Workshop Report

U.S. Environmental Protection Agency

**Collaborative Approaches to Integrated Modeling:
Better Integration for Better Decision-Making**

**JW Marriott Desert Ridge
Phoenix, Arizona**

December 10–12, 2008

EXECUTIVE SUMMARY

OVERVIEW

From December 10 to 12, 2008, the U.S. Environmental Protection Agency (EPA) hosted a workshop called "Collaborative Approaches to Integrated Modeling: Better Integration for Better Decision-Making." EPA's Office of the Science Advisor (OSA) and EPA's Council for Regulatory Environmental Modeling (CREM) organized the meeting, which was held in Phoenix, Arizona. The goal of the workshop was to establish and initiate a community of practice for integrated modeling science and technology. Participants from the public sector, private sector, and academia discussed the benefits and challenges of creating a community of practice. Workshop participants generally supported the development of a community of practice, and they offered a variety of opinions on how this community should function and what objectives it should aim to achieve.

DECEMBER 10, 2008

OPENING REMARKS

Introduction to the Workshop

Gary Foley, EPA, OSA

Dr. Foley opened the meeting by welcoming participants and stressing the importance of partnership across EPA offices to advance the agenda of environmental modeling. He then introduced the first speaker, Molly O'Neill, Assistant Administrator of EPA's Office of Environmental Information (OEI), Ms. O'Neill's presence at the workshop demonstrated OEI's commitment to the activity of modeling, he said.

Welcome Remarks

Molly O'Neill, Assistant Administrator and Chief Information Officer, EPA, OEI

After welcoming workshop participants, Ms. O'Neill discussed the importance of integrated modeling in fulfilling EPA's mission. Emerging environmental issues such as climate change transcend any single medium (e.g., air, water, soil). Thus, to tackle such challenges, scientists must pursue an integrated systems approach. The future of modeling demands collaboration and the development of new tools. Because modeling currently encompasses such a broad range of approaches, new models should also aim for interoperability.

Ms. O'Neill urged workshop participants to use real case studies to promote collaboration, both within EPA and across agencies. Complex technical issues demand that the information technology (IT) community "step up" and provide computer science expertise, thus allowing modelers and other scientists to continue to focus on what they do best. Accordingly, OEI wants to be a partner in integrated modeling and seeks to better understand the challenges that the modeling community will face. Of particular interest is the means by which modelers can use new technologies, such as Web 2.0, to help collaborate with one another.

As a parallel, Ms. O'Neill mentioned the Global Earth Observation System of Systems (GEOSS), an ambitious project whose contributors work in collaborative environments. Topping their list of challenges is climate adaptation, which will be a persistent issue in the years to come. Modeling addresses that challenge as well. Intellect, creativity, and transparency in integrated modeling will not only further research in the field but also instill greater confidence in the field as a whole.

Ms. O'Neill closed by reiterating her support for the workshop and the great importance of the community's work.

Opening Plenary: Integrated Environmental Modeling: Past, Present, Future
Gerry Laniak, EPA, Office of Research and Development (ORD)

Mr. Laniak discussed the importance of integrated modeling, described the evolution of environmental modeling over time, and outlined objectives for the workshop. He noted that modelers face the challenge of convincing leaders and managers to take integrated modeling seriously (i.e., "making the case" that integrated modeling is more than just an interesting concept). To make the case for integrated modeling, scientists can point to a variety of efforts already underway. For example, the U.S. Department of Agriculture (USDA) has established a collaborative software development Web site; the Europeans have already established a standard for modeling; and academic hydrologists have initiated the first steps in forming a Community of Practice (CoP).

The field of environmental modeling began with deterministic and simplistic models, which typically examined a single chemical, medium, or pathway. For example, early models of contaminants' effects on humans considered only direct contact by a maximally exposed individual. Over time, as researchers and administrators became aware of the complexity of environmental issues, environmental modeling also grew in complexity. Models soon incorporated multiple chemicals, media, and pathways. This move to a more holistic approach marked the beginning of what is now known as "integrated modeling." Along with this change in approach came a greater demand for data, changes in scope and resolution, and new sophisticated infrastructures, such as Geographic Information Systems (GIS).

As the integrated modeling community continues to grow into the future, the complexity and scope of projects will continue to increase. Today, with a movement toward better integration, the modeling community is in the middle of a paradigm shift. The workshop presents an opportunity to accelerate the transition. The workshop focuses on two topics central to this shift: 1) the creation of a CoP, and 2) methods to address technical challenges facing modelers.

Mr. Laniak suggested that all participants agree on the definition of a CoP. A CoP can be loosely defined as social learning that emerges and evolves when people with common goals come together. Although all the participants might be considered to be part of a CoP already, the workshop's goals consider a CoP with a greater scope than what currently exists. The question before the workshop participants is whether sufficient support exists for forming such a broad partnership. If such interest exists, then part of the workshop will focus on laying the groundwork for forming the CoP.

The foundation of the CoP requires a discussion on standards and interoperability. Standards provide a structure by which to acquire and report information. They do not impact the science of a model; rather, they focus on how the science is shared. Interoperability refers to the capability to exchange data, which includes evaluating mechanical elements (e.g., file formats) as well as ensuring that the data being exchanged are scientifically meaningful and correct. To provide reliable information to decision-makers, quality assurance (QA) and quality control (QC) are needed to make certain that integrated models are not compromised. Coherence, transparency, and reproducibility all play a part in ensuring the quality of model components. In addition, codifying the processes by which data are described can ensure the integrity and reliability of shared material. Documentation can include explanations of certainty, uncertainties, assumptions, and unknown factors in model components.

Mr. Laniak suggested looking for opportunities to simplify modeling efforts by agreeing upon some common formats and software protocols, rather than spending resources supporting redundant formats. He challenged modelers to adjust to this new way of thinking and be willing to adapt to common formats and systems for the good of the CoP as a whole. Advancing the goals of the community will demand a shift from simply valuing one's own work to valuing the work of the community as a whole. Mr. Laniak closed by quoting soil scientist Dave Brown, who said, "Perfection is the worst enemy of good." He urged workshop participants to lay the groundwork for the CoP without being afraid to save the detailed work for a later date.

Strategies to Promote Collaboration and Facilitate Interoperability

Phillip Dibner, Open Geospatial Consortium

Mr. Dibner provided an overview of the development of the Open Geospatial Consortium (OGC), which serves as an illustrative example of the strategies for forming a CoP. The OGC issues standards, launches new interoperability initiatives, and engages in broader efforts. A related organization, the OGC Interoperability Institute (OGCii), then applies the standards set by OGC in the research arena. In this way, the Interoperability Institute works with the greater geospatial community to advance the scientific goals in more of a hands-on manner.

OGC was born out of frustration with early research in the geospatial community, which was marred by incompatible formats, oversized data sets, and, as a result, stifled progress. Today, OGC has developed several sets of standards available free for use. The organization also teams up with partners across the world and now has alliances with more than 360 members worldwide. The outreach initiative led by OGCii encourages organizations to join the effort. OGC uses a "bottom-up" approach to developing standards by letting members participate in the process and, in return, receive partial funding. New initiatives follow a staged development process, which typically involves two or more cycles of testing and refinement before the standards are approved. After approval, OGC publishes standards in an online catalog, giving end users easier access to resources.

For a new community seeking to model its approach after OGC, certain strategies prove to be most critical. A community should not constrain data formats, data management policy, or the hardware and software platforms used. New communities should also develop a forum where the services of the community can be described and shared. For the initial stages of forming a community, planning and control must be balanced with innovation. When developing new initiatives, a lead architect should facilitate the effort, but discussion and collaboration are vital. Development should focus on objectives rather than policy or preordained designs.

Technology can facilitate effective collaboration within the community. Regular face-to-face meetings are valuable, but other methods of communication can also help support collaboration: e-mail, telephone conferences, Web-based groups (e.g., Google, Yahoo), instant messaging, and chat rooms. Above all, no one should be left out of the conversation. "Back-channel" conversations lead to disorganization.

Geoffrey Moore's 1991 book, *Crossing the Chasm*, addresses the challenges in adopting new technologies. Moore's theory divides the population of adopters into five groups: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. The challenge for new products or approaches, such as interoperability, is to cross the chasm between Early Adopters, who are not afraid of risk, and Early Majority, who are more risk-averse. Successfully crossing the chasm requires targeting the early majority and then launching a campaign to meet the needs of the group.

Mr. Dibner described several strategies for encouraging the adoption of interoperability standards within a CoP, including lowering barriers for participants and investing early to take advantage of increasing returns (i.e., a new technology becomes more valuable as more people adopt it). The community should stress the goals of the initiative and the potential returns.

Discussion

Dr. Foley encouraged participants to consider pilot projects, an approach that has worked under GEOSS. For example, EPA is analyzing opportunities to incorporate more types of data in air quality programs.

PANEL PRESENTATIONS/DISCUSSION: STATE OF THE ART AND PRACTICE IN INTEGRATED MODELING

Facilitator: Dan Loughlin, EPA, ORD

Why Openness and Collaboration Are Essential for Integrated Modeling: Lessons from OpenMI's Development

Roger Moore, Centre for Ecology and Hydrology, United Kingdom

Dr. Moore discussed the formation and evolution of Europe's OpenMI program, which has brought together integrated modelers from across the continent into a unified CoP. European countries face many of the same science, policy, planning, and operational questions as the United States. For example, how will climate change affect ecosystems or flood damage recovery costs? How will a flu pandemic affect the management of sewer treatment or river water? Integrated modeling arose from the need to address questions such as these, which cut across environmental media and scientific disciplines. Rather than try to build complex models of multiple processes, which might not be feasible, modelers need ways to link existing models together.

OpenMI acts as a standard interface for run-time data exchange between models and their components. A useful analogy is to compare the OpenMI to USB ports on a computer. Computers use USB devices to incorporate various components that enhance the system's functionality. OpenMI standardizes modeling components so a modeler can mix and match the capabilities of available pieces to suit his or her research goals.

OpenMI continues to face challenges. For example, advocates for the OpenMI standard have difficulty convincing policymakers that integrated modeling is a worthwhile scientific pursuit, and skepticism from managers can potentially affect the program's funding. Another challenge is that integrated modeling requires a range of expertise—often more than one subject matter expert or organization can provide alone. In response, modelers need to look outward for ideas and expertise. Internet user communities can help meet these challenges by allowing people around the world to contribute remotely and at low cost. Many examples show the value of embracing a broad Web-based user community. For example, the toy company Lego recently developed a product that included a microprocessor, which was subsequently hacked and improved by consumers. Soon, the company had organized the equivalent of a research organization made up entirely of volunteers. OpenMI embraces a similar participatory model, with the OpenMI Association serving as a facilitator. EPA could play a similar role in the United States.

Today, the OpenMI Association seeks to advance integrated modeling through the following steps:

- **Operational demonstrations.** The Association is looking for end users who can incorporate integrated modeling to solve real problems. Several research proposals are currently in development.

- **Outreach.** By incorporating OpenMI into academic curricula, the Association hopes to better prepare the next generation of modelers.
- **Fostering the user community.** The Association seeks to harness user innovation, yet keep the mission focused.

Ultimately, the principal goal for successful integrated modeling is eliminating current barriers and openly collaborating with all interested parties.

MapWindow GIS and Community Development
Dan Ames, Idaho State University

Dr. Ames discussed the development of an open source, standards-based GIS software platform known as MapWindow GIS. MapWindow provides a graphical user interface for users to analyze data, create models, and visualize results through maps, flow charts, or other graphics. MapWindow began as proprietary software, but after a year of sluggish sales, the developers elected to make it available free for download and make the code open source. Adoption has increased greatly; for example, EPA now uses MapWindow GIS for watershed analyses, including BASINS 4.0.

Open-sourcing enables users to view and alter the program code and, if they so choose, share their modified code with the user community. Thus, users can enhance the software not only for their own benefit but also for that of others. Dr. Ames stressed that open-sourcing is not anti-competitive, as it serves as the basis for commercially viable products such as Linux and MySQL. Open source code is also reliable, he said, because it is constantly being reviewed and improved. In one instance, a user from China contacted Dr. Ames regarding significant memory leaks in MapWindow, which he subsequently corrected. MapWindow also allows users to create and share plug-ins that expand the program's functionality. MapWindow administrators facilitate a discussion forum and wiki page that help unite the user community. Users are encouraged to experiment with code and confer with others about new possibilities. The resulting community has now grown well beyond its original group of developers. A similarly inclusive community for a modeling CoP could yield equally positive results.

CUAHSI Community Hydrologic Modeling Platform (CHyMP) Initiative
Larry Murdoch, Clemson University

Dr. Murdoch discussed the Community Hydrologic Modeling Platform (CHyMP) initiative organized by the Consortium of Universities for Advancement of Hydrologic Science, Inc. (CUAHSI), which represents more than 100 U.S. universities. CUAHSI coordinates five nationwide initiatives designed to improve the availability and sharing of data in the hydrologic community. CHyMP is the fifth and newest program spearheaded by CUAHSI. The initiative was born out of a desire to increase the return on investment in hydrologic models, as independently developed models often have redundant uses. CHyMP began in March 2008 and is still in its nascent stages. Its mission is to improve the integration, flexibility, and management of hydrologic models. The communication and collaboration enabled by CHyMP will make modelers more efficient in their research.

A key challenge for the integration of hydrologic models is that different models are designed to analyze and report on different temporal and spatial scales, sometimes using different equations or parameters to model the same environmental phenomenon (e.g., transport or reaction) depending on the scale. CHyMP seeks to tackle this challenge by providing a modeling platform that can address a broad range of scales and processes. Other communities have successfully developed similar programs—for example, the Community Climate System Model, Community Surface Dynamics Modeling System, and NanoHub. In the future, CHyMP might be able to connect with the Hydrologic Information System (HIS), another CUAHSI initiative that comprises hydrologic datasets from observations and simulations. The merging of the two systems could yield a National Water Model that would address national-scale science questions.

The modeling community can benefit from an evolution in the way its members communicate. Journal articles and presentations are antiquated ways to talk about models. New research today should be shared openly, thereby allowing others to have access to it. Such an approach could speed growth and encourage the development of new model functionality. CUAHSI hopes CHyMP can facilitate this evolution.

Nine Agency MOU for Environmental Modeling: Can It Work?
Ken Rojas, U.S. Department of Agriculture (USDA)

Mr. Rojas provided an overview of the Memorandum of Understanding (MOU) for Environmental Modeling, a partnership among nine U.S. government agencies that utilize modeling. The MOU was formed in 2001, bringing agencies together to overcome challenges and reduce redundant research costs through collaboration. The MOU is led by a steering committee composed of representatives from participating agencies; Mr. Rojas currently chairs this committee. The MOU functions through four working groups, each addressing a specific issue within the modeling community (i.e., software design, uncertainty analyses and parameter estimation, modeling of subsurface processes, and watershed modeling).

The MOU has produced several “success stories” to date. In one project, members of the MOU collaborated to improve the way USDA’s National Water and Climate Center forecasts streamflow and water supply. To do so, they integrated the Precipitation Runoff Modeling System with climate and streamflow data, using the Object Modeling System (OMS) as a framework for model assembly, calibration, and analysis. The OMS provides users with a model-building wizard that allows them to take components from existing models and assemble them into new models. Agencies shared the work by providing infrastructure, expertise, analytical tools, or other services to support the effort. A USDA software development laboratory known as CoLab facilitated collaboration.

The MOU has faced some challenges, including the need for funding to pay for contractor support and face-to-face meetings, which tend to be more productive than remote collaboration. In addition, many of the agency staff who work on the MOU also face increasing workloads and responsibilities in their primary jobs.

Mr. Rojas closed by discussing a variety of upcoming projects for the MOU and inviting workshop participants to become involved.

The Community Sediment-Transport Modeling System: Experiences with an Open-Source Approach

Christopher Sherwood, U.S. Geological Survey (USGS)

Dr. Sherwood described USGS's role in developing the Community Sediment-Transport Modeling System (CSTMS), a modeling initiative that integrates meteorological, hydrodynamic, sediment transport, and other models to characterize ocean processes in three dimensions. USGS designed CSTMS as a fully open source model, in part because of the collaborative benefits of open source development (particularly with a topic that covers so many disciplines) and in part because the project was financed through public funds. Developers found that one of the most useful collaborative tools was a type of version-control software known as "Subversion", which helps manage revisions of code. During the development stages, investigators used test cases to assess the effectiveness of the model. Investigators faced challenges when applying the model in areas where local ocean dynamics are forced by regional or global mechanisms, such as the El Niño Southern Oscillation. Organizational challenges for the investigators included competing personalities and agendas, finding ways to reduce the total number of models, stabilizing the code, and harnessing the user community to fix bugs and update model documentation. CSTMS has also had its share of successes, however. An open community of more than 30 investigators actively contributes to the effort. A generous licensing protocol also enables contributors to use their code however they wish. Dr. Sherwood suggested that funding agencies insist on open source code and collaboration and expressed hope that the scientific community can recognize individuals for their collaborative contributions, not just individual achievements like publications.

BREAKOUT DISCUSSION SESSION 1: TECHNICAL CHALLENGES RELATED TO MODEL AND MODELING FRAMEWORK INTEROPERABILITY

Session Co-Chairs:
Group 1: Alexey Voinov, Gerry Laniak
Group 2: John Johnston, Ken Rojas

Charge for Breakout Discussion 1

Mr. Laniak explained that the first set of breakout discussions provide an opportunity to identify challenges related to model interoperability. He encouraged each group to develop two lists: one containing the highest-priority issues, and the other containing challenges that this emerging CoP might explore together through pilot projects.

Following this orientation, two breakout groups met separately to hold discussions based on this charge. They then reconvened in a plenary session, where the co-chairs presented the discussions. The text below summarizes the co-chairs' oral reports. It also includes, where relevant, additional related details discussed during the breakout groups, but not reported out.

Group 1

Major Challenges

Group 1 developed an extensive list of technical challenges that the community will face:

- **The distinction between model interoperability and model integration.** Mr. Laniak explained that interoperability concerns the mechanical aspects of connecting multiple models, but full integration also requires consideration of higher-level scientific aspects. As a modeler from the U.S. Department of Energy (DOE) explained, integration requires more than just matching variables and data types. It also requires scientists to map high-level knowledge, consider the scale of the data, and ensure that the integrated model does not violate any assumptions within the component models. A participant from EPA Region 3 added that scientists must link the underlying chemistry and physics before linking the code. A formulation document or algorithm theoretical basis document can help users evaluate the appropriateness of integrating a given set of models.

- **QA/QC for model integration.** Model users need to be able to trust the information that is transferred from one model to another. Standards can play a role in verifying shared data and ensuring that these data are appropriate. As one participant in the breakout discussion explained, the modeling community knows that certain models simply cannot be plugged together because the data do not match. Modelers should document this information to ensure that others do not misuse their models.

- **Standards must be understood to be evolutionary.** As one participant in the breakout discussion explained, integrated modeling is supposed to be flexible by nature. The ability to swap models like interchangeable parts ensures that the modeling community is able to incorporate the best science as it becomes available. Breakout group participants also recognized that standards alone cannot guarantee that models will be used appropriately. For example, while some modelers might welcome standards that require users to have certain competencies and dictate how they can use a given model, a participant from EPA Region 7 pointed out that in reality it is impossible to regulate users. Instead, the designer of the model must give users information that will allow them to use the model properly, a goal that is best achieved with thorough documentation.

- **Establishing ontologies.** Mr. Dibner explained that before connecting models together, one needs to understand the scientific basis of each model, the type of algorithm each model represents, and the input and output parameters. Thinking of each of these pieces of information as “fields,” Mr. Dibner explained that the values one assigns to each field must come from some vocabulary—an ontology.

- **Harmonizing ontologies among communities of practice.** Model integration will proceed more smoothly if people model information the same way. Most information models include some notions of space and time, but different disciplines might use different terminology. A participant from USDA added that definitions of key concepts can vary, too. For example, one model's definition of "runoff" might differ from another model's.

- **Ensuring system level integrity and testing the product as a whole.** As one participant explained during the breakout session, interoperability does not guarantee that the results of an integrated model will make sense. Even if the individual parts work, that does not automatically mean the sum of the parts will work, too. Several members of the group recommended developing standard protocols for testing coupled or linked models—for example, by comparing the results with empirical observations. More generally, scientists will need to learn how integrated models function as a whole. As one EPA participant noted, modelers understand their individual models well; they know which variables are most sensitive and they know how to tweak the model if needed. Modelers will need to develop a similar understanding and comfort level with linked models. Because integrated models can cross several disciplines, however, an individual modeler might need to collaborate with experts in several other areas to achieve the desired level of understanding.

- **Lack of explicit expression of assumptions in model components.** Implicit assumptions are particularly troublesome if the knowledge lies in the hands of just one expert, who will probably retire someday. Group 1 recommended providing models with more explicit documentation, including any assumptions about scale and information about which variables are considered within the system—and conversely, which factors are excluded from the analysis. During the breakout session, several participants recommended that this information appear in a formulation document. They emphasized that each model should have a formulation document that explains the science, documents any assumptions, and provides contact information for the model developer. This document also can set bounds on the parameters and explain what outputs are reasonable (i.e., a realistic range), and perhaps discuss the outcome of test cases in which the model did or did not work. A participant from DOE suggested posting formulation documents on the Web and perhaps providing links to this Web page within the model code. Another participant emphasized that the formulation document—as well as any other documentation—must consider the end users of the model.

- **Software and hardware independence.** During the breakout session many participants agreed with the need for software- and hardware-independent models, although they disagreed about specific applications. For example, participants disagreed on the extent to which interoperability standards should prescribe specific programming languages. Some members of the group felt that it would be reasonable to prescribe languages for certain applications, noting that language is important at the compiler level, consistency can improve efficiency, and high-performance computing works better when a common language is used. Conversely, others argued that the proliferation of programming languages is a good thing because it takes advantage of hundreds of person-years of coding, and because each language has different strengths. Thus, they urged the group not to create standards that would preclude the use of code that has already been written. One private sector participant reported that computer scientists have already demonstrated the ability to integrate codes in different languages, even with two models transferring data to one another over the Internet. Finding some value in both positions, another participant suggested that the best approach depends on the circumstances. In some cases that warrant “tight” coupling, standardizing the programming language can improve performance. Other cases might require only “loose” coupling, where models can remain in different languages.

The breakout group also discussed hardware compatibility, noting that the OpenMI standard does not work with high-performance parallel computing. Several participants offered examples of how high-performance computing is already in use with environmental models, including a high-resolution flooding model for New Orleans and a model that analyzes the response to a “dirty bomb” incident. Participants generally agreed that the integrated modeling CoP should encourage models that can run on a wide variety of hardware, including high-performance hardware of the future.

- **Performance issues.** Mr. Voinov noted that communicating between models in real time, particularly over the Web, can lead to concerns about data intensity, bandwidth, and parallel computing. The community needs to consider these constraints, particularly in light of the various ways in which agencies such as EPA restrict IT resources. During the breakout discussion, participants emphasized the difference between simply feeding one model’s output into another model and actually enabling real-time synchronization. The latter is much more complicated because it requires rapid transfer of data.

- **Interface control documents.** An interface control document can help ensure interoperability by explaining how to take output data from one model and feed them into another model as input data. During the breakout session, the participant who introduced this idea explained that it arose as a “lesson learned” from past efforts at model integration. Some interface control documents are language-specific, but they also can be written in a more generic way.

- **Model integration versus component integration.** When developing an integrated modeling solution, scientists will need to consider whether they can integrate two models directly, or whether they should break the models down to their component parts and then reassemble an integrated whole. Breaking a model into components might provide a better understanding of how the model works.

- **Manual versus automated integration.** Although full automation might seem desirable, getting two models to interact properly will always require some degree of manual tweaking, particularly as issues such as sensitivity and error propagation arise during the initial stages of integration. However, automation can still play an important role in checking data, running Monte Carlo simulations, and related applications. A participant from EPA Region 3 observed that model interoperability also requires "human interoperability," meaning scientists need to talk to one another.

- **Spatial and temporal synchronization.** Spatial and temporal aspects of the data can be resolved in many ways, but resolution often requires manual effort. First the user must understand how each model works. Some modelers have found it helpful to consult "coupling specialists" who have specific skills and experience in component-level integration.

  During the breakout discussion, participants recognized that time and space are not the only dimensions of concern when integrating models. Models also can differ in their resolution or granularity. For example, one model might use point data while another uses gridded raster data. One EPA participant described the challenge of investigating formaldehyde concentrations near roadways, which could require him to integrate a small-scale emissions model with a larger-scale model of photochemical formation. Similar issues arose with the Chesapeake Bay Program, which successfully integrated models that operated at different resolutions.

  As a private sector participant explained, concatenating models together also can lead to nonlinear behavior and unrealistic, nonphysical results. He warned that modelers must consider sensitivity as well as how to parameterize global factors that might be part of some but not all models. An EPA modeler added that models can be full of assumptions and boundary conditions that make synchronization difficult.

- **Rules and recommendations for design and implementation of future modeling efforts.** The group suggested establishing "rules" to make models developed in the future more interoperable, including establishing documentation rules, implementing a standard "initialize—run—output" design, and requiring a model to be able to save its current state. Several participants elaborated on this last point, noting that before one can trust a set of linked models, one needs to be able to trust whether an individual model can use its own output as input and use its own boundary conditions. A modeler from USGS explained that this concept is called "perfect restart." As a participant from USDA noted, perfect restart can be elusive because even though a model might have embedded numerical accuracy, if it outputs halfway through in a readable form (e.g., by reducing the number of significant digits), then these outputs are fed back into the model as inputs, accuracy will be lost. A DOE modeler suggested that the issue is more a matter of modularity—for example, if Model A stops to communicate with Model B, then starts again, will it start from the same place?

  During the breakout discussion, members of the group provided a few more details about "perfect restart" requirements. One participant gave an example of an ocean model, explaining that once a model has characterized a particular geographic area (e.g., a certain grid cell), it should be able to incorporate boundary conditions from this region when it models conditions in an adjacent area. A model will be more believable if it can operate in this fashion, essentially using intermediate outputs as new inputs. However, an EPA modeler cautioned the group not to recommend restrictions that might preclude modelers from linking a steady-state model in one medium to a time-dependent model in another medium, which can still be a scientifically valid arrangement.

More generally, the breakout group agreed that model code should be open source. They cited several reasons, including: 1) interoperability requires that code be exchangeable, and 2) any model used for regulatory decision-making must be fully transparent. Two participants asserted that models should ideally be fully substitutable, such that a user who cannot obtain access to a proprietary model will be able to find an open source model that performs the same function. Several participants also emphasized that open source models should not require proprietary software to run them, although they disagreed as to how strictly to apply this requirement. For example, they wondered what to do with a model that displays its outputs using ESRI GIS software. One EPA participant argued that this hypothetical model is not fully transparent, while another felt that the model just needs to be able to run completely and generate spatial data fields (output) without proprietary software, and ESRI simply provides a supplemental tool to visualize those outputs.

Priorities for Work in the Near Term

In their presentation to the full workshop, Group 1 identified two projects the community might pursue in the near term to address some of the challenges described above. The two projects were as follows:

- **Selecting three or four model linkage challenges as case studies to help establish standards.** The group suggested selecting three or four case studies to help identify critical areas that would benefit from standards or a shared ontology. In doing so, the investigators should consider what information they need to know in order to link models successfully. During the breakout session, participants suggested that one of these case studies should involve a complex problem that requires dynamic feedback between models. At each time step, each model will need to inform the other about its state and flux. Participants noted several complex variants on this theme. For example, a participant from USGS explained that some modelers also insist on predictive correction, in which Model A takes a partial step, then communicates with Model B before completing the step. A participant from academia observed that some models use different time steps, which can complicate efforts to link them together dynamically.

- **Establishing ontologies.** During the breakout discussion, one participant suggested that researchers start by looking at various disciplines that use modeling, and identifying what standards and ontologies they currently use for model metadata. Reaching a step further, an EPA participant suggested that for each environmental medium, someone familiar with that medium should develop a list of models, the standards they follow, the language in which they are coded, the computational requirements, and their availability (proprietary or open source). Other participants suggested additional fields, including input and output requirements, parameter classifications, time steps, and the model's overall function. As one participant pointed out, this knowledge base might resemble a Unified Modeling Language (UML) class diagram. Populating this knowledge base will ultimately help users decide which models best meet their needs—for example, if they need a screening model with low computational demands, or if they need a more complex model to support a regulatory decision based on a precise increment, such as a Prevention of Significant Deterioration (PSD) permit for air emissions. Regulators and other end users do not necessarily have time to learn the intricacies of every model, so this knowledge base—and, ideally, the model metadata—should provide enough basic information to inform their decisions.

Group 2

Major Challenges

Group 2 identified the following challenges that the integrated modeling community will face:

- **Who is the client, and who is the audience?** In the breakout discussion, several participants from outside EPA mentioned the importance of defining a model's scope and identifying its intended users. An EPA participant noted that in some cases, the people who apply models and work with the output are the same people who developed the models. With so many perspectives represented at the workshop, participants agreed that opinions on this issue are likely to vary.

- **Where is the science?** The group recommended developing a priority list of science questions to focus the CoP. For example, how does one achieve mass balance, and how does one calibrate or quality assure a system of models? This suggestion arose during the breakout discussion when an EPA participant noted that most of the questions and challenges being addressed were technical or organizational issues, rather than science issues. Because science is an integral part of the models, developing a similar list of questions or concerns from a scientific perspective might benefit the modeling community.

- **The need for benchmarks to compare models and frameworks.** Group 2 wondered how best to compare models and frameworks. In the interest of streamlining model development, they specifically cited a need for benchmarks to compare model performance and cost-effectiveness.

- **Migrating legacy models to new frameworks.** Group 2 noted that it can take significant effort—in the range of weeks to months—to migrate a legacy model to a new integrated framework. For example, some people have experienced difficulty migrating EPA models to OpenMI. This challenge can pose a barrier to adoption of new frameworks. Participants elaborated on this point during the breakout session, noting that some legacy models are inflexible and use antiquated coding that requires upgrading or modernization. In addition, some legacy models have no point of contact because their original developers have retired or passed away. Thus, present-day investigators face a steep learning curve when they seek to use legacy models or incorporate them into an interoperable framework. A participant from the National Aeronautics and Space Administration (NASA) noted that model migration might face cultural barriers as well. Many modelers work independently, and managers do not necessarily understand the concept of integrating models as a system.

- **The need for complementary models of varying complexity.** Despite all the discussion about streamlining the use of models, participants recognized that some seemingly redundant models exist for a reason, because even if they model the same environmental process, they might do so with different granularity. For example, they discussed the value of screening models for some applications and more precise models for others (e.g., regulatory decisions).

- **QA/QC when models are changed or adapted to new frameworks.** In their presentation, the group cited the need to verify for the user community that a given model will still give the same answers it did before, even after it has been updated or migrated to a new framework.

- **Bridging the range of hardware technology.** Whatever models the community develops should be able to work on a variety of computing systems, ranging from desktop systems to high-performance computers to cloud networks.

- **Model enhancement versus new development.** How does one decide whether to invest in enhancing an existing model or developing a new one? Considerations might include economics (cost–benefit) or the extent to which users trust the existing model. Model developers might have success extracting algorithms of interest from legacy models. In a related discussion, two participants briefly discussed the proprietary nature of models. When a new model incorporates or builds on a previous model, who should get the credit? The pair agreed that the developer of the new model can take credit only if he or she can prove that the resultant model constitutes a substantial improvement.

- **Documentation of models, algorithms, and frameworks.** Ideally, these components will be documented in a consistent fashion. During the breakout discussion, two EPA participants articulated their frustration with the documentation that accompanies many model components, observing that updated documentation tends to lag behind the development of new code. Some participants suggested that developers should label key features and document key assumptions directly within the code, although a modeler from DOE disagreed, suggesting that this information belongs in a formulation document, not within the code.

  Many participants in the breakout discussion emphasized that models need comprehensive metadata. Users should know what inputs a model will accept and should also know how best to use the output. One participant expressed reservations about linking large-scale models together, warning that model components can have different scales or resolutions. Thus, any standards the community develops should stipulate the responsibility of a modeler to understand the temporal and spatial limitations of borrowed work—which in turn means that modelers need to effectively communicate the assumptions they use. To reduce the occurrence of scale or resolution mismatches, participants suggested automating certain functions. For example, a “smart” framework could help reconcile temporal and spatial differences between model components and identify improper inputs. Programmers might design “red flag” alerts that appear when input data do not match the format or range specified.

- **Maintaining quality code and documentation.** During the breakout discussion, participants discussed ways to control the quality of code and documentation. Some felt that software engineers generally write better code than scientists. One of the participants recommended that authors digitally sign or endorse the effectiveness of their model or component. However, another participant suggested that such endorsement might not guarantee quality, because models have to be used correctly, too—i.e., the wrong model in the right hands might be better than the right model in the wrong hands.

- **Model complexity.** More efficient, more modular code might lead to more useful products. This suggestion arose during the breakout discussion when one participant noted that even with up-to-date documentation, a component might go unused if it seems too complex or the documentation is too long. Most participants expressed support for streamlining model development, although some worried that if the community tries to set tighter timeframes for model development, modelers might compensate by putting less effort into new features. Another participant wondered about the cost–benefit outcome of such decisions.

Priorities for Work in the Near Term

Group 2 suggested the following three technical challenges that the community might explore through pilot projects:

- **Developing a standard for models, ideally similar to the federal geodata standard.** What is the role of standards for various aspects of integrated modeling, particularly with regard to metadata, but also for databases and variables? Among other things, participants generally agreed that the standard framework should explain what each model is and how it should be used.

  A participant from USDA mentioned the possible need for multiple frameworks, perhaps depending on the scale of the components contained therein. Several participants from EPA felt that a principal goal of the CoP would be to develop a framework that can serve a broad base of modelers, whose work would span a range of applications and complexity. Ultimately, they felt that the CoP should aim to develop a common standard, perhaps in the form of a standardized framework. Alternatively, a participant asked if frameworks themselves could be made interoperable without creating an even larger system. Another participant countered by asking how easily a modeler can make his or her model components compatible with multiple frameworks.

- **Communication for interoperability.** How can communication protocols between models, frameworks, and databases be designed to facilitate interoperability? During the breakout discussion, one participant from outside EPA wanted to clarify if, when discussing the linking of models, participants meant the technical demands of linking models or the science within the models. Another participant responded that linking models just to share information would be irresponsible; the point is for models to actually understand each other. An EPA participant agreed and reminded participants that models were written with specific purposes in mind. Interoperability allows components of these models to be assembled in different ways. Another participant asked whether it makes economic sense to break a functional model into its constituent components in the event that they might be used later. Preparing model components so they can be used in this manner takes significant effort and represents a large shift away from current practices. Modelers' motivations vary (e.g., some want to publish their work; others might be more generally concerned with helping their organizations achieve progress), and some will be more reluctant than others to change the way they work.

To communicate effectively, the community needs standard nomenclature and a common language. As one participant from USDA explained, different disciplines within the modeling community, particularly those involved in data collection, have different methods of organizing information and communicating with others. A private sector participant added that some people might even disagree on the definition of a model—for example, whether it must be executable.

- **Establishing basic principles of model transparency, coherence, consistency, reproducibility, and QA.** These standards will govern how members of the community share their work. The community should address how these concepts can be applied to integrated modeling.

Discussion

Following the presentations by the two breakout groups, participants discussed a few additional challenges that the community might face:

- **Convincing modelers to use whatever products (e.g., frameworks) the community develops.** A DOE modeler urged the community to develop standards that members of the community will accept. Several participants from EPA discussed ways to get the various program offices within EPA to work together on integrated modeling—for example, seeking more management support for activities that are not strictly regulatory in nature (such as exploring integrated modeling), or crafting a pilot project with a problem statement that forces multimedia collaboration. One participant from EPA Region 3 recommended that the CoP not just provide services, but also espouse a broader mission that transcends the boundaries of medium-specific program offices. As an example, he noted that his Regional Office carried out a multimedia indicator effort with the goal of "better characterizing the environment." With support from top management (the Regional Administrator), Region 3's program offices worked together to identify potential indicators, then used a decision model to identify four priority challenges. The participant reported that Region 3's project succeeded at fostering collaboration among the program offices, rather than competition.

- **Learning from case studies of modeling efforts that do not turn out as well as expected.** A participant from EPA Region 1 encouraged others to come forward not only with "success stories," but also with examples of integrated modeling efforts that did not work well. Dr. Moore agreed, explaining that the OpenMI Association found this type of exercise to be quite constructive. For example, the Europeans found that many models have been stretched beyond their intended purposes, and they identified several problems that they have handed off to universities to study. Ultimately, this approach should lead to better models and a better understanding of how to integrate them. Another participant noted that NASA and the National Oceanic and Atmospheric Administration (NOAA) have attempted some model integration, and suggested talking with these agencies about their successes and setbacks.

- **Keeping up with evolving computer technology.** Noting that computing technology is constantly improving, participants debated the value of preserving old approaches, particularly the use of legacy code. One private sector participant encouraged the group not to worry so much about the continued use of legacy code, arguing that many people have developed ways to plug legacy codes into larger systems. A modeler from EPA Region 3 agreed with this approach, observing that legacy code often corresponds to "legacy scientists" whose old habits can be difficult to change. Rather than force older modelers to change their ways, the community can move forward "gently" by encouraging the next generation of modelers to use more up-to-date coding practices. Two other participants suggested that the community remain forward-looking by staying abreast of new approaches such as cloud computing. They suggested having a subgroup within the community that focuses on preparing for the future. Dr. Moore provided some additional insights from the OpenMI project, explaining that the first generation of OpenMI was "clunky," but soon evolved into a smoother program. Accordingly, members of the integrated modeling CoP should not be afraid to take a step backward if it will lead to more steps forward in the future.

- **One community of practice, or many?** A participant from EPA wondered whether it might be useful to organize multiple communities at different scales, although he noted that organizing multiple communities could be difficult. Another EPA participant agreed that organizing multiple communities would pose a challenge, and suggested instead that the overall CoP focus on providing overarching recommendations that will help a broad range of users.

DECEMBER 11, 2008

SUCCESSFUL KNOWLEDGE MANAGEMENT PRACTICES

Doretta Gordon, Southwest Research Institute

Dr. Gordon described the Sharable Content Object Reference Model (SCORM), an emerging framework for storing and accessing knowledge that can be used for training. Training methods have evolved over time. In the past, employees learned new skills by taking “monolithic” training courses that required them to leave the workplace, thus costing the employer not only course fees but also lost production time. More recently, training has begun to evolve toward a more pragmatic, “just-in-time” approach.

The SCORM framework was designed to make better use of technology to organize and implement training programs. Six main objectives, dubbed “ilities,” guided the structure of SCORM during its inception:

- **Interoperability:** to share components across platforms
- **Accessibility:** to find and disseminate information easily
- **Reusability:** to use components in multiple and varied contexts
- **Durability:** to withstand technological evolution
- **Maintainability:** to withstand content evolution
- **Adaptability:** to meet the diverse needs of end users or consumers

SCORM starts with a repository of parcels of information, which vary in size, medium, and content. Components come in three levels of granularity: assets (singular files, such as text, video, or other media), sharable content objects (reusable packages of information with a particular intent or organized focus), and content aggregations (entire lessons, topics, or packages). Each object in the repository is catalogued in a registry, which must provide a useful and accurate description of each object. Thus, the completeness of metadata is critical for accessibility and reusability.

To date, one of the largest users of SCORM has been the U.S. military, where the development of object-oriented coursework has helped reduce redundancy among similar training programs. For example, several branches of the military operate the F-15 fighter jet. Rather than create largely duplicative training programs for F-15 pilots, each branch can draw from the same repository of common training objects (e.g., facts and standard procedures), then add customized scenarios as needed.

In the early days of SCORM, most objects were static (e.g. text, images), but more recently Dr. Gordon has seen a growth in multimedia objects (e.g. animations, simulations, videos, etc.). One workshop participant expressed concern that users cannot search multimedia files as easily as text, to which Dr. Gordon replied that searches operate only within the metadata—hence illustrating the need for descriptive metadata. Learning Object Metadata (LOM) is now the standard to follow.

Dr. Gordon then described the process of collecting objects to populate a repository using the Southwest Research Institute’s Expert Knowledge Transformation (EKT) Model. With the coming retirement of the Baby Boomer generation, the ability to preserve the knowledge of older workers and train younger personnel is crucial. One way to capture knowledge from an employee with a unique skill set is through an interview. Unlike declarative knowledge, which is best obtained through discussion, procedural knowledge is best obtained by having the interviewer play the role of a novice student, asking the employee to demonstrate what they do while describing how and why various procedures are being performed. After capturing knowledge from an expert, the interviewer should compile the results and check their accuracy with the expert. Next, contributors break this knowledge into objects with as fine granularity as possible. They then code these knowledge objects in the SCORM registry. Once the objects are entered into the repository, users may search for them on demand.

Ultimately, SCORM aims to marry objects to a Web 2.0 environment, where users' needs are identified and fulfilled without having to search. Trainees have already been given some interactive features, such as chat capabilities, wiki articles, and personal notes attached to the interface.

Discussion

One workshop participant asked if SCORM and EKT could be used to capture model designers' assumptions, thereby making this information accessible to users without having to personally contact the people who developed the model. Dr. Gordon replied that it would be possible to gather this information by interviewing members of the modeling community. Prompted by another participant's question, Dr. Gordon noted that the people who manage a SCORM repository do not necessarily know who will be using the captured knowledge or when, yet it is still important to capture expertise before it "walks out the door."

One participant wondered whether such a detailed knowledge capture system can be seen as a threat to replace experts with "robots." Dr. Gordon admitted that some observers are concerned that SCORM "dumbs down" topics where experts belong. However, SCORM is not intended to replace experts, she said, nor does it create expertise. The system is simply one tool to help train a workforce.

Another participant pointed out that expert knowledge need not come from a retiring employee, but also from experts who are moving to new assignments and might soon forget details of past projects.

BREAKOUT DISCUSSION SESSION 2: DEFINING THE COMMUNITY OF PRACTICE CONCEPT FOR INTEGRATED MODELING

Session Co-Chairs:
Group 1: Roger Moore, Larry Murdoch
Group 2: Alexey Voinov, Dan Ames

Charge for Breakout Discussion 2

Mr. Laniak gave the charge for the second breakout discussion session, which aimed to engage workshop participants in discussing the value of a CoP for integrated modeling. If participants agree to establish a CoP, they will need to consider the ideal characteristics of this CoP and the implementation issues that might arise. Mr. Laniak asked the breakout groups to consider the questions in the participant guide and develop a list of requirements for implementing the CoP.

Following this orientation, the two breakout groups met separately to hold discussions based on this charge. They then reconvened in a plenary session, where the co-chairs presented the discussions. The text below summarizes the co-chairs' oral reports. It also includes, where relevant, additional related details discussed during the breakout groups, but not reported out.

Group 1

Group 1 elected to use its time to focus on five of the nine suggested questions.

Question 1: Who and what would a CoP include?

Group 1 presented the following list of possible participants in the CoP:

- Anyone
- Scientists
- Decision-makers
- Decision scientists (i.e., people who study the science of decision-making)
- Policymakers
- Stakeholders
- People who use integrated models (i.e., clients)
- Programmers, IT people, developers
- Experts across federal agencies
- Consultants and contractors
- Academics at all career stages, from junior level to emeritus
- Students, because this CoP should be an educational vehicle
- Resource managers
- A group facilitator or leader
- Model users

Within the breakout discussion, many participants echoed the need for a diverse community. Through diversity come opportunities for synergy; for example, a scientist writes some basic code and then a programmer finds ways to improve or streamline this code. One participant suggested looking for people with multimedia science skills, which he described as a broad understanding of how different disciplines and components of the environment link together. Another urged the group to seek diversity in age and experience, noting the importance of training students as well as the value that retirees can add. One participant from EPA suggested that the CoP rely on self-selection, in which case the organizers would explicitly state that the group is open to anyone who thinks he or she has a stake. However, another EPA participant cautioned that until the CoP has a clear vision (e.g., "using integrated modeling to characterize the environment"), it may be difficult for potential members to know whether or not they have a stake.

Question 2: What goals and objectives would/will the CoP work toward?

Group 1 presented the following goals and objectives:

- Characterize the Earth.
- Understand and predict complex environmental processes, especially for emerging issues such as climate change.
- Provide decision support systems and policy.
- Develop model validation and QA techniques, providing a pathway for new models to be accepted and brought into use.
- Train this generation.
- Train the next generation of modelers and multimedia scientists.
- Provide a forum for exchanging ideas and learning from each other.
- Provide standards for model interfaces and model peer review.
- Communicate model capabilities.
- Rate and evaluate models; track usage.
- Embrace a culture of sharing, which can provide a competitive advantage.

During the breakout session, several participants suggested that the CoP should not only support model development, but also help put models into practice by getting them into the hands of decision-makers. Models can help decision-makers choose from a variety of options, which might include developing regulations, implementing voluntary programs, or taking no action at all. A DOE modeler suggested developing models with decision-makers' needs in mind, arguing that the best products are those that arise from real clients with real needs. However, an EPA participant cautioned that it is difficult to anticipate what questions will arise in the future. Accordingly, a participant from abroad recommended that the CoP focus more broadly on understanding complex interconnected processes. Adopting a flexible organizational structure will enable the CoP to address whatever research questions might arise in the future.

Breakout participants generally agreed that the community should play a role in developing standards. For example, one modeler observed that traditional validation techniques do not necessarily work for integrated models, so the CoP should develop alternative approaches to validation and QA. Standards can help ensure that models are of sufficient quality, although one EPA participant pointed out that in practice, quality requirements will depend on how a particular model is to be applied. (For example, a rough screening model might not need to meet the same standards as a refined model for complex decision-making.)

Several participants also discussed the need to foster communication among various groups of stakeholders. To capture information about models and modeling practices, the community will need independent views from modelers and others. One participant suggested that the CoP might serve as a combination "help desk" and forum for information exchange. A participant from DOE suggested looking at the California Water and Environmental Modeling Forum as an example, as this group provides Web resources, training, an annual conference, and some standards development (e.g., peer review standards for models).

Recognizing that many modeling efforts are already underway, an EPA participant suggested building the CoP from the bottom up and incorporating existing efforts from EPA program offices and other sources.

Question 3: What can we learn from communities of practice as applied in other areas?
In their report back to the full group, Dr. Murdoch and Dr. Moore suggested looking to open source communities such as Linux and MapWindow GIS for guidance in the following areas:

- How to provide objective product comparisons—for example, model evaluations or ratings.
- Distributing models. (SourceForge might provide a good approach.)
- Successful management approaches (e.g., a board of directors and working groups).
- Possible funding models. (Would EPA consider supporting integrated modeling the way IBM supports the Linux CoP?)
- Methods of embracing the user community and encouraging them to contribute code.

During the breakout discussion, some participants suggested setting up a registry of available models, along with a translation page for model acronyms. SourceForge serves this type of function, providing users with access to many available models.

Participants noted that other successful open source communities provide a process for sorting out “best-of-breed” tools. For example, Linux users can choose among a variety of systems, such as Red Hat and Debian, essentially voting with their feet. Following the same principles, one private sector participant suggested that the most frequently downloaded models might rise to the top of a list, allowing the developers to take credit for developing a useful product and perhaps facilitating some form of natural selection. Alternatively, the system might allow users to vote directly for the best models. Two participants from EPA warned against putting too much stock in direct voting, however, noting that model rating is subjective. In addition, some models are necessary but obscure, so popularity is not necessarily a good surrogate for quality either. The participants also expressed concern about vested interests who might try to manipulate the rankings. In response, a DOE modeler noted that organizations such as Google have developed methods to prevent users from “gaming” the system. This participant also suggested letting users vote on model usability and interface, rather than utility or applicability.

The group also discussed the need for a business structure to manage the CoP, such as a central board of directors. One participant from DOE noted that open communities tend to have more distributed control; another suggested creating a leadership group that represents the broader community. Participants agreed to look to RedHat (Linux) and other open source communities for ideas on a successful business model. A representative from EPA mentioned the importance of nomenclature, noting that the core group might get more attention from EPA management by using a name with some gravitas, such as “Board of Directors” or “Steering Committee.”

To engage users, one participant suggested following the model of MapWindow GIS—a project community that welcomes anyone who wants to participate. However, simply having an open community does not necessarily mean people will contribute their code. As one private sector participant noted, the

UNIX open source community succeeds in getting users to contribute code because the users are developers themselves. A DOE modeler suggested that rather than relying on free labor, an open source modeling community might achieve more success by giving users the opportunity to identify things they would like to improve, then paying developers to make the changes. Another participant suggested that open-sourcing model frameworks might be more useful (and feasible) than open-sourcing the models themselves.

Question 5: What barriers (e.g., organizational, logistical) exist to creating and maintaining a CoP, and how can they be addressed?

Members of the group identified the following obstacles that the CoP might face:

- Competition for resources.
- Convincing people to adopt new practices and embrace a more collaborative culture.
- Some models have source code licensing restrictions.
- Senior management that does not support modeling.
- Setting goals that are too lofty and trying to tackle too many problems at once.
- Diverging goals, with some community members thinking for the long term and others for the short term.

To overcome these obstacles, the CoP should make sure potential members and their managers recognize the benefits of participation, and should set realistic goals.

During the breakout discussion, the group elaborated on the barrier posed by competition. As one academic noted, people are naturally inclined to compete, and researchers and agencies constantly compete for scarce funding. Another participant observed that moving to a culture where “sharing is power” will require a change in mindsets—namely, convincing people that collaboration can actually increase one’s competitive advantage. Because people tend to be set in their ways, changing practices and overcoming inertia might be challenging, several participants noted.

One participant wondered why models that use the FrAMES framework are not open-sourced. A DOE modeler responded that some scientists used to sell their models, leading to licensing issues still linger as a subtle barrier to open-sourcing.

A participant from abroad urged the community not to be overly ambitious, as a single framework that attempts to cover too much ground could be viewed as meddlesome or unrealistic. A participant from the private sector noted that the California Water and Environmental Modeling Forum began as simply a forum, and did not get involved with setting standards until later. This participant urged the integrated modeling community not to start out promising to set standards, as it might set the initial bar too high and scare away some potential members.

Question 7: What are the short- and long-term practices that we currently think will best move us toward our goals?

Group 1 presented the following list of suggestions:

- Obtain funding.
- Convince funding agencies and decision-makers to support these efforts.
- Promote the idea of a CoP, and identify opportunities to achieve early successes that will help demonstrate the utility of the approach.
- Find out what policymakers really need.
- Find a champion within upper management.
- Set up a Web site where members of the community can meet and exchange information.

First and foremost, participants agreed during the breakout session that more funding will help advance the cause of integrated modeling and perhaps motivate community members to embrace a more collaborative approach. One participant added that once scientists have obtained funding for their efforts, their managers might be more willing to give them the freedom to pursue collaborative modeling efforts.

Members of the group suggested several approaches that might help attract support to the integrated modeling effort. One private sector participant suggested a tiered approach to compiling metadata for models, reaching out and obtaining buy-in along the way. Another participant from Environment Canada noted that in his experience, modelers can get more support if they work closely with decision-makers. He suggested breaking barriers by starting small, demonstrating success along the way, and publicizing these successes. Two other participants recommended that modelers not only show managers what their models can do, but also get these managers to spread the word and demonstrate the results to other key decision-makers, which would build confidence and trust. A participant from academia argued that research proposals can be improved by engaging policymakers first and scoping out the types of problems one might address through model development. An EPA participant disagreed, suggesting that rather than blindly asking policymakers what they need, it might be more effective to develop ideas first, then show policymakers how the ideas are relevant to their work. It also helps to find a high-level champion within one’s organization or agency.

To overcome competitive instincts, one participant from academia suggested that community members need to feel that making a contribution will advance them in some way. For example, the CoP could explore ways to attach prestige to collaboration.

Group 2

Group 2 discussed all the charge questions except Question 8 (How will those [recommended] practices use and/or improve upon existing tools, activities, resources?).

Question 1: Who and what would a CoP include?

Group 2 agreed that the CoP should include a wide range of participants. In general, the community will consist of people who share knowledge, share a mission, or share a common set of problems or research interests. The CoP should have some type of core group, potentially funded, to manage the community. Beyond this core management group, the community should be supported by a broad base of volunteers.

During the breakout discussion, one participant from EPA ORD emphasized the importance of having a core group of people to spearhead the effort. While the overall CoP should be open to anyone who wants to join, managing the organization will require a dedicated inner group.

Participants also attempted to clarify the boundaries of a CoP. Overall, most agreed that a CoP is a collaborative network of persons with related interests and goals. Members may engage in work across varied disciplines, not all of which are made up of modelers or users of models. Community members might work on different activities from different perspectives, but all should share some goals, at least tangentially. A participant from the private sector said that he did not identify as being a modeler, but still identified as part of the CoP. The greatest point of agreement among the participants was to make the CoP as inclusive as possible. The collaborative effort should not make closed-door decisions. Participants also emphatically agreed that the CoP should be volunteer-driven.

Question 2: What goals and objectives would/will the CoP work toward?
Group 2 presented the following list of goals and objectives for the CoP:

- Ensure transparency.
- Try to develop a common vocabulary.
- Reduce fragmentation and redundancy, keeping ideas from Dr. Gordon's presentation in mind.
- Promote the use of standards.
- Develop and maintain a platform and tools, and post these resources on a Web site.
- Provide guidelines for best practices.
- Provide an opportunity to see what others are doing.

In presenting this list, Dr. Ames and Mr. Voinov noted that by sharing their work, modelers can "cross-pollinate" new ideas and allow others to use pieces of code (for example) that have already been developed, rather than having to "reinvent the wheel."

During the breakout discussion, participants agreed that transparency is an important component of the CoP, but disagreed as to whether transparency is a goal or a means to achieve other goals. One participant from EPA suggested that during model development, a certain amount of opacity might be appropriate prior to public availability.

A breakout group participant from the private sector mentioned the need for a common vocabulary among members of the community. Because developing integrated models is the ultimate goal, all members of the CoP must understand each other without ambiguity. Another participant agreed that beginning to define key terms would be a reasonable goal. However, developing vocabulary in the field has no end. With new research and advancement, definitions will change and new terms will be added to the lexicon over time. One of the session co-chairs suggested that a common vocabulary should therefore be an objective, rather than a goal. No participants disagreed. One participant from EPA OSA suggested that the presentation by Dr. Gordon containing a list of six important "ilities" provided a good starting point for developing a catalog of definitions. Subsequent discussion moved away from the definition of individual terms when a participant asked if the CoP goals would focus on products or processes. In general, participants favored usable products that could be disseminated to other users as well as platforms to enable meaningful communication within the community. One participant suggested making a list of goals the CoP would not pursue to avoid going down unproductive paths.

Question 3: What can we learn from communities of practice as applied in other areas?
In their report back to the full group, Dr. Ames and Mr. Voinov listed the following "lessons learned" from successful CoPs:

- Specify a domain of interest and set boundaries.
- Obtain sponsors and hire a paid staff.
- Avoid charging members to participate in the community.
- Share ideas and facilitate communication using the Web, wikis, conferences, mailing lists, and other tools.
- Implement standards, but not in a way that forces uniform technical specifications or forces users to adopt a particular platform or approach. Instead, help users identify the most suitable platforms and approaches.

The Open Source Geospatial Foundation (OSGeo) might be an instructive example. OSGeo serves as an umbrella organization for several subgroups, which agree to share ideas and occasionally join forces.

During the breakout discussion, one participant provided more detail on OSGeo, which supports open source geospatial software by sponsoring an annual conference. The regular communication allowed rival open source software groups to come together to reduce fragmentation and redundancy. In 2008, two groups within OSGeo merged. Through open interaction, the groups realized that they engaged in similar work; by combining efforts the groups believed they could further their goals more effectively.

As they reflected on the work of other successful CoPs, participants had mixed feelings about the use of standards. One participant from outside EPA advised that the integrated modeling CoP should not force extreme standards on its members, arguing that commonality of approach or platform stifles creativity. Standards should be implementation standards; that is, the CoP should standardize an approach, not methods. This was met with some disagreement from another participant from outside EPA. Another suggested that the CoP focus on facilitating communication and standardizing the methods by which colleagues interact (e.g. wikis, mailing lists, conferences). Some participants expressed uncertainty over how the CoP might fund the maintenance or coordination of such proposals.

Question 4: If you could wave a magic wand and change one thing to move the community closer to integrated modeling what would it be? If you could change three things?
The group's "wish list" included:

- Developing well-defined model inputs and outputs.
- Creating a common ontology.
- Providing incentives for participation.
- Encouraging collaboration (e.g., giving greater recognition to scholars and government employees who contribute to collaborative efforts).
- Removing organizational barriers.
- Establishing common priorities.
- Developing high-profile output(s).
- Integrating legacy models.
- Securing funding.

During the breakout discussion, many participants agreed that securing funding would be the best single thing that would help solidify a CoP. Long-term funding could help the community resolve technical problems while also creating incentives to produce more work. One participant suggested looking for funding that targets CoPs directly, thereby creating incentives for people to share and collaborate. A participant from the private sector indicated that a national oceanographic program allocates funding in just that way. One participant warned that distributing the community funds would require the CoP to find problems that all members wish to address. Some participants suggested that the best way to garner financial support would be to publicize the importance of the work being done. Acquiring sponsorship or high-profile reviewers could speed up the development of the CoP through increased visibility.

Question 5: What barriers (e.g. organizational, logistical) exist to creating and maintaining a CoP, and how can they be addressed?
Members of the group identified the following obstacles that the CoP might face:

- Scarce funding, particularly in today's economic climate.
- Cultural barriers, particularly institutions and disciplines that promote competition rather than collaboration.
- "Model phobia"—managers and executives who do not believe in modeling.
- Technical issues.
- Inadequate training.

To overcome these barriers, the group suggested focusing on education and outreach, improved communication, and standards to address technical issues.

Question 6: What types of disciplines should ideally be involved and who within those disciplines would be willing to participate actively in this CoP?

Brief brainstorming by the participants yielded a list of groups that might want to be associated with the CoP:

- Developers
- Users
- Scientists from various domains
- Environmentally concerned citizens

A participant from outside EPA mentioned that some modelers engage in relevant research, but might not wish to join the CoP. Another non-EPA participant suggested providing incentives for peripheral parties to become involved in the CoP.

Question 7: What are the short- and long-term practices that we currently think will best move us toward our goals?
Initial responses showed many participants in favor of publishing information about the CoP and its accomplishments to raise awareness and garner support. Other practices mentioned included:

- Short term:
    - Disseminating the white paper and workshop report (this document)
    - Producing an inclusive publication
    - Creating a communication portal and associated tools
- Longer term:
    - Drafting a charter
    - Creating a leadership team, such as that of the MOU
- Very long term:
    - Performing case studies
    - Encouraging top-down participation from managers and funders
    - Organizing regular conferences for community members

One participant from outside EPA noted that many other CoPs are developing, and this CoP must find a way to define its niche. The community must also figure out how best to communicate with other associated communities. A conference among related CoPs might help organize goals and clarify differences among the various groups.

Question 9: In five years, what benchmarks will be used to gauge the progress of the community?
Participants briefly listed several benchmarks that might be used to assess the CoP's progress:

- Guidance for models (e.g., best practices to follow)
- Establishing one major framework as a standard
- Comparison with goals set in Question 2
- A viable, sustainable organization with associated conferences
- Visibility of the CoP

Discussion

A participant from the private sector added that the nascent CoP should seek out expertise from other groups already engaged in similar tasks. As an example, does EPA need the computing capacity to run global simulators? Other organizations already have this capacity and might be able to provide assistance or computing time. The participant reported that his company has initiated an Environmental Systems Integration Campaign and might be willing to provide resources to the integrated modeling community.

A participant from USDA noted that the MOU has chosen three projects to foster. EPA is welcome to participate in these projects.

A participant from the academic community urged modelers to engage end users (e.g., policymakers) early in the process of developing an integrated model. Policymakers should be viewed not as external consultants, but rather as active participants in the model development process. Through participatory modeling, end users will feel greater ownership of the product and ultimately have greater faith in the results. One participant from EPA ORD disagreed, suggesting that policymakers do not always know what they will need in the future, and scientists might be better able to anticipate future challenges. However, two other participants from EPA felt that conversation with policymakers was essential and that they should be involved from the very first day. A participant from EPA OSA suggested the best method to involve policymakers is not to ask what they need, but to ask what they *do*. By understanding users' responsibilities, modelers will gain a better understanding of what is expected from a model. Another participant from outside EPA encouraged the group to include policymakers in the CoP, as their participation can facilitate conversation that promotes innovation within the community.

One participant from abroad suggested that distinguishing between EPA and the new CoP might prove difficult. Although EPA has a heavy presence at the workshop, much of the actual community is still outside the room and not part of EPA. A participant from EPA ORD mentioned that many decision-makers sit at the state and local levels, not at EPA. The participant also cautioned that the future of modeling will have a large IT and mathematical component to it; as a result, including certain non-technical groups might not be appropriate. Another participant disagreed, however, suggesting that the future community will need to engage people in a variety of fields, including communication experts, decision-makers, management, and high-level architects.

DECEMBER 12, 2008

IMPLEMENTATION OF THE COMMUNITY OF PRACTICE CONCEPT TO MODEL AND FRAMEWORK INTEROPERABILITY

Summary of Key Issues

Gerry Laniak, EPA, ORD

Mr. Laniak opened the final day of the workshop by summarizing the issues addressed during the first two days of the meeting. Initial efforts in developing the CoP will include:

- Development of vision and mission statements
- Acquisition of sponsors
- Establishment of a platform for the CoP
- Definition of the areas of interest for the CoP
- Creation of a managerial structure
- Launch of outreach efforts
- Definition of community-wide terms

The CoP's vision and mission statements will ideally incorporate the following principles:

- Interchange of information and knowledge within the community
- The concept of integrated environmental modeling
- Improving the practice of integrated modeling
- Open collaboration
- A cross-disciplinary approach
- Transparency
- Holistic systems approaches
- Inclusiveness

The CoP will need sponsors to provide funding, facilities, and manpower to advance its agenda. A focus on inclusiveness will encourage support from both public and private sources.

In creating a management hierarchy, the CoP will need to define roles and structure. The CoP must write bylaws, define a procedure for making decisions, create a directorial body, and engage in active outreach and recruitment. Above all, the efforts of the directorial body should be entirely transparent.

The CoP will focus on three key areas of interest and research: the science of model integration, the development of science components, and computer science/IT. Although workshop participants discussed a variety of areas of interest, these three can be considered the most important. However, defining explicit areas of interest is not critical because areas of interest can continue to grow organically over time.

During the initial stages, the CoP might focus on efforts such as:

- Establishing the CoP structure.
- Creating a Web page, wiki group, and/or Google group to organize initial materials.
- Planning a future conference or workshop, perhaps in conjunction with other annual conferences.
- Collecting and documenting integrated modeling case studies to get a better sense of the potential interoperability and science issues.
- Publicizing the outcomes of this workshop (e.g., through the meeting summary report).
- Comparing and assessing various frameworks from both IT and science perspectives.

- Establishing an ontology for describing and classifying environmental models.
- Within EPA, working with program offices and regional offices on setting environmental priorities using holistic approaches.
- Obtaining research grants for integrated environmental modeling to instill these concepts in the next generation of modelers and decision-makers.
- Choosing a name for the community.

Discussion
Facilitator: Gerry Laniak, EPA, ORD

Role of Government Agencies in the CoP
A participant from EPA Region 1 suggested that the community retain its links with EPA and develop ties with OEI, arguing that EPA makes up the core of the community and without EPA sponsorship, the community might not succeed. Conversely, a participant from an academic consortium contended that the strength of the community comes from its overarching inclusiveness—not being dominated by one particular agency or university. A modeler from DOE acknowledged that EPA would have interest in the community, but questioned whether EPA should be the central partner. Other agencies might show just as much interest in the integrated modeling community as EPA. Another participant from the private sector agreed that ties with EPA should be welcome, but that the community should form equal ties with other agencies that show interest. Together, a group of supportive agencies can provide the necessary anchor. A participant from abroad recounted that OpenMI received its initial funds from the research division of the European Commission, and then subsequently from the regulatory division. Although the apolitical nature of the European Commission differs somewhat from EPA, funding from the government should not be ruled out. Another participant from DOE suggested building on the preexisting MOU, perhaps by expanding it to a larger international group of various organizations. Another participant from the private sector agreed. Mr. Rojas, the chair of the MOU steering committee, suggested that the MOU can bring experience to the table. If the community presents a new vision, the MOU can encourage its members to participate.

A participant from DOE mentioned the challenges associated with hosting the community Web page on a .gov site, which might hamper open source efforts due to .gov posting requirements (e.g., all files must be officially approved before posting). Another participant from the private sector argued that the challenges extend beyond the technicalities, and also could affect the perception of the community. Some potential community members, particularly international participants, might shy away from the program if the Web address suggests it is a U.S. government activity. Other participants agreed that the community should avoid using a .gov site. Mr. Rojas noted that the Office of Management and Budget did not allow the MOU to use a .org or .com domain. However, another participant noted that the University of North Carolina at Chapel Hill is allowed to use a .org address for a Web site that distributes the Community Multiscale Air Quality (CMAQ) model, even though the effort receives EPA funding. A participant from the private sector commented that despite the large contingent of government employees at the workshop, many people outside the government (and outside the United States) also have an interest in forming the CoP, which should be reason enough to warrant a .org address. Regardless of the Web hosting arrangement, though, the community needs to make clear that it is open to all interested parties.

Management and Governance

A participant from the private sector suggested that the modeling community examine other CoPs to identify best management practices. Three examples might include OpenMI, the World Wide Web Consortium (W3C), and the Integrated Ocean Observing System. The facilitator, Mr. Laniak, proposed making a timeline for the creation of the management structure. Participants generally agreed with the idea of forming a basic managerial structure within a year of the workshop. They also agreed that a coordinating committee should be solidified before the end of the workshop. One participant volunteered to create a Google group during a break in the workshop. This group will facilitate work on the community's goals, mission, and charter/bylaws.

A participant from abroad asked if the new community intended to be a separate legal entity. Should the organization have its own bank account, or will it merely be a loose gathering of interested people? Eventually, it will probably need a bank account if it has a paid staff or runs organized events. Many participants discussed options for financing the community and the complications of accessing and distributing government funds. No clear agreement was reached on how to fund the CoP, but several suggestions were offered. For example, some organizations collect dues from multiple partner agencies.

Several participants suggested deciding which partners, if any, the community should seek. One participant from the private sector offered the support of the International Environmental Modelling and Software Society (iEMSs) to establish an intermediate home for the new community's resources. One participant suggested partnering with EPA; another participant suggested the possibility of becoming an independently chartered work group under the MOU umbrella, which would still allow room for members from outside the nine MOU agencies.

Outreach

Dr. Moore addressed the group regarding outreach, noting that modelers face a considerable challenge in swaying decision-makers to believe in integrated modeling. The community must address real questions that demonstrate the utility of modeling, such as the impacts of climate change on local systems. Accordingly, the community must build a constituency within EPA—the agency that makes many environmental decisions. Community members must begin addressing these types of challenges so the community can "learn by doing." The resultant effort will yield a set of linked models and better experience in effecting interoperability.

One participant suggested creating crisp multimedia presentations, such as videos, to demonstrate the value of integrated modeling in a decision-making context. Another participant from the private sector added that decision-makers appreciate demonstrations with real results, not just raw data. Above all, demonstrations should pertain to the topics of interest to decision-makers. Several other participants from both inside and outside EPA agreed that case studies would be an effective way to promote integrated modeling. For example, the Chesapeake Bay Program shows integrated modeling in action, while several

OpenMI projects (e.g., model of dredging in the Scheldt estuary) demonstrate the value of applying standards for interoperability. One participant suggested finding a case study or scenario where a region suffered unintended consequences that integrated modeling could have prevented. Another suggested showing program managers how they can save money in the future by investing in integrated model development now.

Participants also agreed that the CoP needs to “spread the word” by more than just word of mouth. Mr. Laniak suggested that the community aim to have its Web site be the first result for a Google search of “integrated modeling.” Several participants noted that in order to be ranked highly on Google, the CoP’s Web site must have many other sites linking to it.

Several workshop participants suggested reaching out to contractors and consultants to increase membership, boost visibility, and perhaps assist in funding the CoP. One participant from the private sector noted parallels in the way OGC partners with consultants in the geographic systems community. Logos that can be displayed on partners’ Web sites are an easy way to increase the visibility of the community; contractors also benefit from advertising their membership. Two participants also suggested public acknowledgement of contributions in kind to the community, such as donated time from business partners or other entities. One participant from the private sector said that contractors are eager to look for ways to find mutually beneficial ventures, including within the integrated modeling community. However, another private sector participant explained that some consultants are not-for-profit, and therefore less able to help fund efforts such as the CoP. A participant from abroad suggested that the benefits for joining the community should be written out clearly in a Frequently Asked Questions (FAQs) list on the CoP Web site. Preemptively answering the questions consultants might have will make it easier to attract them to participate in the CoP.

Science Topics

To provide additional background for the discussion, Dr. Moore gave a brief presentation on scientific issues currently being addressed by the Open MI Association, which include:

- Verification, calibration, validation, and optimization of data.
- Scale, uncertainty, and mass balance within models.
- Harmonizing the methodologies used by different modeling communities. For example, sewer modelers use design storms while river modelers use risk-based events (e.g., 100-year storms).
- Access to high performance computing.
- Linking models across different computer platforms.

In Europe, the OpenMI “LIFE” program is addressing some of these problems through research grants to Ph.D. candidates. In addition to university support, every Ph.D. candidate in Europe also has “industrial” support from a government agency, nongovernmental organization, or consulting group. The new integrated modeling CoP might find a similar approach useful.

A participant from academia remarked that getting support from universities in the United States should be relatively straightforward as it is largely a function of funding. Thus, the community can help by steering funding sources (e.g., EPA Star grants) to support integrated modeling. USDA and state agencies also fund grant opportunities.

Review and Comparison of Frameworks

A participant from USDA described an initiative at Colorado State University to assess the implementation of different frameworks and the ramifications for model developers. The effort attempted to develop a quantitative way to compare frameworks by analyzing various parameters (e.g., size and complexity of code). One participant from the private sector asked if IT-oriented groups, such as OEI, evaluated frameworks. However, another participant commented that legacy models and legacy frameworks will not disappear just because they do not fare well in an evaluation. As a participant from DOE pointed out, many framework builders, like model builders, are biased toward their own frameworks. Thus, the community might be better off creating a "meta-framework" that enables models from different frameworks to interact. Such an approach would avoid contention over which framework to use. Framework interoperability is also a key focus of work in the IT community.

A participant from abroad observed that modelers use a variety of approaches to carry out their work—for example, time-oriented models, gridded models, vector models, and economic models. Thus, frameworks have evolved out of different needs. Rather than assess frameworks, the CoP might be better served by simply developing a better understanding of the various framework capabilities. Conversely, a participant from DOE and a participant from EPA maintained that some measurement could still be valuable, noting that a quantitative basis for model comparison supports the community's objective of transparency.

Name for the CoP

Mr. Laniak fielded suggestions from workshop participants for the name of the new CoP. Participants suggested several names and acronyms, but the group did not reach agreement. One participant suggested using a sub-domain of CommunityModeling.org, which is currently owned by iEMSs.

WORKSHOP WRAP-UP AND NEXT STEPS

John Johnston, EPA, ORD

Dr. Johnston delivered a final presentation that summarized the workshop proceedings. Based on the morning's discussion, Dr. Johnston identified the following objectives for implementing the integrated modeling CoP:

- Develop a list of specific tasks to accomplish.
- Establish an identity (i.e., support, membership, vision, mission, platform, etc.).
- Identify the role of the MOU, which could serve as a platform for collaboration. The MOU has been reauthorized for five more years.
- Form a multimedia consortium.
- Facilitate coordination (consider the example of CoLab, for instance).

- Model the CoP after other successful partnerships (e.g., OpenMI, Community Model and Analysis System Center at the University of North Carolina at Chapel Hill).
- Identify ways to secure funding from government, academia, and industry, with a special focus on startup funds. OpenMI was able to secure funding in part due to strong leadership at the top.

To address these objectives, the workshop participants planned to undertake several immediate activities, which are described in Table 1.

Dr. Noha Gaber (EPA OSA) concluded the meeting by thanking attendees for their participation and urging them to continue developing the CoP. She said that the workshop had met its stated objectives, and expressed confidence and optimism in the future of the integrated modeling community.

Table 1. Next Steps for Implementing the CoP
This table was developed onscreen during the discussion.

Step	Objective	Timeframe	Product	Participants/Roles	Special Needs
Organizing committee	Form and establish membership	At workshop	Biweekly open teleconferences	Volunteers from sign-up sheet	Transparency of minutes, decisions, and strategy
CoP Web site	Top-ranked hit for integrated environmental modeling search	3 months	Google search result	Dr. Ames and colleagues	Pizza
Sponsor marketing	List of promising sponsors	6 months	FAQs, list of integrated environmental modeling benefits	EPA, CREM, Raytheon, TetraTech, OpenMI	Acknowledgement of contributors
CoP membership	Membership target	6 months	Google group (online)	All	Bylaws, charter, vision/mission
Vision/mission creation	Documents	3 months	Content for Web pages	Volunteers from sign-up sheet	
Research interests for integrated environmental modeling	Core technical group formed	3–6 months	Grant descriptions, statement of needs	Laniak, Goodall, Ames	
Collect success/failure stories	Communicate integrated environmental modeling examples	1 year	Content for Web pages, demos	Chesapeake Bay Program, OpenMI	Value of integrated environmental modeling, unintended consequences
Compare and contrast frameworks	Cross-framework knowledge	1 year	Articles, framework guidelines, compilation	Laniak, Castleton, Barrett, Redder, Wolfe, Goodall, David, Brandmeyer	Supported by Ph.D. student projects
Partnership with offices/regions, clients	Priority science policy challenges requiring integrated environmental modeling	1 year	Consensus document	EPA Region 3, USDA, EU/OpenMI	
Next meeting	Gather momentum, increase membership	6 months (?)	Ft. Collins, CO (?)	USDA (?)	

U.S. Environmental Protection Agency
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Integrated Modeling Workshop 2008

December 10-12, 2008 • JW Marriott Desert Ridge • Phoenix, AZ

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