeling does not have to be computational and also can be conceptual. A participant suggested that integrated modeling is the marriage of two component pieces: the integration of concepts that make up a model representation and the physical integration of the variables, driving parameters, and communication linkages that comprise a model representation. Many participants agreed that modeling—and integrated modeling in particular—must incorporate this conceptual component. In conceptual integration, multiple models are mapped onto the decision such that each model's relationship to the decision space is shown.

Integrated modeling is a sophisticated response to challenges in describing a complex world that incorporates concepts, data, and management goals from different sources. Integrated environmental modeling refers to any environmental modeling system that is interconnected and enhanced for decision making via a set of software support tools. Integrated modeling is hierarchical, modular, and iterative. Environmental information and processes are systematically organized in the form of interconnected modeling components within a cohesive framework. Data are mapped, moved, or transformed across formats, platforms, or domains. Integrated models can stand alone, interact with each other (e.g., for sequential, comparative, or parallel analyses), or be integrated with other models into a more complex system. Integrated modeling recognizes that little is truly exogenous to an environmental system and that, in such a complex and adaptive system, feedback loops are the norm rather than the exception. Consistent with most environmental systems or ecosystems, integrated modeling addresses multiple pollutants or other stressors across multiple media. Integrated modeling follows a more robust analytical approach (i.e., multiscenario analysis) and requires greater scrutiny than more simple or single-media/single-pollutant models. Some participants remarked that there is a difference between coupled modeling and integrated modeling.

Integrated modeling is often interdisciplinary; in fact, some participants argued that the term “integrated” implies an interdisciplinary approach. Integration can occur across different models ranging from water or air models to outcome or exposure models. A participant noted that, during the past 3 years of integrating across disciplines, output from physical models has been fed into economic models. For example, Region 3 is examining how the interplay between certain physical models affects the preferences of stakeholders. Another participant noted that feedback from economic models can be linked to climate models and vice-versa. People working in different disciplines, however, conceptualize integrated modeling differently; links among these groups are lacking.

Integrated modeling should incorporate support tools such as uncertainty analysis, automated calibration, and database management systems. Integration is usually more than simply linking codes together. The computer science framework must support code reusability, good model selection, and scientific visualization. A participant commented that it is useful to develop a typology, which can help to determine the approach used in integrated modeling.

Participants discussed the potential for redundancies or missing parameters within integrated systems. For example, during development of the linkage between watershed models and BASINS on the Aquatox project, modelers had to ensure that the water quality processes were not being duplicated.

Integrated modeling systems are composed of interoperable components. Interoperability is a key technical component of integrated modeling; however, participants disagreed over the definition of interoperability and whether interoperability is best considered the current state of integrated modeling—and, in fact, a defining characteristic—or an important goal. Some might suggest that interoperable model components are designed to be used in multiple applications for multiple decisions without requiring users to rebuild the same component for each new use. Such a definition of easy communication among the components implies a machine-to-machine level of interoperability. In particular, one revolutionary change that has aided model integration in some cases has been the development of software frameworks so that output from one model can become input to the next. Currently, however, many integrated modeling systems are not interoperable in this sense; quite often the combination of model components requires a great deal of effort by the modeler. Perhaps it would be useful to consider different types or levels of interoperability and integration, from functional or conceptual to technical integration. Participants agreed that, while seamless technical interoperability is an important goal for modelers, some level of interoperability is a defining characteristic of integrated modeling.

Participants agreed that, regardless of the manner of integration and level of interoperability, the manner in which models are linked must be transparent and well documented because the method of linking is often questioned. Even a fairly sophisticated model must be codified so it is open and reproducible and can stand up to scientific scrutiny. In linking models, it is important to consider the intended use for which each individual model was originally developed, as well as its limitations. For example, if assumptions differ among models, this can create vulnerabilities that must be addressed. Validation and verification of models is important but this becomes more difficult with increasing complexity of the integrated system.

A participant suggested that drivers for integrated modeling include the following: (1) The Global Earth Observation System of Systems (GEOSS) international initiative and the U.S. component of this initiative, the Integrated Earth Observation System (IEOS)—both initiatives have 10-year strategies supported by the White House. (2) Information technology—recent advances, such as service-oriented architecture (SOA), can help models and data interoperate. (3) Adaptive management—models should support simulations of alternative strategies, selections, evaluation of outcomes, and adaptive adjustments.

Participants did not reach consensus on a single definition of integrated modeling and noted that there may be a continuum or gradient of definitions of integrated modeling. A participant commented that one of the methods by which integrated modeling is defined is the extent to which it combines any of five global components (biosphere, lithosphere, cryosphere, hydrosphere, and/or exosphere) with numerical methods for establishing the linkages. Some participants suggested the following definition of integrated modeling: An evolving multidimensional process connected by software, and decision making involving diverse spatial and temporal processes, with resources for accommodating alternative models and increasing computational capacity.

Basic science, systems science, and management science need to come together. Existing frameworks permit the marriage of systems engineering and technology to business and policy. EPA has the capacity to build an integrated modeling framework separately or incorporate modeling into an existing framework linked to policy drivers. The best strategy for success will involve collaborations within and outside the Agency to ensure the appropriate expertise, skills, and knowledge set to address the challenges of integrated modeling for decision making.

In summary, participants generally agreed that integrated environmental modeling:

- Comprises interoperable components or modules.
- Can comprise a model integrated within itself.
- Typically encompasses multiple media, multiple pollutants or other stressors, and multiple temporal and/or spatial scales.
- Crosses disciplines.
- Should be conceptual as well as computational (i.e., the numbers must be connected with concepts and with the decision at hand).
- Incorporates visualization tools to aid understanding by decision makers and stakeholders.
- Must be transparent in terms of assumptions and methodology to allow for their application by non-technical users such as communities or industry.
- Addresses specific decision making needs and management goals and requires communication with decision makers.
- Requires uncertainty analysis.
- Can create new vulnerabilities, such as uncertainties not appreciated by the modelers, through the combination of models not designed for integration.

Integrated Modeling and Decision Making

Participants widely agreed with the importance of connecting integrated modeling to the particular question or problem facing a decision maker; this could be considered functional integration. Integrated modeling combines models within decision frameworks, capturing and synthesizing the science and data needed to inform environmental decision making. It should, in a sense, integrate the modelers, decision makers, and other information consumers and serve as a “decision support tool.”

Participants emphasized that models produce outputs used to characterize risk and can be used to inform decisions; however, models stop at informing the decisions.

Advances in integrated modeling can inform and facilitate decision making, but only with improved or increased communication and transparency across all levels. It is important, therefore, to establish or enhance collaborations with experts in a range of areas (e.g., computer technology, information technology, database development, and human health) to ensure that the best models are developed and that these models are accessible and understandable.

Regarding the interface of model development and model application, participants questioned how to integrate decision making, which is not the purview of scientists, into model development. Much model development, automation, and linkage of models has not involved decision makers, managers, or customers at all. With policy driving decisions within the government, what is the role of scientists? How can scientific and research findings be translated and applied to benefit the public and the environment? How can science benefit or inform policymaking and decisions? One approach is to bring decision makers into the model development process early on to provide input on key drivers, "buy into" the process, help scientists better understand the policy process, and allow for justification of the cost of proposed policies supported by the science. The shift from simple "stovepipe" models to more complex integrated modeling involves applications across disciplines that will require a certain comfort level among policymakers as well as scientists. Increased transparency and improved communication at all levels are needed to accomplish these goals.

Some participants raised the issue of uncertainty associated with data, individual models, and integrated models and the impact of uncertainty on decision making. By consulting with policymakers at the start of the model development process, scientists may be better able to anticipate or identify sources of uncertainty early in the model development process to yield models and outcomes associated with a higher level of confidence.

A participant noted that it is also necessary to determine whether modeling is considered to address a particular problem because it represents sound science or because it is cost-effective.

A participant warned that one should be careful to distinguish between integration of models and integrating modeling into decision making; this distinction is not always clear to stakeholders. It is also unclear on which of these topics this workshop was intended to focus. Some participants suggested that it may be useful to hold two separate meetings, one focused on integrated modeling and the other on integration of modeling into decision making. The two concepts then could be brought together under one larger umbrella workshop.

Participants considered problems stemming from attempts to integrate modeling into decision making. In particular, models usually are developed to project risk, impact, remedies, and so forth, for the next 10 to 20 years, whereas policy decisions are made every 5 to 10 years. If EPA intends to move toward integrated modeling, a paradigm shift will be needed to ensure that models adequately take into account and accommodate potential policy drivers. It also must be made clear, however, that assumptions about the future that are embedded within a model do not represent choices about the future.

In summary, participants identified the following items to facilitate the science/policy interface as integrated modeling continues to evolve:

- Include policymakers early in the model development process and obtain feedback on priority policy issues.
- Incorporate project management theory practices (e.g., charter with buy-in, define expectations, develop timelines with milestones and anticipated outcomes).
- Continue modeling as currently or previously done but with an eye to scaling back or tailoring models to specific purposes.
- Develop rapid-response service models to allow for various policy modifications, changes, and/or needs; multiple regulatory scenarios; and multiple environmental systems or pressures.
- Develop look-up tables that include a range of possible or anticipated parameters.
- Communicate across EPA offices regarding ideas and new strategies for the application of models (and integrated modeling in particular) to decision making. Partner to track successes by tying together functions and monitoring use of models.

Statements Regarding the Evolving Nature of Integrated Modeling

All modeling analyses integrate information; therefore, in a sense we have always done integrated modeling. The current focus of integrated modeling reflects a recognition that, in at least some cases, traditional compartments may need to be broken down to obtain better information for integrated decision making. Integrated modeling may represent a re-emergence of systems thinking in response to excessive reductionism.

Participants agreed that integrated modeling is not new but is, rather, evolving with changing needs, availability of new data, the increased complexity of and advances in environmental sciences research and computer/information technology, and increasing computing power. The maturation of integrated environmental modeling also is aided by the emergence of spatial database management systems, the increasing ease with which data and models can be shared, and improvements in other technical resources and tools that facilitate integration. A participant suggested that more common forecasting, hindcasting, software design, and use of reusable model components have made integrated modeling more common. In addition, integrated modeling is evolving and broadening in scope in response to improvements in monitoring systems that provide more environmental data of various spatial and temporal scales. These improvements allow for the application of integrated modeling to more complex, interdependent environmental problems. A participant suggested that the evolution of modeling could be viewed as a disruptive revolutionary process in terms of the technological advances. Environmental analysis previously relied solely on observational research; now, however, both observations and modeling are required to establish credibility.

Some aspects of integrated modeling are in their infancy. In particular, decision makers need to be better educated about modeling so that they have the ability to ask better questions. Modelers, in turn, must develop models with more meaningful output that can answer these questions and inform decisions.

A participant noted that it would be a mistake for the Agency to tout integrated modeling as new; if integrated modeling is seen as something new and untested, funding for integrated modeling efforts may decline.

Another participant suggested that integration has become more high profile and more critically analyzed. Historically, links were made by staff scientists outside the context of modeling; it is easier to criticize a computer program for erroneous decision making than it is to criticize a highly qualified staff scientist.

Question 2: What are examples of instances where integrated models are necessary or desirable?

General Types of Instances

Integrated models are necessary when numerous sites or scenarios must be assessed with a relative paucity of available data. Multidisciplinary questions, or those in which social, political, and economic factors are substantially influencing decision making, would benefit from integration. Integrated models should be used where they would clarify information for decision makers without resulting in an unacceptably high level of uncertainty. Integrated models are important whenever models are used in real local, regional, or global applications. They also are useful when the research or policy question is long-lived compared with the expected longevity of the data source.

Such modeling is necessary or desirable where multiple media (e.g., to capture interactions among the atmosphere, hydrosphere, and land), multiple stressors (e.g., multiple pollutants), multiple pathways, and multiple receptors must be assessed and where it is appropriate to do so. Systems or processes with multiple anthropogenic influences and systems that are significantly linked through two-way (or greater) coupling are appropriate for integrated modeling. In particular, integrated modeling would be useful where there are strong interactions among media and feedback must be incorporated into the modeling. Integration of multimedia fate and transport with exposure and risk assessment can deliver useful insights to decision makers. In these cases, it is necessary to link source information (emissions) to ambient concentrations (whether in air, water, or soil) and, finally, to human health or ecological effects. This process can result in targeted policy decisions.

A participant added that integrated modeling should not necessarily be restricted to multimedia analysis, as a single medium could be integrated across many simulations with interacting factors.

A participant demonstrated the many opportunities for integration via Figure 1 (p. 17) of the IEOS Strategic Plan. This figure links earth observation systems to earth system models (including weather, climate, and atmosphere); links observation systems to observations and earth system models to predictions; links those observations and predictions to decision support; and links decision support to policy decisions, management decisions, and personal decisions that ultimately result in society benefits. The diagram includes ongoing feedback to optimize value and reduce gaps.

Integrated modeling also is necessary for cost-benefit analysis where it is necessary to link environmental modeling with economics. Integrated modeling is desirable when many alternative regulatory or management scenarios must be weighed. Linked models may be especially useful when data, tools, and expertise are not co-located or when resources are limited.

With the transition of EPA to analyses of more complex systems and larger scale studies, there are many instances in which integrated models are, or should be, employed. Although simpler models may be used in the majority of decisions, decision makers often turn to integrated models when outcomes of the simpler models do not fit their social or other goals.

Some participants commented that, although integrated modeling may be useful in updating regulations, there is a general reluctance to do this because results may suggest that the Agency should impose new requirements on industry.

Specific Examples

Participants suggested that integrated modeling would be necessary or desirable to:

- Model earth systems using integrated approaches, such as the National Aeronautics and Space Administration's (NASA) Earth Science Modeling Framework (ESMF).
- Predict which Toxics Release Inventory chemicals, if any, are of concern in specific areas.
- Make predictions about contaminants for which there are strong interactions among media (e.g., air emissions of mercury affecting mercury concentrations in surface water and fish tissue).
- Make projections to aid Superfund and other cleanup programs.
- Conduct greenhouse gas modeling in which information on emissions, costs, sectoral impacts, ecological impacts, and human health impacts should be estimated or modeled under different policy scenarios.
- Predict in-stream water quality.
- Make predictions regarding the bioaccumulation of contaminants such as mercury resulting from deposition.
- Conduct ecosystem services valuation.
- Model watersheds and link watersheds to airsheds.
- Model global circulation.
- Predict ecosystem impacts from international transport.
- Make predictions about the acidification of freshwater ecosystems by sulfur and nitrogen species.
- Make projections about the eutrophication of marine ecosystems by nitrogen.
- Integrate lead concentrations in the environment with blood lead levels in children.
- Inform land-use planning.
- Determine fate, transport, exposure, and the human health and ecological impacts of pollutants.
- Predict impacts in fish of atmospheric deposition of mercury.
- Determine TMDLs.
- Conduct cost-benefit analyses.
- Inform ecosystem management for endangered species and management of marine protected areas.
- Conduct risk assessment of air pollutants and in estuarine assessments (e.g., Chesapeake Bay).
- Model situations involving bidirectional flux of ammonia and nitrogen.
- Characterize or define surf zones by modeling sea salt emissions.
- Support decisions made by the OPPT New Chemicals Program.
- Integrate land use, mobility, emissions, and exposure models.

In particular, the integration of land use, mobility, emissions, and exposure models could be beneficial, for example, in addressing the results of epidemiology studies indicating a higher prevalence of asthma in schools near freeways. A new policy in the State of California based on these studies will make it more difficult to build schools near freeways. This policy is intended to protect children from air pollution; however, if it is implemented poorly, this policy could have unintended negative consequences, such as by increasing the time children spend in transit to schools in “greenfield” areas and discouraging the construction of walkable neighborhood schools.

One participant noted that EPA decision makers would have benefited from an integrated, multimedia assessment of the gas additive methyl tert-butyl ether (MTBE), which was adopted for its clean air attributes. Integrated modeling may have demonstrated the potential for contamination of groundwater and drinking water by MTBE.

Some questions do not require or benefit from integrated modeling; examples include hypothesis testing or situations in which moving in the right direction is more critical than finding a single best point. Further, it may not be appropriate to integrate models if the uncertainty from one module is unacceptably high relative to the higher-tier modules in the system.

Question 3: What examples of successful and unsuccessful decisions exist where integrated modeling was needed or attempted? What were the key factors in determining successes?

Successful Examples

A participant remarked that the selection of good examples depends on the definition of integrated modeling. For example, if integrated modeling does not require addressing concentration and fate and transport in all media, then many examples can be found in watershed assessments of land-water interactions. Participants suggested that criteria for defining success could be based on a comparison of data outputs from a non-integrated model with those from an integrated model.

One example of a successful application of integrated modeling is the concept of a carbon footprint and a mass mailer that was disseminated regarding how to decrease one’s own carbon footprint. A participant noted, with respect to this example, that a good model does not have to be complex.

The new chemical screening program is another example of a successful application of integrated modeling in which air, water, and soil are partitioned for screening.

Risk mitigation for old chemicals often has relied on biological-economic assessments and models, and the decisions regarding these chemicals tend to be supported by stakeholders.

The development of 3MRA was based on cooperation, a solid framework, and vision. Because of delays, however, this model is not being used as originally planned.

Emergency response offers some examples of successful integrated modeling. One such example from outside of EPA is real-time flood forecasting in which meteorological models are integrated with ocean models, river models, urban drainage models, hydrologic models and others, all using real-time data. This integrated system is intended to address only a single question. It includes software dedicated for a single use as well as models that are designed to be reusable in other applications. Another example is hurricane tracking decisions; those based on integrated modeling have proved to be more accurate than decisions based on previous models.

Other successes include: (1) risk screening for environmental indicators; (2) risk mitigation for old chemicals, which relies on biological-economic assessments and models; (3) the Hazardous Waste Identification Rule; (4) polychlorinated biphenyl modeling in Lake Michigan, which was subsequently linked to bioaccumulation in fish and human consumption; and (5) CEAP.

Unsuccessful Examples

Projections of ecological risks from pesticides has not been successful, in part because the models are not well-integrated and are incomplete; these models are, therefore, more difficult to explain to decision makers.

Transportation planning models represent an example of integrated modeling that is not successfully integrated with decision making. For example, decisions to increase highway lanes simply lead to increased use of the highway and increased congestion.

In Chicago, a multimedia air project failed because, although each stakeholder had an agenda, funding was limited to one activity. This process could have been improved by beginning with a narrowly focused goal that could be accomplished initially, which can be expanded to achieve other goals, with successes shown along the way. Earlier involvement of the stakeholders and decision makers also would have benefited this process.

A participant noted that the influence of the White House reaches out across all agencies. When models are offered that are counter to Administration policies, it takes the will of the constituencies to shape the decision makers.

One unsuccessful project was developed to answer a question about HWIR. HWIR disappeared before the answers were available; however, the model will be useful in the future.

Other examples of unsuccessful decisions include: (1) single-species fishery models; (2) early radon detection; (3) early acid rain assessments; (4) evaluation of sewer discharge components; (5) decisions related to arsenic; (6) the Cleaning Material Qualification Protocol (CMQP); and (7) decisions related to soil nutrients.

A participant commented that all failures can become eventual successes; however, when program deadlines are not met, they may be considered a failure to those who invested major resources.

Key Factors in Determining Success

Participants suggested a number of key factors to determining success, including:

- Strong leadership.
- Availability of funding for all components of the integrated model.
- Verified, evaluated, and peer-reviewed models.
- Models validated or tested with available data.
- The use of complete, high-quality data.
- Open-source software.
- Quantification of uncertainty.
- QA procedures.
- Communication, cooperation, collaboration (e.g., inter-agency), and coordination in integrating models.
- An appropriate framework.
- A strategic vision for the application of the model.
- Clearly mandated endpoints with modeling tailored to programmatic needs.
- Appropriate application of models.
- Strong, early involvement of management or the customer.

- Models and results that are easy to explain to stakeholders and decision makers.
- Models that can be used efficiently and in a timely manner, balancing the complexity of the model with timeliness when necessary.
- Support available to update models to keep pace with scientific understanding.
- Transparency of models and availability of documentation.
- Existence of processes by which to evaluate risk both quantitatively and qualitatively.
- Availability and support of post-processing capabilities.
- The ability to show early successes of modeling efforts and to provide initial information, even when the final result or the most complex or realistic version of the model is not yet complete.

Question 4: What are the issues and limitations (i.e., science and technology, statutory or policy, and institutional) related to the use of integrated approaches in current regulatory decision making?

Participants noted that resources, including time and funding, limit integrated modeling approaches. Questions and projects should be better prioritized to allocate limited resources more efficiently. Incentives, such as increased funding of components for which expertise is currently limited, may be helpful.

A participant noted that OMB places great importance on monetizing alternatives; if integrated modeling does not address economics of alternative decisions or policies, OMB will not consider it a valuable endeavor.

Modelers often are required to develop models and provide outcomes or predictions within a short timeframe for regulatory decision making. Although scientists, programmers, and modelers have generally worked on a relatively long-term basis (1 to 5 years), policymakers now expect results within a very short period of time—often within weeks. The required turnaround times may not be practical, especially for more complex modeling, and this makes it difficult to meet legally mandated deadlines. Participants suggested that a two-pronged modeling approach is needed to adapt to this changed timeframe. Specifically, such an approach could include a rapid-response model or assessment with a short-turnaround time as well as development, testing, and implementation of the full model. Scientists should develop simple versions of complex models for management utility. They also should consider performing preliminary testing of scientific data and policy issues by providing or testing for changes in inputs and for multiple regulatory scenarios.

Poor communication and collaboration is problematic in a number of ways. First, integrated modeling is significantly limited by a lack of communication and integration across disciplines and programs within the Agency (i.e., “stovepiping”). Attitudes and organizational culture must change to ameliorate this problem. In particular, offices currently do not consider the existing models developed by other offices and instead develop a new model. To avoid reinventing the wheel, offices should take advantage of the tools developed across all offices. Second, communication between modelers and upper management must be improved. Upper managers may not have the technical expertise to understand the models or their long-term implications. Modelers, for their part, lack the skills to “sell” their models to upper management and others. Ineffective communication with upper management regarding the benefits of integrated modeling (and the disadvantages of not engaging in integrated modeling) can further hinder funding. Third, better relationships also are needed with both decision makers and stakeholders. In particular, integrated modeling is sometimes seen as too complex and this can result in distrust of models by decision makers. Communication to decision makers of model uncertainty and predictive capability must be more transparent. When presenting the results of integrated modeling, it is important to describe the limitations of each component of the model. Integrated modeling also can be limited if appropriate constituents or stakeholders are not included early in the planning process. Users and decision makers should be included in the model development process. This collaboration should provide an opportunity for dialogue between scientists and decision makers to clarify expectations, identify short- and long-term policy needs, assess costs and benefits of different models and policy scenarios, and develop timelines for assessment and outcomes/predictions. Although policymakers are requiring shorter turnarounds, it is important for scientists to ensure that sufficient time is built into the model development process/assessment within the context of policy guidance and needs.

Integrated modeling approaches also are challenged by conceptual limitations; these limitations can hamper communication with decision makers and stakeholders. One participant suggested that, in particular, integrated models must be able to characterize the environment in something other than representative or canonical descriptions.

Scientific and technical limitations include the incompatibility among models to be combined under one framework. Often, integrated modeling combines models that differ in temporal and/or spatial scales or resolutions; such differences must be resolved. Further, in integrated modeling using multiple temporal and spatial scales, one must consider how information is transferred between components. Model components also tend to differ in geographic representativeness and complexity. Legacy models can be difficult to integrate because they were not designed with integration in mind. Frameworks for integration are lacking and this exacerbates the problems inherent in linking existing models. Open-source software—including frameworks—is crucial. Further, models should be more readily accessible, such as through Agency Web sites.

Modeling efforts are hampered by a lack of high-quality data and metadata. Models, and linkages among models, have improved steadily over time, but data quality and accessibility have not improved. Models based on minimal information may be useful for research purposes but not for applications. One way to incorporate more observational data is to adjust model scales. A participant remarked that data are especially lacking for air quality simulations; for example, toxicity information for some chemicals has not been assessed in 20 years. A participant suggested that integrated modeling also is limited by a lack of standardized, meaningful, and analytically tractable environmental indicators.

The implementation of standards for developing models and accessing data is facing resistance by modelers. One outcome of this workshop might be an initiative that supports implementing standards. The modeling community can attest to the level of inconsistency currently present.

Models, model codes, and data inputs and outputs must be able to stand up to heavy scientific and legal scrutiny. Models must be transparent, well documented, and have a well-defined domain. Firewall and bandwidth are problems within EPA and can limit collaboration and communication; for example, information can be lost when large files are transmitted.

Participants repeatedly emphasized the need for improvements in the characterization and quantification of uncertainty. Even for nonintegrated models, additional research and development efforts are required to better address uncertainty. Uncertainty can be quite high in integrated models because the output from one model is used as input in the next; an integrated or multimedia modeling approach is only as strong as the weakest link in the system in terms of uncertainty or other limitations. The limitations in the effective characterization of uncertainty affects both the scientific validity of modeling and the effectiveness of communication with decision makers.

Improvements are needed in the evaluation, validation, verification, and peer review of integrated modeling. A model is a hypothesis that can be supported or rejected; model output must be validated via observational data to determine whether it makes sense. However, validation can be very difficult for some models (e.g., groundwater fate and transport models), especially for those predicting unobservable futures, such as the increased cancer risk to the U.S. population over a 10,000-year period.

Policies often require the Agency to address a certain problem (e.g., air quality or exposure) individually, via multiple stovepiped statutes, without allowing for adequate assessment of complex multimedia impacts of the proposed solution or action. These statutes include the CAA; Clean Water Act (CWA); the Comprehensive Environmental Response, Compensation, and Liability Act; the Resource Conservation and Recovery Act; and the Toxic Substances Control Act. The Agency should delineate the multidimensional decision spaces under these statutes and programs and identify commonalities and opportunities for cross-media integration. For example, enabling statutes such as the CAA and CWA make it difficult to bring together air and water managers to discuss shared problems and the regulation of standards. This kind of problem hinders cross-fertilization of ideas and true interdisciplinary, inter-office collaboration within the Agency.

Moreover, some definitions in such statutes allow so much room for interpretation by different states that the results for human health and the environment may differ from what EPA intended. Differences across states in implementation also can lead to difficulties in assessing the ecosystem effect of the statute. For example, the CAA requires states to regulate air quality, but not deposition and cross-media exposure. Not all participants agreed with this assessment, noting that the CAA does not prevent states from regulating deposition or considering exposure across media and that a statutory fix is not required to improve the Agency's programs. Participants discussed other statutory limitations; for example, projected high emissions of compounds not regulated under the CAA, such as hydrogen sulfide, are unlikely to result in enforcement action unless it can be linked to a human health impact. A participant noted, however, that there are checks and balances on the regulatory process, including citizen lawsuits, the National Academy of Sciences, and the SAB; with this system in place, the Agency should make appropriate decisions over time. Again, this concern may boil down to a lack of communication; this workshop and others like it could promote better communication and allow the Agency to build on its successes.

Participants discussed the importance of decision making risk. A decision maker might incorrectly interpret the uncertainty of a model result as suggesting that a particular decision is not warranted. Participants suggested that the Agency value the risk of making an incorrect decision in this context. One participant suggested that cost-benefit analysis should be expanded to include uncertainty; the cost-benefit of the uncertainty would represent the decision making risk.

Question 5: What are the 10 things the Agency should do to improve the quality and flow of science-based information used to inform regulatory decisions?

Participants agreed that the following 10 Agency actions would improve the quality and flow of science-based information used to inform regulatory decisions:

- Develop transparent models with well-defined domains and ensure that these models meet programmatic needs.
- Improve information sharing by developing an accessible clearinghouse or central database of open-source models and data. This also should allow for further development of individual model components—including both complete, long-term and simpler, quick-response models. Links to academia and industry may enhance model development and design and foster collaborations.

- Increase resources available for model development, integration, documentation, verification, QA/QC, and validation.
- Perform regular backcasting with existing data, model evaluation, and uncertainty analyses.
- Support cyberinfrastructure improvements, such as those affecting the firewall and the ability to back up modeling work.
- Facilitate the use of open-source software.
- Develop standards for data, metadata, models, and architecture.
- Improve collaboration and coordination within EPA (across programs), and between EPA and other federal agencies (e.g., via GEOSS).
- Improve the relationship between decision makers and modelers, increasing (1) modelers' awareness of decision makers' needs to allow for more effective definitions of model outputs for decision makers; and (2) decision makers' awareness of the benefits of modeling and appropriate interpretation of model results and uncertainty analyses.
- Hire more scientists into program management positions to improve understanding of modeling by upper management.

Participants agreed that CREM should focus Agency efforts with respect to integrated environmental modeling. Participants also suggested that the above list should be considered the important principles of integrated modeling.

Other actions suggested by participants included the following:

- Agree on a framework for collaborative integrated modeling.
- Define and promote best practices for integrated modeling.
- Create standard operating procedures and tools for assessing model uncertainty.
- Implement and ensure adequate and consistent QA/QC of methodologies and modeling.
- Develop a standard approach for describing uncertainty to decision makers.

- Improve the presentation and description of models and model output (such as via visualization tools) to improve understanding by decision makers and other nonscientific audiences.
- Develop a rating system for models and describe how the rating system should be used.
- Require sensitivity analysis to be performed for each model.
- Make information about models and model validation available on the Web; if model validation does not exist, provide an explanation.
- Ensure that models have data management plans that include information technology, information management, and QA needs.
- Promote simplicity in modeling, with complexity only increased where it will improve the results.
- Promote modeling at larger spatial scales.
- Facilitate ecosystem- or place-based research and modeling.
- Identify and define cross-media impacts, needs, and requirements and promote more multimedia modeling.
- Develop data libraries or repositories.
- Decentralize control over Web-based software.
- Harness the Environmental Science Connector.
- Develop WIKIs to build a knowledge base of tools, results, and assessments.
- Develop a library of environmental science components rather then environmental science models.
- Promote exchange of information, solutions to integrating models, expertise, and characterization of models.
- Establish a “modeling help center” (or “help desk”) or a mechanism for “loaner expertise” to facilitate the development and dissemination of quick-response models.
- Develop a list of successful integration efforts.
- Provide guidance for the adoption of standards for data distribution and data sharing.
- Make better use of remote sensing data.
- Develop, acquire, and use better analytical tools.
- Improve links between data providers and modelers.
- Prioritize funding available for modeling.
- Increase funding for monitoring.
- Develop an infrastructure for collaboration (e.g., CoLab) among ORD, regional offices, program offices, other agencies, and stakeholders.
- Support peer review and clarify the peer-review policy.
- Educate each other about different roles along the continuum, from core science to applied science to assessment to decision making.

- Enhance collaboration and communication by sponsoring interdisciplinary workshops and conferences.
- Reward research outcomes, not just outputs.
- Reward individual scientists, following the example of rewards for those working on policy.
- Improve communication with the public and the Agency's understanding of decisions of interest to the public.
- Provide tools for local communities and non-technical audiences both with respect to risk and consumer behavior.
- Improve scoping to define relevant policy questions and focus the analyses.
- Make better use of visualization tools to improve understanding of model output by non-technical audiences.
- Promote objective, value-free analyses.
- Let information from models inform decisions, rather than making decisions, and then use modeling information to support the decisions.
- Value the costs of wrong decisions.
- Engage in more accountability evaluations and adaptive management (i.e., hindcasts of regulatory outcomes).

Workshop organizers reminded participants that many of the principles articulated here will be captured in a guidance document currently being prepared by the Agency. A draft of this document has been reviewed by the SAB. In the next 6 months, the draft will be circulated within the Agency (including among the workshop participants) before it is disseminated for public comment; participants were asked to read it and provide comments. The Science Policy Council also must approve this document before it can be disseminated to the public.

Additional Comments

States and regions are resistant to models used in major decisions that then are no longer available.

Much of the discussion at this workshop has focused on regulatory decision making rather than end decision making (a more general term). Integrated modeling for integrated environmental decision making also is necessary at a project and permitting level.

To describe the components of and steps to regulatory decision making such that the role of integrated modeling is clearly defined, the Agency should promote collaboration among ORD, regional offices, program offices, and other stakeholders at all levels of evaluation.

Participants discussed the distinction between simple and complex models that are used to inform decisions. “Simple” models consider single media or single agents or toxins, are empirical, require no calibration, and do not involve varying scenarios. “Complex” deterministic models involve multiple media, multiple pollutants, and various scenarios. There currently is no science-based definition or set of criteria to describe a simple model, but these can be developed. A participant suggested that a simple model is usually an incomplete model based on idealized assumptions. Therefore, the results of a simple model should be tempered by those of a more complex model.

The regulatory and science drivers for integrating modeling technologies include: (1) greater computing capabilities; (2) greater understanding of complex processes and interrelationships (e.g., multimedia issues); (3) long-term cost effectiveness; (4) declining or limited resources; (5) the need to expand beyond single-media studies, analyses, and models; (6) the need to consider all dimensions and develop regulations not constrained or limited by stovepipes; (7) the need to quantify marine ecosystem dynamics through connections to physical and chemical drivers; and (8) greater ability to link models across media and scale.

Participants discussed whether adaptive management is part of the changing decision making landscape and, if so, how this will change demands on integrated modeling technologies. A participant suggested that adaptive management is becoming more prevalent in decision making and that integrated models are suitable for adaptive management because they can handle multiple scenarios with multiple sources, pathways, and receptors.

Participants noted that the expression of uncertainty in the decision making context can be improved by expressing uncertainty in terms of costs and benefits—the cost-benefit of the uncertainty and the cost-benefit of reducing uncertainty. Uncertainty needs to be normalized by a natural variability metric; such a metric (or metrics) could be compared across different scenarios.

Partnering and collaborations will be essential to transitioning to greater use of integrated modeling across EPA. Collaborations must bring together scientists and researchers, programmers and modelers, computer engineers, communication experts and vehicles, and policymakers. A participant suggested that EPA could partner with another agency or commercial company that could perform the modeling for EPA. This may be especially important for certain specialized models for which EPA lacks expertise; if modeling is done exclusively in-house, such models may be overlooked.

EPA possesses modeling capacity but needs to focus on interfacing science and policy to build knowledge-brokering, allowing the Agency to become more policy relevant. To achieve this outcome, the Agency must determine what is needed in the short- and long-term. Also, it must employ decision-based development planning instead of “personality-driven development.” It might be helpful to revisit and evaluate the Chesapeake Bay Program as a model of what to do and, where applicable, what not to do. Some questions and issues to consider include: (1) What integrated decision making does EPA undertake? (2) How are these decisions applied? (3) Is the overall process effective and does it add value?

Although EPA currently does not make decisions in real-time, policy decision making is shifting to favor rapid-response models and assessments. To accommodate this change, EPA may look to other institutional approaches, specifically, centralized and decentralized strategies. The National Weather Service (NWS) exemplifies real-time decision making using a centralized model. The NWS has Modeling Centers that can run models quickly and in real-time with a range of products for society. An essential component of the NWS is the short-term forecast center. However, EPA should take a comprehensive look at the NWS culture before trying to replicate this approach. In contrast, the State of Michigan employs a decentralized approach. The state uses an open-source models repository, partners with universities, and promotes the use of more widely distributed development frameworks because of decreasing resources. Thus, the different components and contributors leverage each other. It was noted, however, that EPA currently does not have the appropriate infrastructure for this type of system, which would require substantial development.

Offices and staff are increasingly interested in integrated modeling training; for example, OPPT currently provides such training and outreach on chemical regulations. Expansion of training across the Agency would require identifying the key information needed by modelers and users and developing and adapting training modules to target audiences (e.g., introductory vs. advanced levels; scientists or policymakers). Kelly Mayo-Bean (OPPT) is setting up a 2.5-day training session in this area later this year; interested parties should contact her.

EPA should consider global marketing efforts and adopting a global environmental outlook. Such efforts would require incorporation of social and economic factors and links to larger models. Key questions include determining how to manage issues of scale (i.e., moving from local to global systems), how to develop appropriate models, and policy needs.

Diminished budgets and increased OMB scrutiny are driving the need for integrated modeling in decision making. It is hoped that integrated modeling will prove to be more cost effective than simpler, single-variable, models. Integrated modeling also is expected to increase accountability.

As integrated modeling and decision making evolve, increased flexibility will need to be built into modeling to meet policy needs. Such flexibility should allow for the ability to change inputs for different policy options (e.g., "look up" tables for quick answers, as developed by the Canadians).

The Agency should maintain integrated modeling and decision making on two levels: modeling expertise ("systems engineering") and quick-turnaround capability for high-profile issues ("business process"). A participant noted that ORD has been criticized for focusing on model research instead of model application.

Participants suggested that, in "thinking outside the box," the Agency should consider:

- Centralized approaches, such as NWS modeling centers for real-time decision making.
- Decentralized approaches, such as Michigan's open-source models repository involving leveraging with universities.
- Whether EPA should develop models. Options include partnering with other agencies or commercial companies. This would ensure that models are not overlooked for lack of EPA in-house expertise.

- OPPT training on chemical regulations for modelers. What other training opportunities should be developed and offered?
- How the Agency can best capture the direction of its modeling and build the appropriate supporting framework and infrastructure to accommodate current and future needs.

JANUARY 31, 2007

PRESENTATIONS ON INTEGRATED MODELING SCIENCE AND TECHNOLOGY ISSUES

Session Chairperson: Lewis Linker, U.S. EPA/CBPO

An Introduction to the OpenMI. A Standard for Model Linking

David Fortune, Wallingford Software, HR Wallingford Group

Mr. Fortune provided an overview of OpenMI, a nonproprietary interface standard for data exchange between models that was designed to allow for straightforward model integration and framework construction. The linkages required for whole catchment models, for example, can require a year to build; OpenMI reduces this time to a matter of days. Technical issues in model linking result from connecting models that differ in processes, spatial representations, temporal resolutions, and terminologies and units; linking models based on different concepts can also create technical issues. OpenMI imposes few constraints on the modeller. In OpenMI, a building block approach is used to link components—models, GUIs, databases, and tools that can be developed on different machines and platforms. In contrast to typical model architecture, the OpenMI "engine" has been converted to an "engine component," which provides and accepts data through an interface. The descriptive part of the OpenMI interface allows other components to determine which items this linkable component can exchange. The configurative part of the interface is the link, which defines the actual connection (which items will be exchanged) in terms of the component, quantity, element set, and DataOperation of the exchange. A number of models have been migrated and are now OpenMI-compliant. OpenMI has been applied to real world problems. For example, OpenMI has been used to predict the effects of the restoration of the Lake Karla wetlands in the Pinios River basin in Greece by linking a water balance model, a groundwater model, a water management model, and a water balance model for a lake to understand the hydrological and ecological response to different strategies. The OpenMI Association was formed as a mechanism for participation in OpenMI; it engages in dissemination of information and maintains the OpenMI standard and environment. Stakeholders include environmental regulators, with increasing support from software and modeling developers.

Discussion

A participant asked whether modules must be recompiled for use with the OpenMI interface or whether the developers of OpenMI have written wrappers. Mr. Fortune responded that it is not necessary to recompile software. OpenMI incorporates a number of wrappers that can be modified for different applications. It is not necessary to use the wrappers, but they are available.

A participant asked whether the developers of OpenMI paid DHI—the software company that created MIKE SHE—to incorporate an OpenMI wrapper around the MIKE SHE model. Mr. Fortune answered that DHI was one of the partners participating in OpenMI development and therefore the company had an interest in using the OpenMI interface with many of its own models. He noted that DHI and other partners assume that integrated modeling will become much more widely used and that this represents a wise investment for them.

Overview of an Integrated Modeling System for Supporting Multiscale Source-to-Effect Studies of Human Health Risks

Sastry Isukapalli, Rutgers University

Dr. Isukapalli described the Center for Exposure and Risk Modeling's (CERM) development of an infra-structure for both exposure assessment and health impact analysis in addressing the source-to-outcome continuum. CERM uses the Modeling Environment for Total Risk (MENTOR) studies for the exposure assessment and the Dose-Response Information Analysis (DORIAN) system for the health impact analysis. This example of integrated modeling is problem-driven. A major issue in implementing consistent source-to-dose modeling is sequentially moving from the larger scale (macroenvironment) level to the personal scale (microenvironment) level, at which exposure occurs in people. Analysis of exposures to environmental contaminants, and subsequent doses and effects, is typically a multiscale problem in terms of both the environment/microenvironment and the biological processes involved. For example, CMAQ was used to predict spatiotemporal patterns of surface formaldehyde and benzene concentrations at the single census tract level. MENTOR-1A was then used to estimate the 90th percentile of seasonal averages of daily personal formaldehyde and benzene intake resulting from outdoor air. The physiologically based toxicokinetic modules of MENTOR-3P characterize cumulative and aggregate exposure uptake and target tissue dose for multiple chemicals and for physiology with intra- and interindividual variation and variability. In an example related to emergency planning, MENTOR has been used to predict estimates of individual biological doses of anthrax; this application of MENTOR showed that predictions made using standard techniques were inaccurate by an order of magnitude. MENTOR and DORIAN are mechanistically consistent, a property that is crucial for integrated modeling. The modularity and use of open standards allows for the use of the most appropriate module for a given modeling step. Uncertainties are characterized using traditionally or computationally efficient alternatives. Formal lumping methods and "pre-computed" models provide fast equivalent modeling systems for faster applications.

Discussion

A participant noted that Dr. Isukapalli examined individual chemicals at a census tract level and asked how these results compared with those of the National Air Toxics Assessment (NATA), which also was conducted at a census tract level. Dr. Isukapalli explained that the calculations for his models differ from those of NATA and the modeling results; therefore, they are not comparable.

Collaborative Model Development

Olaf David, USDA/ARS

Dr. David addressed means of facilitating collaborative model development using infrastructure and a framework. Collaborative modeling efforts within ARS include more than 100 soil, water, plant, and animal models related to the agricultural community. These models were developed over time on an as-needed basis using the best current technology. Maintenance of these models is proving to be difficult and costly, however, and model alternation and integration also is demanding. Two efforts are currently underway to alleviate these issues. First, support is provided for the development of simulation models using a software project management infrastructure via USDA's CoLab. Second, the OMS provides a common platform or framework for model development and application. CoLab is comprised of two major components: (1) CodeBeamer, a commercial Web application to help manage project development, communication, and documents; and (2) Subversion, an open-source version control system. The benefits of CoLab include on-time product delivery; facilitated workflow and peer review; live document management; and real-time visibility on tasks, bugs, resources, and projects. OMS supports the building of new models and decision support tools from reusable, standardized components from a library. OMS also promotes longevity and improvement of existing ARS models by decomposing them into their science component parts. OMS allows for "customized modeling" in which a model is fitted to the problem and customer need. Both CoLab and OMS have been used to incorporate technology and legacy models. For example, ARS' Unified Water and Wind Erosion model is based on the Water Erosion Prediction Project and the Wind Erosion Prediction System.

Discussion

A participant asked whether university researchers can host their own projects through CoLab. Dr. David responded that university researchers may join CoLab and use it to work on a project. There are costs associated with the use of CoLab, however, so a small contribution would be expected once the researcher begins actively working on the project.

FRAMES and 3MRA: An Integrated Modeling Infrastructure and Example Resident Modeling System

Justin Babendreier and Gerry Laniak, U.S. EPA/ORD/NERL

The ORD defines integrated environmental modeling as any "multi-dimensional" environmental modeling construct that is interconnected and enhanced for decision making via a set of software support tools. These support tools may facilitate the assimilation and reuse of models and datasets; use GIS to manage, store, and manipulate model input and output; characterize and quantify or qualify sources of uncertainty; or provide a system of user interfaces for pre- and post-processing. The Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES) is an underlying software infrastructure housing 3MRA and other models and modeling systems. 3MRA is a set of models for conducting site-specific or site-based risk assessments, and "rolled-up" studies on regional and national scales. FRAMES-3MRA is a state-of-the-science human and ecological exposure and risk assessment technology encompassing multiple media, multiple pathways, multiple receptors, risk, and assessment. The 3MRA exposure and risk assessment methodology provides site-based, data-driven, integrated human and ecological assessments. This methodology provides tiered data using all available data sources (both regionally and nationally) and population-based risk estimates by site, source, and chemical. 3MRA is intended for regulatory applications in its manner of integrating exposure and risk assessment across media, pathways, and receptors. 3MRA can characterize uncertainty and variability and accommodates evolving science and problem statements. Further, 3MRA has successfully undergone approximately 50 peer reviews. A fundamental capability of 3MRA is its ability to quantify "safe" material, waste, or waste-stream concentration levels for use, treatment, storage, disposal, and/or reuse management practices.

Data Standards Are Part of the Integrated Modeling Picture

Linda Spencer, U.S. EPA/Office of Environmental Information

Dr. Spencer discussed the importance of data standards in providing meaning when large datasets are aggregated in an integrated system environment. A data standard is a documented agreement on representation, formats, and definitions for common data. A standard is approved by a recognized standards organization that provides rules, guidelines, or characteristics for activities aimed at achieving the optimum degree of order in a given context. As defined by the International Organization for Standards, a data standard contains the data element, data meaning, data transport (through XML tags), and data management. Data standards promote understanding of data, support business needs, support the efficient and accurate exchange of information, and enable the effective use of aggregated data for the purpose of comparisons. Data standards can facilitate integrated modeling efforts. For example, when output from one model is used as input for the next, it is important to know what went into the first model in the system; data standards help ameliorate such problems. Metadata management is important because it promotes data discovery and provides descriptions of the data that help to ensure their appropriate use. Data standards provide context and definitions for data elements; however, current problems include a wide selection of data standards, standards that apply to multiple categories, and standards developed without harmonization. EPA attempts to mitigate these and other problems by, for example, working with other standards organizations to harmonize across standards. Principles of EPA data standard development include: (1) leveraging national and international standards; (2) using a consensus-based approach; (3) fostering data exchange; and (4) promoting use of data standards through accessibility. More information can be found at: http://iaspub.epa.gov/edr/epastd$.startup and http://www.envdatastandards.net/section/standards.

Discussion

A participant remarked that daylight savings time poses problems similar to the Y2K problem and asked if the data standards community has developed a way to address this. Dr. Spencer replied that she could not answer this question but does not believe it is being addressed through the data standards community.

A participant asked if guidance is available for writing standards, such as for software. Dr. Spencer responded that the Office of Environmental Information (OEI) does have such guidance.

A participant asked whether the OEI has developed standards for documenting an application programming interface (API) produced outside of the Agency. Dr. Spencer answered that OEI has not developed this kind of standard, but the Environmental Information Exchange Network does have guidance related to APIs.

A participant asked how the OEI enforces data standards. Dr. Spencer replied that enforcement is a problem. Data standards enforcement is done via self-reporting by all EPA offices twice each year. Contractors and grant recipients are required to comply with standards, but again, enforcement is generally via self-reporting. OEI also can conduct a performance review if requested.

Cumulative Risk Prioritization Tool: Prioritizing Cumulative Inhalation Risks and Developing Solutions
Jeff Yurk, U.S. EPA, Region 6

Mr. Yurk provided a regional perspective of how integrated modeling can address concerns for safe air, drinking water, and food at the community level. Region 6 developed the Regional Air Impact Modeling Initiative (RAIMI), a tool that assesses “community-level” inhalation impact and evaluates an unlimited number of stationary and mobile sources. In contrast to earlier efforts, RAIMI attributes impact back to individual compounds and emission sources to provide strategic and tailored environmental actions. For example, Port Neches, Texas (Jefferson County), a region with 16 major industrial facilities, 1,500 point source emissions, 82 area and mobile source categories, and more than 188 hazardous air pollutants (HAPs), has the highest potential for exposure in Region 6. EPA identified and prioritized two facilities and five point sources, identified local data gaps, and prioritized one area and two mobile emission source categories. For the identified source, which was shared with the Texas Commission on Environmental Quality, source impacts were validated by mobile monitoring, and a solution (covering a wastewater impoundment) was negotiated. Concentrations of HAPs dropped three orders of magnitude after the enforcement action. Enforcement would not have been possible without linked models that tracked the impact back to the sources. Results of RAIMI modeling can be used to target risk-based inspection, prioritize reduction efforts for ozone precursors, identify risk trends, determine the significance of data gaps, track emissions reduction efforts, and support monitoring programs. Verification occurs by comparing model results to monitoring data or by reviewing facility permit files to validate source parameters or emissions. The goal of this effort is to identify individual sources for targeted reductions, not simply to identify areas of concern. Solutions can include voluntary reductions, permit modifications, or enforcement negotiations. Initial findings of this modeling effort suggest that a small number of sources and chemicals are responsible for a majority of the impact.

Discussion

A participant asked what percentage of the budget for Region 6 is devoted to modeling. Mr. Yurk responded that this depends, first, on the time required to determine whether emissions inventory data are usable and, second, whether it is necessary either to generate surrogate emissions or request emissions data from the facility.

A participant wondered whether Region 6 has encompassed the shoreline of the Gulf of Mexico in its modeling. Mr. Yurk replied that he has not yet modeled the Gulf, but this could be done with the appropriate air model.

Regarding the development of models used by Region 6, a participant asked about relationships between the Region and other offices and whether ORD, in particular, was a partner in model development. Mr. Yurk explained that ORD's Integrated Exposure Model, though it is not able to be implemented for the Region's needs without modification, nevertheless provided the basis for the Region's modeling work. He added that regional issues can arise quickly and ORD often is not able to respond quickly enough. ORD has been intimately involved, however, in the peer review of this model, and other offices also have provided assistance.

BASINS—Integrating With Open-Source GIS

Russ Kinerson, U.S. EPA/Office of Water

Dr. Kinerson provided an overview of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), an integrated GIS, data analysis, and modeling system designed to support watershed-based analysis and TMDL development. BASINS provides the means to establish a digitized watershed to determine how to monitor TMDLs from nonpoint sources based on data at the national level. BASINS builds on existing technology to integrate existing models (HSPF and SWAT) and incorporates nationally derived datasets. Easy-to-use GIS technology supports the organization, display, selection, and analysis of information. Windows technology provides a GUI that facilitates interaction with the data and provides analytical tools. Automatic linkage streamlines the flow of information. The latest version of BASINS (4.0) improves on earlier versions by using open-source GIS tools. The core of BASINS has become independent of any proprietary GIS platform while still accommodating users of several different GIS software platforms. The MapWindow Plug-in Manager is fully extensible using a plug-in extension interface and supports both vector and raster data manipulation in most common file formats. The adoption of open-source technology is an advantage because it renders expensive proprietary GIS products unnecessary, and open-source tools provide greater stability and transparency. Further, the source code for all components is available to end users and the federal government.

BREAKOUT DISCUSSION SESSION 2: UNDERSTANDING SCIENCE AND TECHNOLOGY ISSUES FOR INTEGRATED MODELING AND DECISION MAKING APPROACHES IN EPA

Session Co-Chairs: Olaf David, Sastry Isukapalli, Kenneth Schere, Ken Rojas, and Russ Kinerson

The purpose of discussion session was to engage workshop participants in reflecting on science and technology implementation issues to achieve integration in modeling and decision making.

Considering User and Decision Support Needs and Model Integration

Question 1: What are reasonable levels of integration that can be achieved scientifically, organizationally, and with respect to collaborative mechanisms?

The level of integration that can be achieved is affected by factors such as cost, time, political significance, and value to stakeholders. Integration within EPA headquarters and offices should be achieved before engaging regional offices or other federal agencies. Clear delineation of scientific and organizational roles will lead to better integration.

Some participants suggested that there is no limit to the degree of integration that can be achieved if time, political will, and funding are aligned. Other participants remarked that there is a limit to the key drivers that can be brought into an integrative framework. For instance, many regional planning organizations and authorities charged with transportation infrastructures still operate as they did in the 1980s and are resistant to rethinking their assumptions. Decisions are made with little rigor or analysis. Such organizations might be more willing to change if the science was made more transparent.

Some participants advocated a “community of practice”—an informal group of individuals interested in collaboration who are able to come together to discuss collaborative projects. A community of practice enables communication to occur at the peer level such that participants are not required to go through upper levels of management to communicate or collaborate with a colleague in another program, office, or agency. An organizer and a forum to encourage individual participation would be required to establish a community of practice. Many participants recommended using an existing tool such as CoLab to manage these issues.

Collaboration would be facilitated by the establishment of a models clearinghouse organized by topic or medium. Collaborative efforts would eliminate duplication and enable more efficient use of the resources and technological capabilities of various agencies and offices. Management should be involved and should provide incentives for collaboration, such as through performance reviews. Some barriers to collaboration and integration arise when organizations are out of date and respond too slowly to management and decision making needs. Participants agreed on the importance of identifying a well-defined problem and a practical goal or target.

A participant reported the need to justify each project to management to demonstrate that it meets performance standards. Because of limited resources at the regional level, for example, anything outside the plan or job description is questioned unless it has immediate applications or benefits. Further, managers may require a solution in 2 months, which is insufficient time for a long-term collaborative solution. A participant suggested that management should work more closely with modelers, using simple existing models to solve problems and then expanding to more complex, long-term models.

The institutional barriers to progress in collaboration and integration are time and resources. One technique used in industry is a “use-it-or-lose-it” source of funds as an institutional incentive. Use of these funds does not require approval by all managers in the chain of command. Some participants suggested that EPA consider the importance of working across media and leveraging other funds to provide meaningful benefits.

Improved planning could facilitate integration and collaboration. First, a plan should be developed for every model; this plan should address the purpose of the model, its output, the intended user or decision maker, and the need it will address. Second, a marketing strategy should be developed for any product arising from a model that serves a specific purpose. Finally, an overall strategic plan, including objectives, a framework, case studies, and guidance, would allow the Agency to address each decision making problem and management need using a long-term, integrated, collaborative approach. Without a strategic plan, the Agency can only respond to problems day-to-day on a short-term basis.

Question 2: We may be faced with a level of complexity in decision making such that the integrated models used to inform such decisions cannot be "validated" with real world observations. How does this lack of validation impact the value of information to the decision maker?

The importance of validation depends on the usefulness of model results to the decision and the contentiousness of the decision. Information on validation should be available for decision makers, depending on the purpose and importance of the application. It may not be possible to validate every model with observational data; nevertheless, it may be valuable to determine whether several different models predict the same result. Alternatively, when a model cannot be validated, it may be useful to run alternative scenarios and determine the relative likelihoods of different predicted outcomes.

A participant noted that, as a system becomes more complex, it is less likely that the important variables can be accurately predicted. Industry sometimes argues that a particular model cannot be used because it is so complex that it cannot be validated. Further, models often are used to predict unobservable futures. Some consider such predictions to be useful, but others suggest that these predictions should be made only with caution or not at all.

A participant observed that projections often are made with completely unvalidated models and management does not encourage or require validation. Models like CMAQ are well-tested, but older models never undergo validation.

Other participants countered that validation is an abused notion that is overrated and misunderstood. The world is complex; the fact that we approach it with simple concepts does not make it simple. Validation is not a necessary part of integrated models and one might argue that integrated models cannot be validated. Most participants argued that models must be validated and that models that cannot be validated present a problem; however, there is a slow progression away from this way of thinking.

Rather than “validation,” other terminology might be more appropriate such as “evaluation.” Alternatively, one might simply determine whether the model is appropriate for the intended use. A participant noted that the Agency uses the word “corroboration” and emphasizes model transparency; this allows the Agency to determine whether the model is being used appropriately to meet a specific objective. This philosophy is becoming increasingly widespread. Many participants agreed that the term “validation” should be replaced with a term such as “corroboration” or “evaluation,” which implies that validation is the goal, even if it is never achieved.

Validation also is a difficult subject for political reasons—the important question is whether the model makes sense. A conceptual model that puts information in context must be separated from the decision and any associated political statements; model output is not the final word. The output from a model is a way to frame the discussion, organize the data, and explain certain, but not all, factors. The decision maker must explain how results from a model figured into the decision, but it is important to distinguish between the model results and the decision.

A participant noted that the Agency is developing a guidance document (now in draft form) that includes a discussion of model evaluation. The notion of evaluation as used in this document has been peer-reviewed and endorsed by the SAB. Further, there is global acceptance that the kind of approach to evaluation proposed in the document is similar to the approach in Europe and elsewhere. If best practices are followed regarding uncertainty analysis and validation, then the Agency can demonstrate that a particular model is of sufficiently good quality. Model precision is not being abandoned, nor is the practice of comparing model predictions to field observations. Validation is one way of evaluating a model, but it is important not to get stuck on “validation.” All participants will have an opportunity to comment on this guidance document within the next 2 months.

Question 3: What attributes of integrated modeling systems are crucial for meeting the needs of the users and providing effective decision support?

Participants identified a variety of attributes of integrated modeling systems that are crucial for meeting the needs of users, including transparency, validation and verification, systems, and models. Regarding transparency, the model should be chosen or developed with the decision maker in mind. It should be possible to explain a model and its output in lay terms and to explain effects that can be linked. It must be possible to validate the input and to explain uncertainty. Systems should be user-friendly and dynamic, with results available in a timely manner to address an immediate need. Systems also should be flexible and should facilitate integration. Assumptions should be consistent across models. Models should strike an adequate balance between complexity and simplicity and between costs and benefits, and should serve to formalize comparisons among alternatives and remain current based on new evidence. Models should generate more than data—they also should generate descriptive output and interpretation and visualization of outcomes. Further, models should be capable of running in real time, allowing a given scenario to be validated within the timeline of the decision makers.

A change of direction would provide an opportunity to answer political needs. For example, using GIS-based visualization would be helpful for those users and decision makers who think visually. Additionally, user-friendly interfaces are needed.

<u>Approaches to Integration</u>

Question 4: What are the science and technology barriers/challenges to model integration?

Science Barriers

A lack of high-quality empirical data for complex systems limits model integration because it makes the validation of models and generation of uncertainty estimates more difficult.

Evaluation and assessment of the Agency's modeling efforts by the larger community of scientists and modelers—including EPA scientists, academic researchers, and others—limits model integration. Within EPA, some participants noted that it currently is difficult to obtain feedback on modeling efforts; a well-structured, periodic peer review process could address this shortcoming. More effective partnerships between academic and government environmental modeling centers would promote an assessment of modeling efforts by the larger scientific community. Although not currently a common practice in our fields, this is important for professional credibility and will lead to improvements in EPA's modeling efforts.

Integrated modeling requires interdisciplinary knowledge and collaboration; however, differences in scientific and program cultures and training present a challenge. For example, water quality modelers have an engineering background, whereas modelers of living resource management issues come from an ecological background. Fisheries management modelers and researchers understand the impact of water quality on fisheries, but may be resistant to the notion, related to the current emphasis on ecosystem services, that fisheries can have a significant impact on water quality. Similarly, water quality modelers may lack crucial knowledge of living resources that will reduce the validity of integrated models. Improved understanding and collaboration among modelers is required to successfully integrate disciplines within a model.

Technology Barriers

Some of the technology barriers to integration include:

- A lack of a clear conceptual model of the problem and resulting challenges for linking models.
- Data that differ in quality, such that the module with the lowest quality data affects the rest of the integrated system (i.e., in the sense of a "weakest link").
- A lack of commonly accepted standards for data, models, and data sharing.
- A lack of open-source models and software and the limitations imposed by proprietary models.
- A need for platform independence of model codes.
- A lack of interoperability among models to be integrated.
- Different spatial and temporal scales among models.
- Different data formats and units conventions.
- Different discretization type (finite-element method vs. finite-difference method); these differences could be addressed using ESMF, OpenMI, or similar frameworks.
- Different degrees of complexity of design or process among models.
- Rapidly changing underlying frameworks (e.g., BASINS and ArcView).
- Legacy codes that were not designed for integration.
- Inefficient code sharing.
- Limitations in computing power.
- Insufficient QA/QC procedures.
- Limitations in the expertise of modelers.
- Inadequate resources (funding, time, and staff) devoted to software engineering.
- Inadequate means of measuring, quantifying, and controlling uncertainty.
- The potential to use models outside of their range of applicability and validity.

Participants discussed in some detail the challenges posed by differences in timescales. For example, an air model might treat the transfer of a substance to or from underlying water with an hourly time step, whereas the water model to which it is linked might employ a much longer timescale of action (e.g., on the order of months or years). Adjusting a water model to use an hourly time step can be difficult and expensive. When integrating two models with very different timescales of action, it is difficult to determine how to appropriately mesh them. To maintain the overall accuracy of the integration, however, one should model at the highest level of resolution. An intermediate layer, or interface, between two such models may provide a means of matching the timescales.

Models could be used outside the circumstances for which they are valid. When integrated with other models, the boundary conditions set for the integrated system may drive some component models beyond the bounds of applicability. This highlights the need for a clear understanding of the limitations on individual model use.

The expertise of individual modelers is relevant to the topic of technological challenges. One modeler may have complete knowledge of one model or general knowledge of a number of models; a single modeler rarely will have both kinds of knowledge. Therefore, two types of modelers are needed—specialists in individual models and model integration specialists.

Some integrated modeling efforts lack a clear conceptual model of the problem to be solved, including clearly defined endpoints and the path to reach the endpoints. This can result in technological challenges in linking models.

Other Barriers

A participant raised the issue of longevity of integrated modeling systems. Quite often, a great deal of effort is spent developing systems that then are not used. To address this problem, it is important to maintain corporate knowledge of such models, plan for succession, and train new staff regarding existing modeling systems.

A participant described organizational and cultural barriers to the use of models developed elsewhere and a tendency to rely on existing models without incorporating other components ("NIH syndrome"). Another cultural barrier is a reluctance to change and to adopt new and better modeling approaches.

Question 5: What are the common goals for environmental modeling technology development?

Participants recommended the following goals:

- Seamless integration, or interoperability and the development of best technologies to ease the interfacing of various models.
- Further development of verification and validation of models.
- Improved QA/QC procedures.
- Transparency, comprehensive, and well-documented integrated models.
- Models designed to address the particular environmental protection problem or issue and based on a clear understanding of the problem and use of the best available science.
- Tools to improve decision makers' understanding and interpretation of output, such as post-processing visualization and decision support tools.
- Models designed to be "user-friendly," whether the primary users will experienced or nontechnical users.
- Standardized data input formats.
- An emphasis on open-source tools.
- Platform independence of model codes.
- Easy exchange of model results and conditions.
- A greater focus on efficiency.
- Ease of access to data to run and validate models.
- Easy and efficient evaluation of alternative models or integrated models.
- Models developed with only the level of complexity required to answer the research and/or regulatory question.
- Models designed to be practical but still accurate at all important scales of time, length, and mass resolution.
- Reduced cost of integration and application of models.

Participants noted that the above goals generally require increased resources, including funding, staff, and time.

Some participants noted that there is tension, if not conflict, between some of these goals. For example, it may be difficult to design practical models using the best available science, depending on the definitions of these terms. It will be necessary to achieve a balance between such goals on a case-by-case basis.

Some participants questioned whether verification and validation should be a goal because true validation is difficult, if not impossible, in integrated modeling.

A participant noted that evaluation of alternative integrated models is inherently difficult. This process should not be lost in the process of integration and should be aided by technological improvements.

Question 6: What is the future of data access, retrieval, and processing for environmental modeling?

Participants predicted that cyberinfrastructure will facilitate the development of shared computing power and shared databases and will facilitate data discovery and access. DataGrid technology may be one means of achieving this. Data and models will be accessible wirelessly and will be transmitted via large bandwidths. Increased sharing of data and models will have to be reconciled with security concerns that may arise as a result of such efforts. In addition, because improvements in cyberinfrastructure and data sharing will facilitate data access, individuals who are not experts in a particular domain—and who are not among the anticipated users of a dataset or model—may unintentionally misuse or misinterpret data and models. Data exchange will be further facilitated by the standardization of data exchange formats (e.g., XML, HDF, ODF, or netCDF). Participants discussed ongoing cyberinfrastructure initiatives, such as one by the National Science Foundation to promote data sharing in environmental and ecological disciplines.

Participants discussed data standards and predicted that standards for metadata and other conventions (e.g., reporting formats, station naming, and data quality objectives) will increasingly be followed in data collection. Metadata standards will facilitate data discovery, and data standards will facilitate integration across components. A participant noted that some data standards discussed at this workshop already are in use. Quite often, however, there is a lack of awareness of existing data standards. Further, it is important to distinguish between community-based standards and proprietary standards. Community-based standards are the standards accepted and used by nearly everyone in the field; they become de facto standards. Some standards approved by standards organizations, on the other hand, are not widely used.

The future of data access may involve data from different sources that are processed in a particular way. For example, monitoring data in water quality must be adjusted for replicates in observations, limits of detection, and internal inconsistencies. This is true of most datasets. For this reason, data libraries for models may be part of the future of integrated environmental modeling. In a data library, data would be acquired from various sources and pre-processed for use.

Formats and facilities for long-term data storage will be addressed in the future. Currently, old data often are stored in a format or a version of software that has become obsolete. This makes reuse of such data difficult. Centralized data storage facilities, or repositories, will be developed and used increasingly.

The volume and accessibility of data have exploded recently; it will be important to develop and implement a rigorous QA/QC system that incorporates standards to decrease errors in data input and retrieval, traces data, tracks and monitors the chain of custody, and provides for version control. Additional features include mechanisms to inform users of updates, modifications, and corrections to the database, datasets, and models; record keeping functions to show how data were collected and by whom; and model development and modification.

Environmental modeling will be modular, flexible, and accessible. To facilitate integration, models will be interoperable and standardized to fit into many frameworks. Environmental modeling will incorporate Web-based interactive applications, which will help minimize the need to redesign user interfaces. Modeling utilities, such as the Package for Analysis and Visualization of Environmental data (PAVE), netCDF, HDF, and ODF, will be centralized.

Regarding spatial data and tools, participants predicted that, increasingly, open-source GIS technology will be used to help generate spatial (and perhaps temporal) inputs for models. Many groups already are using satellite data for data assimilation, and this trend will continue. GEOSS will facilitate online real-time information management, which in turn will result in faster and more rigorous environmental model development and skill assessment.

A participant remarked that the future is bright with respect to the quantity of data that can be accessed, retrieved, and processed. With these technological improvements, however, it is important to ensure that errors are not increased.

Question 7: What are the different approaches for technology integration and what are the applications and limitations to each approach (e.g., bottom-up, top-down, centralization, etc.)? Is a mixture possible (e.g., generic support software is centralized; specific standards for "publishing" modeling software are established, etc.)? To what extent should integrated models be modular?

Top-down approaches assume that one can define the software integration fully ahead of time and therefore may be too inflexible in many cases. Top-down integration requires the individual components and legacy codes to adapt to a new framework and this can be difficult. Running a simple set of models using a top-down approach requires substantial infrastructure; large-scale systems become especially problematic. It may be dangerous to assume that software engineers know how to put together an integrated system with sufficient flexibility for this kind of approach. Participants concluded that a top-down approach, which could be considered a “command and control” approach, might be most appropriate for new systems or where existing models are limited, with due attention to modularization.

In bottom-up integration, a framework is built to adapt to model needs; this can result in difficult design issues. A participant suggested that bottom-up approaches appear to be the most scientifically defensible approach. Basic commonalities or standards, however, must be established at the outset for the various media-specific models to exchange information. A bottom-up approach may be most appropriate for old systems, with existing models to be integrated.

Centralized architecture requires significant effort. Centralization can be useful if participants can virtually access the computing facility and the centralized computing is powerful enough. Modeling systems can be assembled through standardized protocols. A participant suggested that a centralized approach would allow for the use of “community” models such that each group conducts its own integration.

All three approaches have limitations. A proper approach would consider the availability of resources, existing capability, the nature of the integration, and the objective of the integration.

A participant suggested that an SOA approach may be useful.

Participants agreed that the different types of approaches are not mutually exclusive, and a mixture of approaches is both possible and desirable. A mixed approach may be most practical for a large effort in which many models are integrated. OpenMI and ESMF are essentially mixed approaches in that they allow for less organization from the top.

Participants agreed that integrated models should be as modular as possible.

Question 8: Types of integrated models include multimedia and cross-disciplinary models (e.g., linking models for natural systems and models for engineered systems and economic and social dynamics). What are the challenges with each type of integration?

Participants noted that proper oversight of the overall integration is necessary. Multimedia and cross-disciplinary integration requires a generalist or multidisciplinary researcher who will ask the right questions to ensure that the appropriate inputs are used and that the output meets the needs of the final users (often the decision makers). In addition, in multimedia and cross-disciplinary modeling, model evaluation becomes extremely difficult.

Modeling across media is often easier than modeling across disciplines because different disciplines use different languages and may differ regarding the type of data collected. For cross-disciplinary modeling, it may be necessary to agree to a common terminology. A participant noted that the Semantic Web for Earth and Environmental Terminology is attempting to develop an ontological framework and this may help address problems arising from the use of different terminologies across disciplines.

Some disciplines are not very different from one another. For example, water and air models represent different media but these disciplines are similar in approach. Models integrating other disciplines, such as economics or ecology, can be harder to combine because the disciplines to be combined may have to move further away from their respective comfort zones.

Problems of scale can be exacerbated with cross-disciplinary modeling. For example, small differences in an air or water model can be magnified in an economic model. Conversely, the uncertainty in an air or water model may make little difference in an economic model that involves binary decisions. Further, addressing the uncertainty issue in models combining such different disciplines can be difficult, and extrapolating far into the future with cross-disciplinary integrated modeling can be particularly dangerous.

A participant suggested that, in one sense, the challenge of multimedia and cross-disciplinary models is an advantage in that cooperation between media or disciplines is forced and usually opportunities are present in the interface between the media or disciplines.

Question 9: What are the different challenges associated with integrating models in a unidirectional flow of materials and energy (i.e., statically linked feed-forward models) versus integrating models in a bidirectional flow (i.e., dynamically coupled models with feedbacks)? How can these challenges be addressed?

Bidirectional integrated models with feedback are much more challenging—and require greater computing resources—than unidirectional (feed forward) integrated models. A bidirectional model is more challenging technologically because it requires concurrently running modules synchronized by a master controller. This is computationally demanding. In a unidirectional model, the modules can be run sequentially with no overlap.

Participants noted that a two-way feedback loop can be problematic for the first model in an integrated system; the resulting inconsistencies sometimes cannot be resolved. Feedback models can become unstable relatively easily and are sometimes too fragile.

Model dynamics and interactions along boundaries can be a major problem with bidirectional models. Compared with feed forward integrated models, the need to match granularity becomes paramount in bidirectional flow integrated models. New developments in handling unstructured grids may be useful for this purpose.

Simpler models can be linked in a feed forward manner. Scientifically, however, an integrated modeling system incorporating feedback may be more realistic. Research models should include feedback to improve process descriptions.

Participants discussed situations in which the output of two models overlap and this area of overlap must be stripped from the results. An example of this situation is the linking of the Water Quality Analysis Simulation Program model with AQUATOX. When integrating models that overlap in results within feed forward systems, problems can arise if different models express the same parameter differently. All such systems have this problem to some extent. When two models share some outputs, these outputs must be normalized across the system to eliminate inconsistencies. A participant suggested that sensitivity analysis can help to determine whether the two models produce different answers. In some cases, it may be best to fuse the two models into a single model.

Sometimes even in a feedback system, components may have very different timescales of action. A major challenge with global modeling is that modeling processes must now be synchronized and this is a huge burden on computational resources. Spatial resolution has increased greatly as well, perhaps pushing the limits of increases in computational power.

Question 10: What are the challenges associated with integrating models that deal with different spatial and temporal scales and resolutions? How can these challenges be addressed?

Differences among models in spatial and temporal scales and resolutions present a special challenge. When models with different spatial and temporal scales are integrated, spurious, unstable results can occur. Further, it is important to ensure that the inputs to each downstream model in the integrated system should not go beyond the validity range of that model.

To address differences in spatial or temporal scale or resolution, participants agreed that it is crucial to establish the conceptual model of the overall system and carefully identify or design the framework. The framework or interface should be able to go between different temporal and spatial scales. Individual components do not need to be completely normalized spatially and temporally as long as the framework can address the different spatial and/or temporal scales without violating the assumptions of any of the individual components. This was the rationale behind developing ESMF, a framework for atmospheric research developed through a multi-agency effort. ESMF is a toolkit to bridge different grid types, different georegistrations of the earth, and different timescales in two and three dimensions. In addition to ESMF, a framework such as OpenMI might have the necessary flexibility. Participants agreed that it is important to base the integration framework on the conceptual model.

In physical oceanography and meteorology, for example, modelers typically address differences in spatial or temporal resolutions by nesting (typically through one-way coupling) high-resolution models within coarse resolution models of the same medium using a variety of numerical methods. Another way to address these problems is by Reynolds-averaging the higher resolution model to the resolution of the coarse model.

A participant noted that problems also may arise if models are mismatched in terms of discretization (i.e., such that one model uses the finite element method and another uses the finite difference method of discretization) and therefore have different grid structures. In these cases, it is necessary to make the grid structures match. Improvements in technology, however, will ameliorate this problem.

Question 11: How can scenario analyses be used with integrated models to provide a systematic exploration of multiple futures?

Participants agreed that this is a question for environmental modeling generally and is not unique to integrated models, per se. Scenario analyses drive the design of the model and the “futures” are the endpoints for many problems.

Scenario analyses can be used to assess whether an integrated model is appropriate for a particular question by comparing futures predicted by an individual model with those predicted by an integrated system. Such comparisons allow one to obtain insight into the level of integration at which the results of an integrated modeling system diverge from those of a single model.

Although some problems only can be addressed using integrated modeling, it is important to determine whether integration is appropriate and practical in terms of the cost. If scenarios and probability distributions can vary, then the use of integrated modeling can become more meaningful scientifically. The use of integrated modeling to address scenario analyses, however, can be quite complicated, in part because results may be significantly impacted by errors in individual models or in the linkages among models.

Architecture, Standards, and Infrastructure Issues

Question 12: What are the implications of public domain, open-source, and proprietary software in the future of environmental modeling?

EPA should consider using all three categories of software, depending on the Agency's needs, potential legal implications, and costs. The issue of open-source versus proprietary software is more important for data than for programs and models. Sometimes open-source software and models are superior; in other cases, it is necessary to spend money on proprietary software. Participants agreed that there will be a movement toward greater use of open-source software and continued use of some proprietary software.

Question 13: Integrated modeling frameworks abound. How can better interoperability among frameworks be facilitated?

EPA should strive to facilitate improved interoperability among frameworks. Participants noted that there are no good examples of interoperability among frameworks, adding that most frameworks are disconnected. Because most frameworks use similar concepts, improved interoperability could be achieved after isolating components and separating temporal and spatial elements.

Major reorganization or restructuring would be needed to facilitate model connectivity. Efforts such as Message Passing Interface might be more feasible.

Licensing issues across frameworks require special consideration in cases where proprietary components are incorporated into open-source systems.

Ultimately, efforts to increase or improve interoperability should balance the amount of work relative to the anticipated benefit of improvement within a specific timeframe with regard to the use and reuse of tools and data. Factors such as file format, output, model structure, desired outcome, and required or ongoing modifications all contribute to decisions regarding whether to unify existing frameworks. One example where this effort may be worthwhile is in the integration of a number of disparate models.

Question 14: Is there a path to standards-based sharing of environmental modeling technologies that will eliminate redundant model support software, link scientists and modelers more efficiently, and so forth?

It may be beneficial to develop searchable catalogs of existing open-source models and capabilities. This would promote reuse of models. Catalogs could be tailored to potential users, communities, and standard practices.

As part of this effort, it is critical that models be updated, which, in turn, involves determining how best to provide different levels of information and data (e.g., model application or purpose and data availability, updating, or accessibility). Questions to be answered include: (1) How can or should models be searched? (2) What browsing options and strategies should be offered? (3) How will users be able to browse or search the models? (4) Which set of variables does each of the models process or analyze? (5) What characteristics are desired for inputs and outputs? It may be useful to develop controlled vocabularies to categorize and classify models.

EPA also may want to consider classifying models, perhaps as applied models and as research models. Further characterizations and issues include identifying the most likely audience(s) for the different types of models, determining which datasets should be attached to each model or whether data should be centrally located, and incorporating and/or tracking legacy models. CoLab is just one model that EPA could consider following. CoLab includes both public and private access portals and is available for searching at any time. It is an integrated system with a broad range of components that supports numerous studies and analyses. About 15 to 20 organizations use CoLab, and system maintenance involves ongoing active model development and a dynamic query system. Additional features include point-of-contact information and version control for individual projects. EPA should consider using dynamic resources such as WIKIs as a bridge between modelers and collaborators to maintain and update models and model structures.

Participants distinguished between linking modeling frameworks and linking models and questioned whether and how modeling frameworks might be integrated, perhaps using an API or a system such as ESMF. There are licensing issues for frameworks that will affect how proprietary models can be used within the framework.

Question 15: What role does the development of ontologies play in facilitating the documentation, reuse, and integration of models?

Ontology development exploits relationships among data to search for and retrieve information, in contrast with the methods used by text-based data search engines. Although potentially significant, the process is labor-intensive and can require retooling for each type of application. Considerable efforts are needed in this area, particularly in the daunting task of reconciling disparate sectors and groups. Possible considerations for EPA include: (1) controlled vocabularies; (2) ontologies that capture functionalities (e.g., the clean waters project) between and within models and among data sources; and (3) self-describing models.

A first step might be to identify and catalog current efforts, and then share information on ongoing strategies and activities across groups or offices to increase intra-agency communication. Next steps involve characterizing "manageable" data, defining ontologies and attributes of the desired system, and testing with a range of model queries. Questions regarding which variables to access, how much overlap exists or is needed between variables, linkage (forward, backward, or lateral), and the automation of decision points contribute to the design of decision trees. Programmers and modelers must have a solid understanding of the terminology used to ensure optimal searching capabilities and user-appropriate output.

Participants suggested that the development of ontologies will eventually play an important role.

Question 16: How can data libraries be established to support modeling activities?

A starting point for this activity is to define data libraries and their intended purpose. In other words, does a data library refer to a repository, inventory, catalog, or other type of database or data center? The Agency also must determine which data should be included in these libraries and the storage capacity needed to support these libraries.

Question 17: What infrastructure components are required to support integrated modeling? How can distributed and collaborative model development be enhanced?

Before answering this question, it might be prudent for the Agency (or an office or division) to define the key problems it would like to solve and to identify the infrastructure components and features needed to support these models and technologies by initially answering the following questions:

- What is the purpose of the model or technology application?
- Is a more broad-based approach needed, or will smaller or single-point models be anticipated?
- What are the boundaries and data constraints?
- What type of grid support is needed and/or available?
- Regarding small- and large-scale modeling, what common factors are to be used?
- What test beds and baseline features are desired or available?
- What framework is needed?
- Which framework should be brought into modeling?
- How will this framework be verified?

For PC-based high-performance model testing, some grid solutions (e.g., Monaco and APEC) work fairly well; however, more complex applications, such as an API, are not recommended. Processor speed and capacity also must be evaluated; PCs generally have one processor, whereas networks use two or more processors.

It is also important to address multi-threading and how memory parallelization can be optimized to accommodate multiple tracks or multiple threading within the operating system. The class of integrated models also is important. For example, a 1-year run of the CMAQ model would require approximately 4 terabytes of working memory, which cannot currently be handled by desktops. Therefore, the Agency will need to determine which analyses and datasets will be run, who will run them, and the availability of systems and hardware to accommodate these activities.

Infrastructure component features to be considered include high-end (which are preferred) versus low-end (which are probably too limited), bandwidth, current and ongoing costs, and Agency policy for as-needed accessibility of these components by modelers.

Ongoing training for current and future EPA programmers and modelers is essential to these efforts, including short- and long-term courses offered internally and/or outside the Agency. To ensure that appropriate and optimal technologies and models are being used, the Agency is strongly encouraged to promote and establish collaborations and partnerships based on expertise and skill sets required, including computer engineering, modeling, programming, and environmental science or other science applications. A participant suggested that EPA follow a business model for pairing programmers with designers and modelers.

Participants stressed that the Agency should look beyond current needs and capabilities and anticipate future features and capacities.

Once these parameters are determined, there are several integrated models that EPA can explore further, such as CoLab. NASA also uses operational modeling technologies to demonstrate the value of data that could be plugged into EPA models. The interoperability of these models may require additional scrutiny with respect to factors such as model chaining, co-location (i.e., decentralization) of groups, and access to data to test or run models for EPA purposes.

In summary, infrastructure and architecture requirements depend on research and policy goals that will need to be determined at the Agency level. Factors to consider include:

- Anticipated data and processor needs as well as model design and development must be accommodated.
- Collaboration and ongoing training is needed to ensure that appropriate expertise is in place at the Agency. Computer engineers, scientists, programmers, and modelers are needed to address scientific applications, technology capabilities, modeling, and programming requirements.
- Collaboration and consultation across disciplines is needed to determine how best to organize teams and strategies for infrastructure and architecture development.
- A mechanism or process is needed for tracking versions of models and the history of each model.

<u>Additional Comments</u>

The following issues and questions were raised regarding data accessibility:

- With the explosion of data volume and related storage and accessibility requirements and concerns, the Agency should consider the advantages and challenges of automatic data collection and possibly build QA/QC concerns into business processes.
- Centralization of data, who can access these data, and how? What safeguards are needed for proprietary data and the database as a whole?

- How will data and database alterations and updates be tracked, and how will users be notified of such changes?
- What is the chain-of-custody of data and datasets?
- How should the issue of proprietary software and data be addressed? Participants encouraged the open-sourcing of data and the identification of resources available for development and updating; however, there are positive and negative implications associated with both open-source and proprietary data regarding data accessibility and use of models (e.g., provenance, updating costs, continued model development, and maintenance of infrastructure).

Regarding the development of ontologies for integrated modeling, it is important to identify and define or describe functional relationships within and across models. To achieve this goal, existing efforts/models, data dictionaries, and representation of metadata should be shared.

BREAKOUT DISCUSSION SESSION 3: INTEGRATED MODELING VISION AND STRATEGIC PLAN

Session Co-Chairs: Gerry Laniak, Justin Babendreier

The purpose of this discussion session was to consolidate and refine input from previous discussions into a first draft of a clearly articulated vision for EPA and the specific steps the Agency must take to realize this vision.

Question 1: What are some challenging management areas that would benefit from integrated models, analysis, and management of the problem?

A participant suggested that the ecosystem services paradigm would benefit from integrated modeling. For example, EPA is more formally building ecosystem services into the FRAMES-3MRA model. This will allow the Agency to expand from projections along the source-to-outcome continuum to include an additional cost-benefit rationale in the products of the model system. To move from ecological assessment to an ecosystem services paradigm, the Agency will need to bring in social and economic models.

Drought is one of the near-term opportunity areas related to IEOS, the U.S. component of GEOSS. The Western Governors Association (WGA) is pushing for a national integrated drought information system, which is likely to receive significant funding in the near future. Currently, the WGA is focused on responding to drought. There could be a real opportunity, however, to consider means of preventing drought conditions, such as through changes in land management practices or ecological restoration. This effort would probably require collaboration with other agencies.

Integrated modeling may benefit ORD's Regional Vulnerability Assessment, which is charged with determining where to focus energy and resources to effectively address critical environmental stressors.

A participant noted that sustainability is an emerging area of management concern; it will become increasingly important to apply integrated modeling to sustainability.

Relating global scale to local projections—with respect to climate change, for example—is an emerging area to which integrated modeling should be applied. Many of the Agency's water programs, in particular, would benefit from recommendations that would allow them to move forward with this kind of effort.

Participants discussed at length the potential to link integrated modeling to monitoring, which could allow the Agency to more selectively monitor areas in which either uncertainty or risk is greatest. For example, there is a need for mercury modeling that would identify areas with the greatest risk of impact to fish and wildlife for more intense monitoring. Such modeling also could allow for selective monitoring in areas in which uncertainty in the estimates of mercury concentrations is greatest. The results of the monitoring, in turn, could be used to strengthen the models, in part by reducing uncertainty. In his presentation, Dr. Schnoor described a similar system in which "smart" models are connected to sensors in an adaptive manner. The researchers determine where to move the sensors based on the modeling results. Systems in which modeling systems are linked to sensors may become more prevalent in the future.

A participant suggested that data-assimilative models could be used to evaluate existing observing systems and proposed observing systems by conducting Observing System Experiments and Observing System Simulation Experiments, respectively, in terms of their efficiency in extending the predictability of the modeling system.

Linked modeling and monitoring may allow for more efficient use of limited resources. In Canada, for example, funding for monitoring has decreased. For this reason, EC scientists use modeling to prioritize locations for monitoring stations. The monitoring and modeling are integrated such that monitoring data strengthen modeling and modeling results guide monitoring.

Increasingly EPA will be able to apply this kind of system to the Agency's accountability goals by modeling changes in the ambient environment expected to occur following a decision or action and adaptively monitoring to determine if the expected changes occur. Participants considered the relative importance of using modeling either to make real-time changes in monitoring or to guide monitoring over the long term. In the context of program effectiveness and accountability, real time may not be a useful concept; instead, it may be more valuable for this purpose to have long-term monitoring records.

Links between modeling and monitoring should be done more systematically and more regionally, whether the region is the United States or at the level of the Chesapeake Bay.

A participant remarked that the linking of monitoring and modeling implies that the granularity and time step of models and measurements match. This may not always work for forecasting but may be appropriate for tracking the results of decisions or actions.

Participants agreed that a monitoring program without a modeling component is limited and not fully applied and, similarly, modeling without monitoring also is flawed and incomplete. There will be increasing opportunities to adaptively adjust monitoring in response to modeling and to improve models with the results of monitoring.

Question 2: Assuming a modest budget to implement integrated modeling was available, what would be the best initial projects that would be able to demonstrate success?

A participant noted that some offices already have completed many projects. For example, an effort to link global projections of climate change effects to a local scale (New England) already has been completed. Further, the definition of integrated modeling—and whether it refers to multiple data layers within the same model, multiple models linked together, or other systems—will affect recommendations of the best initial projects.

Workshop organizers suggested that participants consider how the Agency might build on these previous experiences in integrated modeling. In addition, the linkages between models in current and previous integrated modeling efforts—including those relating global projections to local scales—have been fairly ad hoc. Therefore, the Agency should attempt to learn from previous and existing efforts to develop a more systematic approach and improve future integrated modeling efforts.

Participants were asked to consider whether it is important to link frameworks and how such linkages could be facilitated.

A participant commented that it would be important to know how many different models or modeling system frameworks are linked with CMAQ and/or HSPF. There have been a number of very successful interactions of CMAQ with other models, but these have been geared toward particular applications. It will be useful to extract lessons learned from the existing examples and promote ease of use. This will allow the Agency to generalize its capabilities.

To relate global projections (e.g., regarding climate change) to a regional or local scale, a participant noted that a flexible API is required for linkage. It may be beneficial to define a pilot within the Agency to evaluate ESMF as a way to integrate models for this purpose. The National Center for Atmospheric Research is applying ESMF in this way in meteorology and the NWS will be using it for modeling as well. By gaining some internal experience with ESMF, EPA could determine whether this framework could be used to more formally establish multimedia connections in modeling.

EPA's TMDL Program has a tremendous backlog of TMDLs to be completed in all states. This requires a conceptual model because it is not practical to develop separate models for each case. Although BASINS is available for such uses, the practitioner still must customize BASINS for a particular area and this is expensive. It would be helpful if BASINS or a similar framework had methods for calibration and ease of use that could be applied more globally. A U.S.-wide watershed BASINS calibration (integrated with CMAQ and the Climate Assessment Tool) is within the Agency's grasp because of the many databases that will become available nationwide. A U.S.-wide watershed BASINS calibration could be referenced as a baseline in making permitting decisions. This could be a start to a community model approach, and different parameters and inputs could be added to address particular problem areas.

With respect to environmental outcomes and fulfilling EPA's obligations under GPRA, it would be useful to find a project that connects a decision or action with the environmental outcome. The purpose of such a project would be to determine whether past actions or decisions were effective. It may be appropriate, for example, to develop a pilot project at the regional level demonstrating outcomes using integrated modeling in combination with long-term monitoring data.

A participant noted that, in the U.S.-Mexico border region, the Regions are engaging in diesel retrofit and other projects to improve conditions locally. At present, the Regions can count the number of trucks and buses retrofitted, but there is no way to show the environmental results from these projects and it is crucial that the Agency shows outcomes.

A participant reiterated the recommendation that EPA develop WIKI technology or an equivalent method to develop a community of practice—a community resource that would capture the community's knowledge of models and frameworks. Such a resource would allow the Agency to build a better knowledge base dynamically from the experts, with continual improvement. For example, such a project could capture the community's knowledge about linking and interfacing with CMAQ. EPA would then be better able to explore potential areas for integration. In comparison to what CREM has done with respect to the Models Knowledge Base, a community of practice would require the grassroots participation of modelers. It should be done, however, in close coordination with CREM and the Models Knowledge Base.

Emergency response planning may be an area in which the Agency should consider planning an initial integrated modeling project. It may be beneficial to evaluate the models currently used in emergency response analysis, what is needed in terms of integration, and whether existing modeling results are being factored into decision making.

A participant noted that the SAB currently is meeting to discuss an assessment of the nitrogen problem nationwide. The SAB is focusing on the uncertainties surrounding nitrogen and the challenges in managing it for human health and ecosystem protection. This issue is nationwide in scope and may be affected by pending legislation. This problem is multimedia and has scalar effects that propagate through air, water, and human health and, therefore, could be suitable as an initial project.

Another ongoing effort will identify a number of regional laboratories that will focus on the responses of different systems to a common scenario. For example, one scenario might be related to energy, such as an increased use of biofuels. This kind of scenario would propagate throughout air, water, land, and the economy and would be of utility to program offices and to regional and local planners. These scenarios will be based largely on existing data and will be combined in a comprehensive, integrated way; they will be very modeling-dependent. Integrated modeling could be applied to these scenarios as an initial project.

A participant referred to a conclusion of the previous breakout session that multimedia modeling is much easier than multidisciplinary modeling and recommended that the Agency take advantage of ongoing work in multidisciplinary modeling. For example, air quality and health relationships might be a good area for focus. Specifically, the Agency could consider an analysis of wildfires, a type of emergency that recurs every year. This involves modeling and observations and is both multimedia and multidisciplinary. Wildfire analysis represents a real opportunity as an initial project; however, it would require cross-agency collaboration.

In response to a request for clarification regarding how decisions are made with respect to deposition profiles (e.g., whether 10-year or 20-year profiles are provided), a participant responded that these decisions are based on the regulatory assessments required by the Agency and are made through coordination with major regulatory programs that impact air emissions with respect to human health or ecosystem protection. Data are summarized in a form deemed most useful to those requesting the information. Multidisciplinary collaboration is key to these determinations.

Integrated modeling approaches are relevant to air emissions and deposition. Source-to-receptor modeling, ambient air quality data, and emissions inventories could be integrated to improve understanding, but this would require going out to the field and collecting data. With respect to air quality, the Agency has been successful in learning exactly what the utilities are emitting and when. If the Agency does not move toward obtaining this kind of data from other sources, it will not be possible to track emissions and to connect them to risk. Emissions monitoring data are crucial to addressing program effectiveness and accountability; modeling alone will not be sufficient to address those questions.

A participant noted, with respect to multisource air toxics, that a national rule regarding benzene reduction will soon go into effect; EPA is being asked how it will demonstrate the benefits of this rule. A great deal of modeling has been conducted from the perspective of impact analysis. The question now is whether we can go from emissions to exposure to risk and combine modeling efforts with observations. This may represent an opportunity for partnerships because of the level of interest and available funding from industry. The goal is to use currently available data (from observations) and model outputs to inform the decision.

Question 3: How can the benefits and opportunities provided by integrated modeling be communicated to decision makers?

In theory, the evaluation of cross-media modeling needs should take place within the analytic blueprint process. For example, the analysis for the CAMR was very much multimedia and used real data. It may be useful to ask decision makers how well this worked and to identify the weakest link in this process.

A participant noted that Region 3 has an outstanding decision making process. It is a stakeholder process in which lay people, including members of the regulated community, assess the science and how well the science is supporting decision making. It may be beneficial to ask stakeholders how well integrated modeling is working from their perspectives, in terms of informing decisions. Further, it may be possible to follow this example to improve the Agency's communication regarding integrated modeling.

In reference to the notion of the "weakest link" in the use of integrated modeling in decision making, a participant remarked that there was uncertainty across all of the links in the chain in the integrated modeling process that informed the CAMR. In particular, modelers attempted to link mercury deposition to mercury concentrations in fish tissue and from there to human exposure. Many problems arose because of the inconsistency of the data collected across the states. The lack of coordination in data collection substantially limited EPA's ability to conduct a meta-analysis across the country or for a region; these data were critical to making strong linkages. Modelers were forced to make assumptions that probably introduced more uncertainty into the models. Based on comments in response to the rule, it appears that the Agency may not have sufficiently addressed concerns in local areas. This is a sign that the Agency requires better information and more coordination across the states and other entities collecting data to ensure consistency.

With respect to case studies demonstrating the benefits of integrated modeling, a participant noted that the presentations on the Chesapeake Bay as a case study should have emphasized that, without integrated modeling, the Agency would have failed in making its assessment. The actions of the states alone would not have been sufficient to reach water quality standards in the Bay, and EPA was able to demonstrate, based on integrated modeling, that the Agency could achieve those reductions through the air program.

Participants discussed the importance of multidisciplinary collaboration. For example, decisions regarding emissions inventories and deposition profiles are determined through a collaborative process among modeling teams. Offices should support this kind of early cross-office collaboration, both in terms of resources and time, to help determine the offices' respective roles in project concepts. This kind of collaboration could be the real mechanism by which the opportunities provided by integrated modeling will be communicated to decision makers.

Another successful case study is a system in which watershed practitioners anywhere in the lower 48 states can be provided with projections of nitrate and ammonia deposition. This appears to be a very complete and adequate product and represents real progress in terms of multimedia integration.

The current disconnect between ORD and the regions could be addressed by establishing a short-term detail program in which an ORD modeler is assigned temporarily to a Region. The modeler would be tasked with learning what the Region is doing and determining how models and integrated systems could be changed to better address the needs of the Regions. Alternatively, or in addition, problem formulation workshops may help determine how existing models and resources could be tapped to address the needs of the regions or program offices.

Participants were reminded that the organizing committee will develop a White Paper based on this workshop. Participants agreed that the White Paper should include, perhaps as an appendix, a compendium of examples in which integrated modeling has been used successfully to inform decision making. A participant noted that the Agency sometimes fails to assess lessons learned after decisions and recommended that the White Paper also include examples of failures and a compilation of lessons learned.

Question 4: What are some future activities that the CREM and other groups within the Agency should implement to facilitate greater model integration?

Participants agreed on the following suggestions:

- The White Paper should outline a strategic plan.
- The White Paper should list action items along with a plan for followup to ensure that action items are addressed.
- CREM should engage in further dialogue with the EPA GEOSS group to consider opportunities for collaboration.
- Participants should ensure that their managers understand the need for integrated modeling and the role of CREM with respect to the appropriate development and application of models.

Additional Comments

A participant noted that the definition of integrated modeling remains unclear. At this workshop, the term appears to have been used more loosely to refer to multimedia modeling as opposed to a more strict definition in which models are more tightly coupled, as through a framework.

Workshop Wrap-Up and Next Steps

The workshop organizing committee will have a conference call within 2 weeks to initiate a process by which to develop and finalize the White Paper. Participants should expect a request for additional information, including the benefits of previous integrated modeling efforts. Participants also should be prepared to review and comment on the White Paper. A revised participants list will be sent after the workshop. Powerpoint presentations and the workshop summary will be disseminated to participants and posted on the CREM Web Site.

Workshop organizers thanked the participants for engaging in productive discussions throughout the workshop.

Integrated Modeling for Integrated Environmental Decision Making

U.S. Environmental Protection Agency
Main Campus
Research Triangle Park, NC
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Final Participants List

Michael Adam
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Superfund Remediation and Technology Innovation
Ariel Rios Building (5203P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 603-9915
E-mail: adam.michael@epa.gov

Rochelle Araujo
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (D301-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4109
E-mail: araujo.rochelle@epa.gov

Justin Babendreier
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
Regulatory Support Branch
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8344
E-mail: babendreier.justin@epa.gov

John Bachmann (retired)
U.S. Environmental Protection Agency
Chapel Hill, NC 27516
Telephone: (919) 619-0769
E-mail: johnbachmann@bellsouth.net

Chad Bailey
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Transportation and Air Quality
Assessment and Standards Division (HEBTC)
2000 Traverwood Drive
Ann Arbor, MI 48105
Telephone: (734) 214-4954

E-mail: bailey.chad@epa.gov

Jesse Bash
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1375
E-mail: pierce.tom@epa.gov

Thomas Baugh
U.S. Environmental Protection Agency
Region 4
61 Forsyth Street, SW
Atlanta, GA 30303
Telephone: (404) 562-8275
E-mail: baugh.thomasl@epa.gov

David Beck
U.S. Environmental Protection Agency
Office of Policy, Economics, and Innovation (C304-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5421
E-mail: beck.david@epa.gov

Lindsey Bender
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Radiation and Indoor Air
Radiation Protection Division
Ariel Rios Building (6608J)
1200 Pennsylvania Avenue, NW
Washington, DC 20460-2001
Telephone: (202) 343-9479
E-mail: bender.lindsey@epa.gov

Jo Ellen Brandmeyer
RTI International
Environmental Health and Safety Department
P.O. Box 12194
3040 Cornwallis Road
Research Triangle Park, NC 27709
Telephone: (919) 541-5961
E-mail: brandmeyer@rti.org

Russell Bullock
U.S. Environmental Protection Agency
National Oceanic and Atmospheric Administration
Air Resources Laboratory
Atmospheric Modeling Division (E243-03)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1349
E-mail: bullock.russell@epa.gov

Scott Burks
U.S. Environmental Protection Agency
Office of Environmental Information
National Computer Center (N229-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3352
E-mail: burks.scott@epa.gov

Brian Caruso
U.S. Environmental Protection Agency
Office of Research and Development
Region 8
999 18th Street

Denver, CO 80202
Telephone: (303) 312-6573
E-mail: caruso.brian@epa.gov

Shao-Hang Chu
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards (C539-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5382
E-mail: chu.shao-hang@epa.gov

Edmund Coe
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Transportation and Air Quality
Transportation and Climate Division
Ariel Rios Building (6401A)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 564-8994
E-mail: coe.edmund@epa.gov

Ellen Cooter
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1334
E-mail: cooter.ellen@epa.gov

Larry Cupitt
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (D305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0349
E-mail: cupitt.larry@epa.gov

Olaf David
U.S. Department of Agriculture
Agricultural Systems Research Unit
Agricultural Research Service
2150 Centre Avenue, Suite 200
Fort Collins, CO 80526
Telephone: (970) 492-7316
E-mail: olaf.david@ars.usda.gov

J. Michael Davis
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4162
E-mail: davis.jmichael@epa.gov

Joe DeCarolis
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3200
E-mail: decarolis.joseph@epa.gov

Robin Dennis
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2870
E-mail: dennis.robin@epa.gov

Rob DeWoskin
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1089
E-mail: dewoskin.rob@epa.gov

Kathy Driver
U.S. Environmental Protection Agency
Office of Research and Development
Office of Resources Management Administration
Human Resources and Organizational Development Branch (E205-07)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3008
E-mail: driver.kathy@epa.gov

Rebecca Dudder
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division (E305-2)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5376
E-mail: dudder.rebecca@epa.gov

Stephen Edwards
U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory (B305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0514
E-mail: edwards.stephen@epa.gov

Ken Elstein
U.S. Environmental Protection Agency
Office of Research and Development
Office of Resources Management and Administration
Human Resources and Organizational Development Branch (E205-07)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3581
E-mail: elstein.kenneth@epa.gov

Allen Fawcett
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Atmospheric Programs
Ariel Rios Building (6207J)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 343-9436

E-mail: fawcett.allen@epa.gov

Cathy Fehrenbacher
U.S. Environmental Protection Agency
Office of Pollution Prevention and Toxics
Exposure Assessment Branch
Ariel Rios Building (7406M)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 564-8551
E-mail: fehrenbacher.cathy@epa.gov

Gary Foley
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Research (B105-15)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0711
E-mail: foley.gary@epa.gov

David Fortune
Wallingford Software
Hawbery Park
Wallingford, OX10 8BA
United Kingdom
Telephone: +44 1491 822 297
E-mail:
david.fortune@wallingfordsoftware.com

Tyler Fox
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards (C439-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5562
E-mail: fox.tyler@epa.gov

Noha Gaber
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Research
Ariel Rios Building (8701F)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 343-9898
E-mail: gaber.noha@epa.gov

Julia Gamas
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Atmospheric Protection Branch
ISAW (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-9715
E-mail: gamas.julia@epa.gov

Venu Ghanta
U.S. Environmental Protection Agency
Office of Environmental Information
Toxics Release Inventory Division
Ariel Rios Building (5412P)
1200 Pennsylvania Avenue, NW
Washington, DC 20003
Telephone: (202) 566-1274
E-mail: ghanta.venu@epa.gov

Robin Gonzalez
U.S. Environmental Protection Agency
Office of Environmental Information
National Computer Center (N229-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5659
E-mail: gonzalez.robin@epa.gov

Doug Grano
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division (C504-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3292
E-mail: grano.doug@epa.gov

Lester Grant (retired)
National Center for Environmental Assessment
517 Colony Woods Drive
Chapel Hill, NC 27517
Telephone: (919) 942-2365
E-mail: ldgrant27517@yahoo.com

Dave Guinnup
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division (C539-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5368
E-mail: guinnup.dave@epa.gov

Paul Harten
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Sustainable Technology Division (MS 445)
26 W Martin Luther King Drive
Cincinnati, OH 45268
Telephone: (513) 569-7045
E-mail: harten.paul@epa.gov

Tala Henry
U.S. Environmental Protection Agency
Office of Pollution Prevention and Toxics
Ariel Rios Building (7403M)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 564-2959
E-mail: henry.tala@epa.gov

Barry Herchenroder
U.S. Environmental Protection Agency
Office of Environmental Information
National Computer Center (N127-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1991
E-mail: henry.tala@epa.gov

Bryan Hubbell
U.S. Environmental Protection Agency
Office of Air and Radiation

Office of Air Quality Planning and Standards
(C504-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0621
E-mail: hubbell.bryan@epa.gov

Mika Hunter
U.S. Environmental Protection Agency
Office of Pesticide Programs
Biopesticides and Pollution Prevention Division
Microbial Pesticides Branch
Ariel Rios Building (7911P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 308-0041
E-mail: hunter.mika@epa.gov

Sastry Isukapalli
The State University of New Jersey
Environmental and Occupational Health Sciences Institute
A Joint Institute of University of Medicine and Dentistry of New Jersey
Robert Wood Johnson Medical School at Rutgers
170 Frelinghuysen Road
Piscataway, NJ 08854
Telephone: (732) 445-0171
E-mail: ssi@fidelio.rutgers.edu

Beth Jackson
U.S. Environmental Protection Agency
Office of Environmental Information
Ariel Rios Building (2842T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0626
E-mail: jackson.elizabeth@epa.gov

Laura Jackson
U.S. Environmental Protection Agency
Office of Research and Development
(B343-06)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3088
E-mail: jackson.laura@epa.gov

Barnes Johnson
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Superfund Remediation and Technology Innovation
Ariel Rios Building (5201P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 603-8960
E-mail: johnson.barnes@epa.gov

Timothy Johnson
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0575
E-mail: johnson.tim@epa.gov

Ozge Kaplan
U.S. Environmental Protection Agency

Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Atmospheric Protection Branch
ISAW (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5069
E-mail: kaplan.ozge@epa.gov

Serpil Kayin
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Atmospheric Programs
Clean Air Markets Division
Ariel Rios Building (6204J)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 343-9390
E-mail: kayin.serpil@epa.gov

Russell Kinerson
U.S. Environmental Protection Agency
Office of Water
Ariel Rios Building (4305T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0392
E-mail: kinerson.russell@epa.gov

David Kirchgessner
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
(E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4021
E-mail: kirchgessner.david@epa.gov

Paul Koch
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Research
Ariel Rios Building (8701F)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 343-9243
E-mail: koch.paul@epa.gov

Stephen Kraemer
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
960 College Station Road
Athens, GA 30605-2700
Telephone: (706) 355-8340
E-mail: kraemer.stephen@epa.gov

Jim Laity
Office of Management and Budget
Office of Information and Regulatory Affairs
725 17th Street, NW
Washington, DC 20503
Telephone: (202) 395-5168
E-mail: jlaity@omb.eop.gov

Gerry Laniak
U.S. Environmental Protection Agency

Office of Research and Development
National Exposure Research Laboratory
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8316
E-mail: laniak.gerry@epa.gov

Kathryn Lindsay
Environment Canada
Knowledge Integration Strategies Division
70 Crémazie, 7th Floor
Gatineau, Quebec K1A 0H3
Canada
Telephone: (819) 994-8406
E-mail: kathryn.lindsay@ec.gc.ca

Lewis Linker
U.S. Environmental Protection Agency
Chesapeake Bay Program Office
Region 3
410 Severn Avenue
Annapolis, MD 21403
Telephone: (410) 267-5741
E-mail: linker.lewis@epa.gov

Dan Loughlin
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3928
E-mail: loughlin.dan@epa.gov

Susan Lundquist
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Information Analysis and Access
Environmental Analysis Division
Analytical Support Branch
National Computer Center (N295C)
4930 Old Page Road
Durham, NC 27587
Telephone: (919) 541-1131
E-mail: lundquist.susan@epa.gov

Ross Lunetta
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Emission Standards Division
Landscape Characterization Branch (E243-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4256
E-mail: lunetta.ross@epa.gov

Deborah Mangis
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (D305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3086
E-mail: mangis.deborah@epa.gov

Stephen Marley
National Aeronautics and Space Administration

Geosciences Interoperability Office
Goddard Space Flight Center
Applied Sciences Program
Greenbelt, MD 20771
Telephone: (301) 286-1814
E-mail: stephen.r.marley.1@gsfc.nasa.gov

Richard Martin
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Information Analysis and Access (N276-01)
4930 Old Page Road
Research Triangle Park, NC 27711
Telephone: (919) 541-5121
E-mail: martin.rick@epa.gov

Shawn Matott
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
Research Support Branch
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8346
E-mail: matott.shawn@epa.gov

Kelly Mayo-Bean
U.S. Environmental Protection Agency
Office of Pollution Prevention and Toxics
Ariel Rios Building (7403M)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 564-7662
E-mail: mayo.kelly@epa.gov

Qingyu Meng
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4153
E-mail: meng.qingyu@epa.gov

Tessa Milofsky
U.S. Environmental Protection Agency
Office of Pesticide Programs
Biopesticides and Pollution Prevention Division
Microbial Pesticides Branch
Ariel Rios Building (7511P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 308-0455
E-mail: milofsky.tessa@epa.gov

Bruce Mintz
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (D305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0272
E-mail: mintz.bruce@epa.gov

David Mobley
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory

Atmospheric Modeling Division (E243-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4676
E-mail: mobley.david@epa.gov

Christopher Mooers
University of Miami
Rosenstiel School of Marine and Atmospheric Science
Ocean Prediction Experimental Laboratory
4600 Rickenbacker Causeway
Miami, FL 33149-1098
Telephone: (305) 421-4088
E-mail: cmooers@rsmas.miami.edu

Shaibal Mukerjee
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Human Exposure and Atmospheric Sciences Division
Exposure Modeling Research Branch (E205-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1865
E-mail: mukerjee.shaibal@epa.gov

Ines Pagan
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2322
E-mail: pagan.ines@epa.gov

Rajbir Parmar
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8306
E-mail: parmar.rajbir@epa.gov

Pasky Pascual
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Research
Ariel Rios Building (8701F)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 343-9710
E-mail: pascual.pasky@epa.gov

Heidi Paulsen
U.S. Environmental Protection Agency
Office of Environmental Information
Center for Environmental Computing (N229-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1834
E-mail: paulsen.heidi@epa.gov

Lynne Petterson
U.S. Environmental Protection Agency

Office of Research and Development
National Exposure Research Laboratory
(D343-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3582
E-mail: petterson.lynne@epa.gov

Drew Pilant
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Landscape Characterization Branch
(E243-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0648
E-mail: pilant.drew@epa.gov

Rob Pinder
U.S. Environmental Protection Agency
Office of Research and Development
Atmospheric Modeling Division (E243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3731
E-mail: pinder.rob@epa.gov

Alberto Protzel
U.S. Environmental Protection Agency
Office of Pesticide Programs
Toxicology Branch
Ariel Rios Building (7509P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 305-5347
E-mail: protzel.alberto@epa.gov

Tom Purucker
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
Economic Analysis Branch
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8123
E-mail: purucker.tom@epa.gov

David Raikow
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
(642)
26 W Martin Luther King Drive
Cincinnati, OH 45268
Telephone: (513) 569-7383
E-mail: raikow.david@epamail.epa.gov

S.T. Rao
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4541
E-mail: rao.st@epa.gov

Brenda Rashleigh
U.S. Environmental Protection Agency
Office of Research and Development

National Exposure Research Laboratory
(960) College Station Road
Athens, GA 30605
Telephone: (706) 355-8148
E-mail: rashleigh.brenda@epa.gov

Larry Reed
MDB, Inc.
100 Capitola Drive
Durham, NC 27713
Telephone: (919) 794-4703
E-mail: lreed@michaeldbaker.com

David Reif
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Computational Toxicology (D343-03)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2574
E-mail: reif.david@epa.gov

Larry Reiter
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (D305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2106
E-mail: reiter.larry@epa.gov

Joseph Retzer
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Technology Operations and Planning
National Computer Center (N229-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4190
E-mail: retzer.joseph@epa.gov

Bill Rhodes
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory (E305-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2853
E-mail: rhodes.bill@epa.gov

Joann Rice
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards (C304-06)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3372
E-mail: rice.joann@epa.gov

Ken Rojas
U.S. Department of Agriculture
Natural Resource Conservation Service
2150 Centre Avenue, Building A
Fort Collins, CO 80526
Telephone: (970) 492-7326
E-mail: ken.rojas@ftc.usda.gov

Kenneth Rygwelski

U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Mid-Continent Ecology Division
9311 Groh Road
Grosse Ile, MI 48138
Telephone: (734) 692-7641
E-mail: rygwelski.kenneth@epa.gov

Zubair Saleem
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Ariel Rios Building (5307P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 308-0467
E-mail: saleem.zubair@epa.gov

Reeder Sams
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0661
E-mail: sams.reeder@epa.gov

Tom Scheitlin
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Technology Operations and Planning
Center for Environmental Computing
National Computer Center (N276-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0707
E-mail: scheitlin.tom@epa.gov

Kenneth Schere
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-03)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3795
E-mail: schere.kenneth@epa.gov

Jerry Schnoor
The University of Iowa
School of Engineering
4119 Seamans Center for the Engineering Arts and Sciences
Iowa City, IA 52242
Telephone: (319) 335-5649
E-mail: jschnoor@engineering.uiowa.edu

Donna Schwede
U.S. Environmental Protection Agency
National Oceanic and Atmospheric Administration
Atmospheric Sciences Modeling Division (E243-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3255
E-mail: schwede.donna@epa.gov

Banalata Sen
U.S. Environmental Protection Agency

Office of Research and Development
National Center for Environmental Assessment (B243-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1198
E-mail: sen.banalata@epa.gov

Imran Shah
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Computational Toxicology (B205-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1391
E-mail: shah.imran@epa.gov

Carol Shay
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division (E305-02)
Atmospheric Protection Branch
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1868
E-mail: shay.carol@epa.gov

Gary Shenk
U.S. Environmental Protection Agency
Chesapeake Bay Program Office
Region 3
410 Severn Avenue, Suite 109
Annapolis, MD 21401
Telephone: (410) 267-5745
E-mail: gshenk@chesapeakebay.net

Joseph Sickles
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division (E243-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2446
E-mail: sickles.joseph@epa.gov

Alison Simcox
U.S. Environmental Protection Agency
Region 1
1 Congress Street
Suite 1100
Mail Code: CAQ
Boston, MA 02114-2023
Telephone: (617) 918-1684
E-mail: simcox.alison@epa.gov

Leonid Sokoletsky
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division (E243-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3071
E-mail: sokoletsky.leonid@epa.gov

Ben Smith
U.S. Environmental Protection Agency

Office of Environmental Information
Toxics Release Inventory Program Division
Ariel Rios Building (2844T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0816
E-mail: smith.ben@epa.gov

Betsy Smith
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory (E243-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-0620
E-mail: smith.betsy@epa.gov

Linda Spencer
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Information Collection
Collection Strategies Division
Data Standards Branch
Ariel Rios Building (2822T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-1651
E-mail: spencer.linda@epa.gov

Carvin Stevens
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Human Exposure and Atmospheric Sciences Division (E205-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-1515
E-mail: stevens.carvin@epa.gov

John Sykes
U.S. Environmental Protection Agency
Office of Research and Development
(MD-75)
2525 Highway 54
Durham, NC 27705
Telephone: (919) 541-2953
E-mail: sykes.john@epa.gov

Peter Tsirigotis
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Emissions, Monitoring, and Analysis Division
(D205-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-9411
E-mail: tsirigotis.peter@epa.gov

Michael Uhl
U.S. Environmental Protection Agency
Office of Environmental Information
National Computer Center
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4283
E-mail: uhl.mike@epa.gov

Jim Vickery
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory

(D305-01)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-2184
E-mail: vickery.james@epa.gov

Randy Waite
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
(C504-04)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-5447
E-mail: waite.randy@epa.gov

Susan Waters
Environment Canada
Science Assessment and Integration
351 St. Joseph Boulevard, PVM-Sixth Floor
Gatineau, Quebec K1A 0H3
Canada
Telephone: (819) 956-9317
E-mail: susan.waters@ec.gc.ca

Chet Wayland
U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Air Quality Assessment Division (C304-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4603
E-mail: wayland.richard@epa.gov

Marjorie Wellman
U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Ariel Rios Building (4305T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0407
E-mail: wellman.marjorie@epa.gov

Candida West
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8023
E-mail: west.candida@epa.gov

Jeff West
U.S. Environmental Protection Agency
Office of Research and Development
National Oceanic and Atmospheric Administration
Mobile Environmental Radiation Laboratories
National Exposure Research Laboratory
Atmospheric Modeling Division (E243-02)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-4635
E-mail: west.jeffrey@epa.gov

Lindsay Wichers
U.S. Environmental Protection Agency
Office of Research and Development
National Center for Environmental Assessment (B243-01)

109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-7792
E-mail: wichers.lindsay@epa.gov

Lauren Wisniewski
U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Ariel Rios Building (4305T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0394
E-mail: wisniewski.lauren@epa.gov

Dave Wolf
U.S. Environmental Protection Agency
Office of Environmental Information
Ariel Rios Building (2843T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0690
E-mail: wolf.dave@epa.gov

Kurt Wolfe
U.S. Environmental Protection Agency
Office of Research and Development
Ecosystems Research Division
960 College Station Road
Athens, GA 30605
Telephone: (706) 355-8311
E-mail: wolfe.kurt@epa.gov

David Wong
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Atmospheric Modeling Development Branch
(E243-03)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3400
E-mail: wong.david-c@epa.gov

Isaac Wong
Environment Canada
Science and Technology Department
867 Lakeshore Road, Box 5050
Burlington, Ontario L7R 4A6
Canada
Telephone: (905) 336-4439
E-mail: isaac.wong@ec.gc.ca

Dorsey Worthy
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division
Landscape Characterization Branch
(E243-05)
109 TW Alexander Drive
Research Triangle Park, NC 27711
Telephone: (919) 541-3075
E-mail: worthy.dorsey@epa.gov

T.J. Wyatt
U.S. Environmental Protection Agency
Office of Pesticide Programs
Biological and Economic Analysis Division
Ariel Rios Building (7503P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 308-7228
E-mail: wyatt.tj@epa.gov

Phil Yang
National Aeronautics and Space Administration
Geoscience Interoperability Office
Code 610.0
Goddard Space Flight Center
Greenbelt, MD 20771
Telephone: (703) 993-4742
E-mail: cyang3@gmu.edu

Steve Young
U.S. Environmental Protection Agency
Office of Environmental Information
Office of Information Analysis and Access
Ariel Rios Building (2841T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (202) 566-0608
E-mail: young.steve@epa.gov

Jeff Yurk
U.S. Environmental Protection Agency
Region 6
Enforcement Division
1445 Ross Avenue, Suite 1200
Dallas, TX 75201
Telephone: (214) 665-8309
E-mail: yurk.jeffrey@epa.gov

Larry Zaragoza
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Superfund Remediation and Technology Innovation
Ariel Rios Building (5202P)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Telephone: (703) 603-8867
E-mail: zaragoza.larry@epa.gov

Contractor Support

Jacquelyn Beals, Ph.D.
The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: jbeals@mbc.edu

Mary Cerny, M.S.
The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: marycat@compuserve.com

Elsa Desautels
The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: edesautels@scgcorp.com

Maria Smith
The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: msmith@scgcorp.com

Maryellen Smith

The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: melsmith@mindspring.com

Bette Stallman, Ph.D.
The Scientific Consulting Group, Inc.
656 Quince Orchard Road, Suite 210
Gaithersburg, MD 20878
Telephone: (301) 670-4990
E-mail: estallman@scgcorp.com