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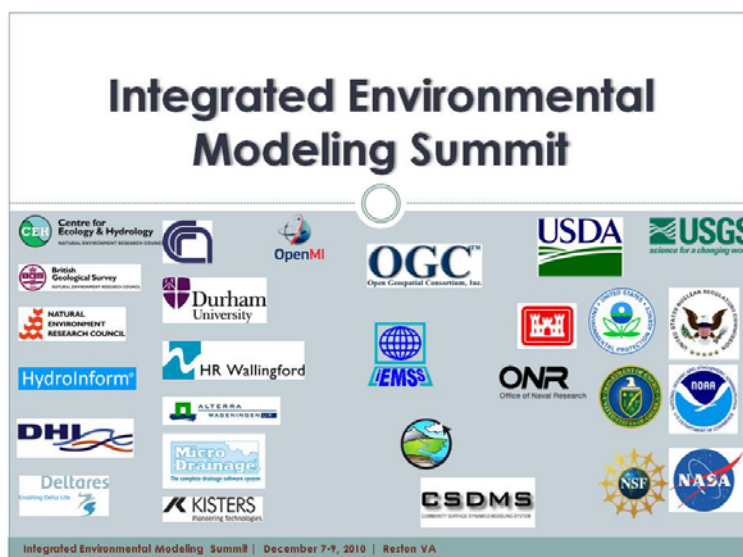
International Summit on Integrated Environmental Modeling
December 7-9, 2010
USGS Headquarters, Reston, VA

Office of Research and Development
Ecosystems Research Division, Athens Georgia

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Workshop Report

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Executive Summary

This report describes the International Summit on Integrated Environmental Modeling (IEM), held in Washington, DC on 7th-9th December 2010. The meeting brought together 57 scientists and managers from leading US and European government and non-governmental organizations, universities and companies together with international organizations. The Summit built on previous meetings which have been convened over a number of years, including: the US Environmental Protection Agency (US EPA) workshop on Collaborative Approaches to Integrated Modeling: Better Integration for Better Decision-Making (December, 2008); the AGU Fall Meeting, San Francisco (December 2009); and the International Congress on Environmental Modeling and Software (July 2010). From these meetings there is now recognition that many separate communities are involved in developing IEM. The aim of the Summit was to bring together two key groupings, the US and Europe, with the intention of creating a community open to all.

The workshop reviewed the current state-of-the-art and concluded that there are a large number of activities and means to provide the technology for integrated modeling: US EPA's FRAMES, EU-funded OpenMI, Common Component Architecture (CCA) for CSDMS and Object Modeling System (OMS) by the US Department of Agriculture.

Summit participants discussed what is needed to advance the science, technology and application of integrated environmental modeling worldwide. The vision statement developed and higher-level goals for each of these topics are summarized in Table 1 below. The common themes that emerged from discussions included the following needs: to provide accessible linkable components, to address uncertainty in linked model systems, to professionalize the development of integrated models, to engage properly with stakeholders and develop a Community of Practice to aid the development and uptake of IEM.

Many fruitful opportunities for collaboration leading to projects were identified. The need for a "showcase" project to demonstrated beyond doubt the utility of IEM in solving problems for decision-makers was recognized. There was also the realization that a number of short-term projects, so-called "low-hanging fruit," are required. These would aid promotion of IEM by practitioners and include gathering examples where IEM has helped to make better decisions. To encourage collaboration, 16 longer-term collaborative projects were identified, including developing a Community of Practice for IEM (CIEM). Given the positive energy and atmosphere of the meeting, it was agreed to produce a roadmap setting out how to achieve the IEM vision.

Table 1 Visions and goals for an IEM Roadmap

Topic	Vision	Goals
Science	Science supporting IEM and its application will continue evolving to inform policy decisions and communicate environmental problems and solutions to society. IEM will use state-of-the-art predictive capabilities for multi-scale, multiple interacting processes that represent environmental responses to perturbations in natural or engineered settings. Uncertainty analysis will be used to evaluate the limitations of IEM critically.	a. Establishing a scientifically sound methodology for approaching problems which require integrated modeling to find a solution b. Establishing scientifically respected, controlled vocabularies, ontologies and catalogues of processes, process variables, models and exchange items to reduce the opportunity for error and automate construction of the model chain c. Understanding and developing the means to handle the scientific issues that arise when models based on different scales are linked d. Understanding and developing the means to handle the scientific issues that arise when models which run at different temporal or spatial resolutions are linked e. Understanding and developing the means to reduce the instabilities that arise when models are linked f. Developing methods for assessing, quantifying and displaying the uncertainties arising from the use of integrated modeling g. Developing an approach to model development and a mindset among developers that assumes at a point in a model's life cycle, it will need to be linked to other models
Technology	IEM technology will make it easier to find, use, develop, integrate, understand, and future-proof models and data.	a. Raising the level of interoperability and portability of modeling components b. Automating IM processes that are irrelevant to the IM user c. Improving the accessibility of tools by lowering the barriers to entry d. Creating a web service market supported by e-infrastructure e. Creating the ability to assess uncertainty and pass it down the model chain to deliver the science work listed above f. Establishing an IEM culture based upon best practices
Application	IEM will support robust and defensible decision-making that provides for a range of users and that produces results in an appropriate form, using readily available data and models.	a. Providing modeling platforms that make data, models and tools readily available b. Establishing show-case projects that demonstrate the added value of integrated modeling c. Describing uncertainty associated with results d. Developing systems to manage and maintain an audit trail of integrated model runs e. Engaging stakeholders

Organization/Community	IEM community will be open (sharing), efficient, transparent and collaborative to advance science and technologies for making effective environmental decisions, for issues requiring trans-disciplinary approach, and for societal benefits.	a. Establish an inclusive IEM Community of Practice (CoP) that: (1) Recognizes realistic goals; (2) Exists as the communication platform; (3) Attracts funding; and (4) Operates under clearly defined contributions from each member/ member organization b. Create an e-infrastructure that: (1) Provides a single catalogue of components (models, data, tools); (2) Supports access to HPC & cloud computing; (3) Broadcasts funding opportunities for IEM; and (4) Provides links to IEM practitioners and experts c. Create a comprehensive IEM Education Plan encompassing technical workforce, users and the public. d. Reach common, agreed-upon standards of model linking and data sharing. e. Assure that funding for CoP operations and projects in IEM is readily available and coordinated across organizations

1 Introduction

1.1 Background

It has become clear that there are "islands of excellence" emerging all around the world related to integrated environmental modeling (IEM). For example, in Europe, the OpenMI Association is championing the use of the OpenMI standard for linking models at run-time. In the US, FRAMES is being developed by the US Environmental Protection Agency (US EPA), Common Component Architecture (CCA) by the Community Surface Dynamics Modeling System (CSDMS), and Object Modeling System (OMS) by the US Department for Agriculture (USDA). The complete list is too long to enumerate here; however, the shared objective of all these initiatives is to enable us to better understand and predict the wider implications of environmental events and their management. In practical terms, it is about modeling how processes will interact. Such an ability is essential to understanding and encapsulating how the earth system works, and to finding sustainable solutions to the many challenges, large and small, facing the world. If IEM can be made into a practical tool, a vast array of products and services should result.

While the potential of integrated modeling has been apparent for some time, we have lacked the technology, standards, and organization to realize that potential. As Voinov et al. (2010) pointed out, "there are significant scientific and technical challenges associated with constructing complex Earth systems models. Overcoming these difficulties will require a collaborative modeling approach based on the fundamental principles of open scientific research, including the sharing of ideas, data, and software." Furthermore, it is recognized that the work of transforming integrated modeling from its present state, essentially a research tool, to something that, ultimately, anyone can use will require international efforts. The challenges are considerable and so are the resources required. Formal and informal meetings have been occurring for some time with the goals of promoting IEM and accelerating its development:

- In December 2008, the US EPA organized a workshop on "***Collaborative Approaches to Integrated Modeling: Better Integration for Better Decision-Making***", to establish and initiate a community of practice for integrated modeling science and technology. As a result of this workshop and further discussions with several science-based communities who conduct integrated environmental modeling, the unanimous conclusion that a web-facilitated community of practice would be of great value to environmental modelers was reached. The US EPA then worked with US and international collaborators to initiate the Community of Practice for Integrated Environmental Modeling (CIEM).

- At the AGU 2009 Fall meeting, the OpenMI Association suggested that IEM had reached a stage for its potential to be demonstrated. A roadmap was therefore required to demonstrate to potential users, developers and funding agencies that the potential was achievable and would repay any investment required. The investment would not only show returns in better and more sustainable decisions and fewer unanticipated outcomes, but it could ultimately lead to a new wealth-generating industry.

- At the International Congress on Environmental Modeling and Software in July 2010, the US EPA launched the Community of Practice for Integrated Environmental Modeling, as well as its online portal, the iemHUB. A workshop on the "Future of Science and Technology of Integrated Modeling" was also organized to provide participants opportunities to discuss advancing the science and technology of integrated modeling for environmental assessment and decision-making. The workshop also sought to identify software and computational technology trends and how these might impact the development of integrated modeling. It was expected that these discussions would inform a technology roadmap for IEM.

Initially, the meeting was conceived as a workshop for a small, self-selected group of US and EU integrated modelers (see Appendix 1). Funding was obtained from the UK Foreign and Commonwealth Office's Science and Innovation Network, which supports transatlantic cooperation. However, the meeting rapidly became a much bigger event to be attended by senior representatives of major government agencies, commercial companies and universities and, consequently, attracted additional funding in cash and in-kind from the British Geological Survey (BGS), the US Geological Survey (USGS), the US EPA, the OpenMI Association, the Community of Practice on Integrated Environmental Modeling (CIEM) and the Interagency Steering Committee on Multimedia Environmental Modeling (ISCMEM). The result was a meeting of astonishing energy, with outputs far exceeding expectations of conveners.

As a result of the workshop, this report is one of five documents to be produced to aid promotion of IEM and help secure funding (for more information see https:\\iemhub.org/resources/366/supportingdocs[1]):

1. A factual report on the workshop (this document).

2. A paper for a special edition of the Environmental Modelling and Software journal that summarizes thinking behind the steps required to achieve the IEM vision.

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[1] Note whilst iemHUB is open to all, potential users need to register and obtain a username and password to gain access to the documents and other resources held there.

3. A roadmap detailing steps required to achieve this vision.

4. A Nature paper on IEM principles.

5. Supporting material to communicate the vision and roadmap to a range of stakeholders.

The workshop report itself summarizes both the workshop and its outcomes. It describes what was undertaken which includes: establishing a vision, identifying goals and projects, and summarizing a path forward. More detailed descriptions of workshop outputs are provided as links to the iemHUB. Whilst it was supported by both European and US organizations, for consistency with outputs from the workshop, American English is preferred throughout this report unless a direct quote, organizational name or reference is used.

1.2 What is Integrated Environmental Modeling (IEM)?

At its most basic level, integrated modeling (IM) is about linking computer models that simulate different processes to help understand and predict how those processes will interact in particular situations. Integrated environmental modeling (IEM) applies integrated modeling to the analysis of environmental problems. Its main application lies in impact analysis -- especially looking at the wider consequences of events and policies. Another application, for example, is optimizing the conjunctive use of different resources. IEM is not limited to analyzing interactions between natural processes; it frequently involves predicting how various events or policies to manage the natural world could impact society or the economy.

Importantly, IM focuses on linking models, databases, and institutional structures to support decision making; it is not focused on the models themselves or on the science that individual models represent.

IM and IEM issues include: the design of the integrated analytical framework; modeling component connectivity mechanisms and standards, i.e., improving interoperability; wide accessibility of integrated modeling by improving ease of use and reliability; enhancements to make IEM an acceptable tool for regulators by automatically creating audit trails and ensuring repeatability; reduction of unanticipated outcomes through links between IEM and artificial intelligence; integrated model evaluation; passing uncertainty down the model chain; developing decision-support interfaces; information architecture; web-based access; community building; and education and research.

1.3 Workshop outline

The workshop was held over three days at the USGS HQ at Reston, VA and its agenda can be found in Appendix 2. Matt Larsen, Associate Director - Climate and Land Use Change, USGS gave the opening address. Day One focused on developing a common understanding of the background   and drivers for IEM, the state-of-the-art and current practice, formulating a consensus vision for the future of integrated environmental modeling, and articulating the major challenges to achieving that vision. The challenges were grouped into four topic areas: science, technology, applications and organizational/social issues.

Day Two allowed participants to build on discussions of Day One and articulate a path forward for addressing each set of challenges. The path forward included a vision with associated goals and activities for each challenge category. Recognizing overlap between these categories, break-out discussions gave all Summit participants the opportunity to provide input into all four aspects of the IEM Roadmap.   The participants were divided into groups that sequentially visited each break-out room for 90 minutes, where they focused on one aspect of the Roadmap.   Co-facilitators of each topic remained in the room to summarize what was discussed by each visiting group and capture their new ideas or thoughts. The goal was to build a Roadmap including input of all summit participants.

On Day Three, the co-facilitators for each Day Two topic reported in a series of presentations on the vision, goals and activities related to the science, technology, application and organization/social aspects of IEM.

Participants then identified collaborative projects on which they could and would work together. A short discussion on the need for and form of a governance structure and funding mechanisms followed, concluding that a facilitating group would be necessary and that it would require funding. The workshop was closed by Denis Peach, Chief Scientist of the BGS. He thanked the participants for the remarkable energy and commitment they brought to the meeting and he assigned the task of drawing together the meeting's results to the conveners.

2 Day One – Laying the groundwork for roadmap development

2.1 Drivers for IEM

Pierre Glynn (USGS) gave a presentation on the science and policy drivers for IEM, its applications, and the developments needed for it to become a useful and useable tool. The presentation is available on iemHUB at https://iemhub.org/resources/293.

2.1.1 Why do we need IEM?

The immediate drivers behind IEM are the environmental problems that face policymakers and which have been eloquently set out by the Belmont Forum. They require a greatly increased understanding of Earth processes and of the Earth as a system and, hence, lead to the science need for IEM. This, in turn, has led to the hunt for better ways of linking existing process models to study, understand and predict their interactions.

The purpose of IEM is to aid in finding and testing potential solutions to complex environmental problems. Typically, solving these problems requires a wide range people and organizations who can contribute knowledge and or resources with those who are or may be affected by the problem or the solution. IEM can help when the knowledge is or can be encapsulated in the form of models; it allows models of different processes to be linked and, hence, a greater understanding achieved of how the processes will collectively respond to possible solutions. If the models are connected to analytical and visualization tools, the decision-makers can weigh the pros and cons and select the most acceptable option. IEM is often required for "system of systems" analyses that are undertaken across a range of spatial and temporal scales and across multiple domains. Many organizations throughout the world deal with such problems.

Table 2 provides examples of "system studies" undertaken by the USGS (and other agencies) that could greatly benefit from IEM, especially if further development allowed its wide adoption across not only the science community, but also resource and environmental management and policy communities.

Table 2 Examples of USGS applications for IEM

Location	Issues
Chesapeake Bay	Land-use, water quality and climate change
Upper Klamath Basin (OR)	Water allocation and fish stocks
Everglades and south Florida	Ecosystem services & biodiversity, invasives, sea level rise, storm surges and human development
Southern California	Multi-hazards: earthquakes, fire, mudslides & floods
San Francisco Bay – Delta	Water, invasives and climate change
Mid-western states	Agriculture and bio-energy: benefits and impacts
US land mass	Energy and mineral extraction: benefits and environmental costs

2.1.2 How will IEM be most useful?

To become a useful and practical tool for scientists, policy-makers and managers, IEM needs to be driven toward the following areas:

- Standards for linkage – so that independently developed modelling components can be easily linked

- Standards for semantics – so we can ensure linkages are valid

- Standards for model descriptions – so we can find models and later automate the linkage process

- Ease of use:

    o hide, eliminate or automate all model integration steps that are irrelevant to the problem-solver

    o develop checks for invalid linkages

    o develop tools for handling scale issues in space and time

- Critical mass of linkable components - wide variety of linkable modeling components needs to be established and made available and accessible, including creation of 'model marts'

- Adapters - for the foreseeable future there will be a number of linking standards; therefore, 'adapters' must be available so models following different interface standards can be linked

- Examples of successful applications of IEM - a wide range are required for newcomers to follow and to build confidence among users and funding agencies.

- Transparency – it must be easy to see and understand what happens at every stage in a model chain

- Auditing – the process of creating and storing an audit trail of the data, modeling components and results should be automated so it is possible to recreate model runs whose results have been used to make critical decisions

- Uncertainty – techniques are required for assessing uncertainty in data and model results and for passing uncertainty down the model chain.

- Systems for testing compliancy with standards

- Model size independence – it should be possible to integrate models of all types and sizes, i.e., it should support the linkage of small and/or simple models and large and/ or complex models

- Model platform independence – it should be possible to integrate models running on different computing platforms

- Model data volume/data exchange rate independence – it should be possible to link models where the volumes of data and or the required speed of exchange are either very high or low.

- Support and training – academia and industry need to be engaged in providing support and training for IEM practitioners

- Research – research programs need to be established to find solutions to unsolved model integration problems.

- and many others.

2.2 The State-of-the-art

The State-of-the-Art discussion was introduced by Alexey Voinov (University of Twente) and can be found on the iemHUB at https://iemhub.org/resources/265. As there is no agreed set of terms for describing integrated modeling, and the audience was multinational and drawn from many disciplines, he began by establishing a terminology. In particular, he drew upon the definition provided by US EPA (2008) of 'integrated modeling' (IM) as a systems analysis approach to environmental assessment that employs a set of interdependent components (numerical and conceptual models, scientific and other data and assessment methods) brought together to create a modeling system capable of simulating environmental systems. He differentiated 'integrated modeling' (the assembly of a variety of components into an entire model for a given purpose [e.g., understanding the impact of climate change on flood frequency]), from 'model integration' which is concerned with mechanics and standards necessary to enable one modeling component to pass data or information to another.

In the environmental sector, the driver of integrated modeling is the need to understand Earth's system so fair and sustainable solutions can be found to societal challenges. Examples are food

and water security, energy, and environmental change. In the area of environmental change, integrated modeling has already been used to create climate models (which are themselves an assembly of individual process models) and to link climate models to ocean models. More recently, IEM has been used to couple climate and land surface models. Integrated modeling is not confined to solving big or long-term issues, however; it is equally applicable to everyday tasks or shorter term problems such as optimizing the operation of sewer networks and water treatment, where IEM has already shown benefits. An unexpected benefit of IM is that it could lead to modeling studies becoming significantly cheaper. In fact, some model developers believe that the first practical use of IM will be to improve efficiency in model development and application communities which often conduct their work on behalf of public authorities (and at taxpayer expense).

Challenges for IEM include developing better methods to anticipate the impact of events and better management responses to those events so that well-intended policies do not create worse situations than they set out to resolve. Such negative effects can emerge in geographical, environmental, social or economic areas or fields that are very different from those of the original problem. For example, few people predicted that the switch to biofuels might lead to widespread starvation. Presently, models, which can take many forms, are the only way to capture our knowledge of processes, enabling us to predict how they might lead to different outcomes under different circumstances. There is a growing realization, however, that it is neither practical nor useful to construct a single model encapsulating all the processes needed for decision-making and planning (Argent, 2006; US EPA, 2008). Not only are such large models extremely wasteful of resources, they are rarely reusable and frequently fail to make use of existing process models. These are often referred to as 'legacy models' -- the result of a huge, historic investment representing state-of-the-art modeling. Consequently, there are currently attempts to convert existing models into building blocks from which more complex models can be assembled (Warner et al., 2008; Barthel, et al., 2008; Argent et al., 2009). In today's IT terminology, these are referred to as 'components'; components that can be linked are 'linkable components'. The term 'modeling component' now has a wider meaning that is not limited to models: it includes files, databases, analytical tools and visualization tools and, indeed, any component required to make up a modeling system.

Examples of attempts to streamline model integration are:

- The US EPA, in conjunction with the US Nuclear Regulatory Commission, US Army Corps of Engineers, and US Department of Energy's Pacific Northwest National Laboratory, has been developing the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES-1) (2009) system to manage execution and data flow among multiple science

modules. It uses a fixed file format system to exchange data between components. The Multimedia, Multi-pathway, Multi-receptor Risk Analysis system (FRAMES-3MRA) (2009) (Babendreier and Castleton, 2005) is an extension of FRAMES-1 and is based on an API and dictionary system to exchange data. 3MRA is a collection of 17 modules that describe the release, fate and transport, exposure, and risk (human and ecological) associated with contaminants deposited in various land-based waste management units (e.g., landfills, waste piles). The 17 models in 3MRA cannot be easily replaced. FRAMES-2 (Whelan et al., 2010) represents the best attributes of FRAMES-1 and FRAMES-3MRA and is designed to allow for easier registration and replacement of models and support components.

- The Open Modeling Interface and Environment (OpenMI, 2009) developed by a consortium of European private companies, research establishments and universities co-funded by the European Commission is a standard for model linkage in the water domain (Moore, et al., 2005). The OpenMI standard version 1.4 defined an interface that allows time-dependent models to exchange data at runtime; hence, OpenMI-compliant models can be run in parallel and share information at each time-step. It is, therefore, particularly appropriate for situations where it is necessary to simulate interacting processes, such as changes in flow which increases nutrients which affect plant growth in a river which, in turn, affects flow. It can handle feedback loops and iteration. It can link models based on different modeling concepts. The OpenMI is generic and can link models from different domains (hydraulics, hydrology, ecology, water quality, economics etc.), environments (atmospheric, freshwater, marine, terrestrial, urban, rural, etc.), scales and resolutions (spatial or temporal), platforms, or suppliers. It is not limited to linking models, but can also link any modeling components. The OpenMI version 2.0 paves the way for linking models that run in a super-computing environment and models provided as web services. It can exchange a wider range of data types and simplifies the exchange process when models have no spatial and or temporal dimensions, such as a terrain model. While version 1.4 only provided a 'get values' data option, version 2.0 also provides a 'set values' option to facilitate model optimization.

- The Common Component Architecture (CCA) is a product developed by the Department of Energy and Lawrence Livermore National Lab teams (Bernholdt et al., 2004) which targets high performance computers and complex models. The CCA supports parallel and distributed computing, as well as local high-performance connections between components, in a language-independent manner. The design places minimal requirements on components and facilitates integration of existing legacy code into the CCA environment by means of the Babel (2004) language interoperability tool, which currently supports C, C++, Fortran 77, Fortran 90/95, and Python. The CCA is being applied in a variety of

disciplines, including combustion research, global climate simulation, and computational chemistry; it has also been adopted as the backbone in the Community Surface Dynamic Modeling System (CSDMS, csdms.colorado.edu).

- The Object Modeling System (OMS) was developed by the US Department of Agriculture (David et al., 2002; Kralisch et al., 2004; Ahuja et al., 2005). In contrast to FRAMES and some other systems, OMS requires modules to be rewritten in Java prior to insertion into the system library. Instead of just linking pre-existing blocks or components, OMS provides the tools and integrated framework to develop the components of an IEM in a coherent way.

Despite the evident need for IEM, it has yet to "take off" in the way its proponents hoped. The reasons include: (1) lack of a convincing set of demonstrated added value provided by IEM; (2) lack of a critical mass of available and accessible linkable modeling components; and (3) difficulty of use and other barriers to entry, such as making existing models linkable. However, communities of practice are slowly emerging as a part of a number of IEM initiatives, which are attempting to address the challenges of IEM. Currently, the initiatives and their communities are relatively isolated because there is no umbrella organization to bring them together. Examples of these communities and initiatives include:

- OpenMI Association which makes the OpenMI standard freely available (www.openmi.org);

- CSDMS - Community Surface Dynamic Modeling System which "makes earth surface process models available, has computational resources for model simulations, and couples models that bridge critical process domains" (csdms.colorado.edu);

- CCMP - Chesapeake Community Modeling Program, dedicated to advancing the cause of accessible, open-source environmental models of the Chesapeake Bay in support of research & management efforts (ches.communitymodeling.org);

- ESMF – the Earth System Modeling Framework: software for building and coupling weather, climate, and related models (www.earthsystemmodeling.org)

- CHyMP – the Community Hydrologic Modeling Platform (www.cuahsi.org/chymp.html),

and other platforms.

There are also communities designed to support individual models and software packages, such as:

- GRASS - free Geographic Information System (GIS) software used for geospatial data management and analysis, image processing, graphics/maps production, spatial modeling, and visualization (grass.fbk.eu);

- MapWindow - another GIS project that includes a free desktop geographic information system (GIS) application with an extensible plugin architecture (www.mapwindow.org);

- ADCIRC - a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions (www.unc.edu/ims/adcirc/);

and many others.

The need for an umbrella organization to synchronize these efforts could encourage adoption of minimum standards to facilitate communication and collaboration, and accelerate innovation and use of IEM is what led to our International Summit.

2.3 A vision for IEM

Roger Moore (OpenMI Association) led the discussion on the future of IEM. His talk is available on the iemHUB at https://iemhub.org/resources/303. The purpose of this session was to define a vision and, hence, a set of objectives for the integrated modeling community. From those objectives, subsequent sessions identified challenges to be overcome and a Roadmap for achieving the vision.

The International Summit was held because people closely involved with integrated modeling saw its huge potential and opportunities for science, industry and the whole of society. It was realized, however, that, few people outside the modeling community were aware of those opportunities and that, of those few, a number were skeptical of whether the opportunities could ever be achieved.

Before looking forward, the session dealt with two related points: the difficult and complex challenges of environmental problem-solving, and why recent advances in IEM encourage us to believe these challenges can be overcome.

The primary concerns about IEM are expressed in many ways, but essentially relate to the idea that presently our abilities to model individual environmental, social and economic processes are often limited. Thus, the probability that we would learn or predict anything useful about the interactions between those processes by linking current models could be extremely low. Further, it is often suggested that any integrated models capable of providing useful results would be so complex we could not create them. So why persist?

The counter-argument was provided with two examples: e development of jet airliners and use of Google Maps on mobile phones. Both ventures would have seemed impossibly complex had they been proposed as part of a full-scope, long-term vision in 1903 or 1970, respectively. Yet, these two accomplishments were achieved as the result of hundreds of thousands of small advances in many domains. Both started in back rooms and universities and were then taken up by governments and industry. Eventually the products emerged that are now being used by everyone. It took time, but it happened. The development and future of IEM can be expected to be similar. We know there are challenges ahead, but we have every confidence they can be overcome. Determination and persistence is all that is required.

Looking toward the future, the main driver for integrated modeling will be the need for environmental sustainability allied to socio-economic impacts. Integrated modeling is the only way of testing/predicting the likely sustainability of a proposed policy. With some important exceptions to date, single process models have been used to test the viability of environmental solutions or policies. To examine the wider implications of a policy or scheme, however, absolutely requires the linkage and integration of a number of individual process models, typically across very different domains of investigation. For example, whereas the feasibility of a new reservoir would only have been looked at for its ability to supply a required amount of water, in the past, now its impact on the environment, society and the economy must also be considered.

In our vision for the future of IEM, standards and platforms will emerge to make it much easier to put models together and increase our understanding of how Earth's system works and, most importantly, how man's activities and the earth system interact. At first, existing models will be linked and many results will be less than perfect; however, relatively simple applications will emerge that provide better results than are presently achievable with individual process models (e.g., optimizing sewer operation during times of flooding). Initial couplings will tend to be between models within a domain, but there is already pressure to make couplings across domain boundaries (e.g., linking medical models to environmental models). This is an area where there are real possibilities for innovation and synergy. It is our hope that open, transparent collaborations and linkages, using the promising tools offered by new media and communication platforms (such as the Web 2.0), can be exploited to enable workers across the world to leverage their efforts and resources, driving innovation and the synergistic application and use of IEM to new heights.

In assessing sustainability, the wider implications of a policy must be anticipated so they can be evaluated. As many unanticipated outcomes have demonstrated, there is considerable room for improvement. Our vision of the future shows the number of unanticipated outcomes being reduced. By storing process descriptions so that potential interactions between processes can be

explored, and by linking process descriptions to models and data sources, it should be possible to spot connections and, thus, consequences that would otherwise be missed. In time it should be possible to semi-automate anticipating and quantifying impacts, beneficial or otherwise. We may not eliminate 'Black Swans' (low probability high-impact events with negative consequences), but we can work to reduce their frequency and their impacts.

At the moment, IEM requires experts for its application, yet an important element of the vision is that IEM be accessible to everyone. The transition is expected to happen in small steps. To create the huge resources required and increase the rate of innovation, it is envisaged that a global community of practice will emerge to facilitate collaboration, cooperation and communication. A small set of standards will evolve so people and models can communicate. To show how benefits of integrated modeling can be made available to all, an example (using a model developed by the NRCS) of how a farmer with a mobile phone could walk into a field and obtain immediate guidance on the agricultural management of his crops to minimize soil erosion was given. He merely had to locate himself using maps on his phone, then run a small application which connected to the integrated data and modeling resources of the USGS and USDA (NRCS).

In our vision, the evolution of integrated modeling follows a similar path to digital mapping, which were initiated by individuals and small academic groups. The first hesitant steps outside were with the support of government agencies which facilitated the transition from research to the operational world. The next stage, which has yet to happen for integrated modeling, is to gain the interest of industry. Although digital mapping sped up map production, facilitated planning processes and, later, provided ways to analyze and exploit the content of paper maps, it has led to an entire new wealth-creating industry and unlocked opportunities never dreamed of by its initiators. We expect integrated modeling to create similar opportunities.

The session's conclusion was that although challenges to our vision are considerable, no one believes they are insurmountable. Armed with experience from previous developments, we can assemble the resources and innovative minds required to overcome them. Sustainability in managing our landscapes and resources is so important that we cannot afford to fail. The wealth-generating opportunities of IEM will help ensure that we succeed.

2.4 Challenges ahead

Having outlined a vision of the potential opportunities IEM could create, this session set out to identify the challenges that must be overcome for the vision to be achieved. Pierre Glynn (USGS) presented an outline of these. His presentation is available on the iemHUB at https://iemhub.org/resources/295.   There are many challenges ahead that could easily

discourage the most ardent supporters of IEM. An historical view of past human endeavors, such as the development of communications or advances in flight technologies, shows that the specifics of today's capabilities or the precise and complete sequence of incremental achievements could hardly have been envisioned during the initial stages of development of these technologies. Nevertheless, progress was made because there was a constant societal need for the developing technologies, that allowed (and funded) ways to overcoming of individual challenges, often providing immediately useful advances. The development community also had a vision of what technological development could mean for our future.   Development of IEM depends on a general vision and meeting incremental challenges as they arise, with immediately useful benefits. As was mentioned at the Summit, there are many ways to think about and categorize challenges IEM must meet. One way spelled out in the Summit's Participant Guide and in a presentation at the workshop is to consider the evolutionary, iterative stages in the lifecycle of a given IEM: (1) definition, (2) assembly, (3) execution and processing, (4) interpretation, (5) application and follow-ups, and (6) education and propagation to a broader community. Another way, derived from the four working groups of the Summit, is to categorize the challenges as scientific, technological, application, and/or organizational and social challenges. This report provides a broad-brush summary reported on in the four categories.

Scientific challenges include accurate capture and representation of uncertainty in input data, conceptual models and IEM results. Construction and execution of data assimilation, process assimilation, and model abstraction strategies were also mentioned, as were challenges of defining, implementing and linking IEM processes to integrate across a range of spatial scales, time scales, and disciplinary domains. Clearly establishing and understanding IEM domain boundaries, parameterizations, and constitutive relations (i.e., what is empirical vs. what is based on conservation laws) are also important challenges, as well as development and integration of appropriate objective functions, best practices, and cross-scale testing procedures for the IEM. It was recognized that different types of IEM applications (prognostic vs. diagnostic; forecasting vs. nowcasting vs. hindcasting) had their own types of scientific challenges, but that these different types of applications, when properly defined and understood within their respective limitations, could also help inform each other and build confidence. The role of science in helping building confidence in IEM through open-access and peer-review was also mentioned, -- most importantly by providing expert opinion and understanding on the appropriate levels of complexity and simplicity in IEM construction and interpretation. Finally, the need for better understanding and linkages between the social science and the physical/chemical/biological science aspects of IEM was also mentioned. This is a fundamental challenge for inter-disciplinary approaches in a range of disciplines and a number of issues, including recognition by peers in the science community for inter- and trans-disciplinary research, must be considered.

Technology challenges discussed during the Summit related to disparate ontologies, meta-data standards, meta-model definitions, and lack of semantic interoperability. They relate to the need for more sophisticated, adaptable, and linkable model frameworks, enhanced use of the Cloud, web services, multiple computer platforms and processors, and expert communities. They include developing better technology for data (and model) mining, discovery, and linkages and also developing better tools to analyze, interpret, and visualize data, conceptual models and IEM results. Challenges also include development of technologies that could educate about, understand and build confidence in IEM results and applications.

Application challenges included appropriately defining measures of success and demonstrating successful applications of IEM. Applying IEM successfully -- where success could not have been obtained as easily through other means -- is essential to further development of IEM science and technology, to growth of the IEM community of practice, and to the embrace of IEM by the general population. It was recognized that the scale of IEM applications has much to do with understanding and confidence in IEM results and, ultimately, with adoption of IEM throughout the community. A three-month IEM forecast is much easier to test, and possibly build confidence in, compared to a 100-year or even decadal-scale forecast. Individuals and communities may relate better to a local or regional IEM prediction or process explanation than a global prediction, explanation or other IEM application. Allied to this is the challenge of assessing and presenting uncertainty from different sources in a way that a range of decision-makers can readily appreciate. Clear, simple explanations of what IEM can, and can't, be used for are essential for any demonstration project. Equally important are explanations of how IEM can serve the objectives and organizational missions of agencies or communities, and of what the political limits might be in management actions taken as a result of IEM results and interpretations. Some application challenges will result from the need to apply creativity and appropriate understanding of IEM assumptions and limitations while applying/transferring results of an IEM or IEM application to another problem or situation. Finally, and perhaps most importantly, IEM applications will require constant reassessment of whether the right questions are being asked, and determining what roles IEM developers, topical experts, users, managers and the public should play in formulating these questions, and interpreting results so that appropriate management and policy actions are taken.

Organization/Community challenges included appropriate engagement with and support from developers, users, academia, and governmental and non-governmental organizations. Traditionally, numerical codes and model applications were controlled by a limited number of people, usually those developing the code and a few applying it to a given problem. By the nature of their complexity, IEMs and their applications require a much broader community of developers, users and others (and computer and other resources) to support the IEM, to share

responsibilities, and to interpret and apply its results. Challenges to IEM growth, development and applications include transcending disciplinary barriers, as well as mission, organizational and cultural barriers, while still maintaining incentives for individuals and specific communities and organizations to contribute actively. Challenges also include teaching IEM at a range of educational levels and developing IEM "integration experts" that can lead development and proper application of IEM. Involving the private sector, which will complement initial growth of IEM in the government and academic communities, is also an essential requirement (and challenge) for IEM development and growth. Reinsurers are already investigating IEM to help assess hurricane damage by integrating Atmospheric-Oceanic-Circulation-Financial models, so can provide expertise as well as capital. Beyond needs for increased funding and inter-organizational communication, successful use and growth of IEM also requires a balance between multi-expert and multi-user group consensus, and allowing individual expertise in building and applying IEM. In other words, IEM community structures, and feedback and accountability processes, must allow the wisdom of communities to shine, rather than the follies of the flock in order to show IEM to its full advantage).

2.5 Results of breakout groups for Day One

Throughout Day One, participants were able to break into smaller groups to further identify the current landscape of IEM's state-of-the-art and practice; develop vision statements related to the science, technology, application and organization/community aspects of IEM; and identify the challenges to achieving those visions. The findings of Day One breakout sessions can be found on the iemHUB at https://iemhub.org/resources/281.

Based on the previous presentations, the IEM Summit participants developed vision statements for four areas:

- **Science:** Science supporting IEM and its application will continue to evolve to inform policy decisions and communicate to society environmental problems and solutions. IEM will use state-of-the-art predictive capabilities for multi-scale multiple interacting processes that represent environmental responses to perturbations in natural or engineered settings. Uncertainty analysis will be used to critically evaluate the limitations of IEM.

- **Technology:** IEM technology will make it easier to find, use, develop, integrate, understand, and future-proof models and data.

- **Application:** IEM will support robust and defensible decision-making providing for a range of users, producing results in an appropriate form, using readily available data and models.

- **Organization/Community:** The IEM community will be open (sharing), efficient, transparent, and collaborative, to advance science & technologies to make effective environmental decisions for societal benefits.

3 Day Two – Developing the IEM Roadmap

On Day Two participants broke into four groups. Each group was asked to expand/clarify the Day One vision statements into a revised vision statement and set of IEM goals for each topic area: science, technology, applications and organization/community. They were then asked to propose activities to achieve the goals. The results follow.

3.1 Science vision, goals and activities

A summary of the discussions of the science area breakouts can be found on the iemHUB at https://iemhub.org/resources/352.

3.1.1 Vision

Science supporting IEM and its application will continue to evolve to inform policy decisions and communicate to society environmental problems and solutions. IEM will use state-of-the-art predictive capabilities for multi-scale multiple interacting processes that represent environmental responses to perturbations in natural or engineered settings. Uncertainty analysis will be used to critically evaluate the limitations of IEM.

3.1.2 Goals

The break out groups identified the following Science goals:

a. Establishing a scientifically sound methodology for approaching problems which require integrated modeling in order to find a solution

b. Establishing scientifically respected controlled vocabularies, ontologies and catalogues of processes, process variables, models and exchange items to reduce the opportunity for error and automate the construction of the model chain

c. Understanding and developing the means to handle the scientific issues that arise when models based on different scales are linked

d. Understanding and developing the means to handle the scientific issues that arise when models which run at different temporal or spatial resolutions are linked

e. Understanding and developing the means to reduce the occurrence of instabilities that arise when models are linked

f. Developing methods for assessing, quantifying and displaying the uncertainties arising from the use of integrated modeling

g. Developing an approach to model development and a mindset among developers that assumes that, at some point in a model's life cycle, there will be a need to link it to other models

h. By working with the artificial intelligence community, developing ways of exploiting the growing knowledge of process interaction to identify and predict the possible wider implications of events and policies and so lower the risk of 'unforeseen consequences'.

3.1.3 Activities

To achieve the specified IEM goals the breakout groups proposed the following Science activities for each goal:

a) Developing an integrated modeling methodology

- Review the approaches of past and present IEM projects
- Develop and publicize best practice

b) Establishing scientifically respected controlled vocabularies, ontologies and catalogues of processes, process variables, models and exchange items to reduce the opportunity for error and automate the construction of the model chain

- Identify current problems and the opportunities ahead – need to reduce the opportunity for error in building model chains, automating model chain construction, linking IEM to artificial intelligence, needs of regulators, lowering the barriers created by national and domain specific languages, etc.
- Build on/adopt existing controlled vocabularies
- Develop ontology structures for describing processes and models
- Develop methods for searching for links between processes
- Develop methods for linking process descriptions to model descriptions
- Develop methods for auto mating the construction of a model chain

c) **Understanding and developing the means to handle the scientific issues that arise when models based on different scales are linked**

- Review existing work on scale issues

- Study the scale issues that are likely to arise as it becomes easier to link models

- Develop methods to warn users that a scale issue might arise when two models are linked and suggest options for handling them

d) Understanding and developing the means to handle the scientific issues that arise when models which run at different temporal or spatial resolutions are linked

- Review existing work on linkage issues

- Study the issues that have and/or are likely to arise as it becomes easier to link models

- Develop methods to warn users that an issue might arise when two models are linked and suggest options for handling them

e) Understanding and developing the means to reduce the occurrence of instabilities that arise when models are linked

- Review existing work on instability in models

- Examine known instances of instability occurring where models have been linked

- Develop procedures for recognizing the potential for instability in a coupling and the step to avoid or reduce the likelihood of instability

f) Developing methods for assessing, quantifying and displaying the uncertainties arising from the use of integrated modeling

- Review existing work

- Identify the opportunity for error in the model chain

- Develop methods for capturing and recording uncertainty

- Develop methods for passing uncertainty down the model chain

- Develop methods for displaying uncertainty

g) Developing an approach to model development and a mindset among developers that assumes that, at some point in a model's life cycle, there will be a need to link it to other models

The activities are implicit in the goal.

h) By working with the artificial intelligence (AI) community, developing ways of exploiting the growing knowledge of process interaction to identify and predict the possible wider implications of events and policies and so lower the risk of 'unforeseen consequences'

- Review AI work in this field

- Consider how IEM ontologies might need to be modified to incorporate AI thinking

- Undertake research projects to explore how the wider implications of a proposal might be identified and then assessed quantitatively or qualitatively

3.2 Technology vision, goals and activities

A summary of the discussions of the technology area breakouts can be found on the iemHUB at https://iemhub.org/resources/380.

3.2.1 Vision

IEM technology will make it easier to find, use, develop, integrate, understand, and future-proof models and data.

3.2.2 Goals

The breakout groups identified the following goals:

a. Raising the level of interoperability and portability of modeling components

b. Automating IM processes that are irrelevant to the IM user

c. Improving the usability of tools – lowering the barriers to entry – increasing access

d. Creating a web service market supported by e-infrastructure

e. Creating the ability to assess uncertainty and pass it down the model chain – delivers the science work above

f. Establishing an IEM culture based upon best practice

3.2.3 Activities

To achieve the goals the breakout groups proposed the following activities for each goal:

a) Raising the level of interoperability and portability of modeling components

- Develop use cases and create test beds by which standards and frameworks can be assessed

- Identify the base standard common to the main existing standards (e.g. ESMF, OpenMI, CSDMS/CCA, FRAMES and OMS)

- Develop adapters allowing data exchange between the main existing standards (e.g. ESMF, OpenMI, CSDMS/CCA, FRAMES and OMS)

- Develop a 'meta model' standard for describing models and modeling components for both cataloguing models and as a first step towards validating linkages and automating the construction of model chains

- Develop ontologies to improve semantic interoperability – builds on the science activities

b) Automating IM processes that are irrelevant to the IM user

- Develop/advance tools that support the migration of models to conform with standards

- Develop/advance tools for meta model and data extraction from IM components

- Develop/advance tools for finding, linking and running models

- Develop ontologies and apply AI techniques to automate the construction of models chains

c) Improving the usability of tools – lowering the barriers to entry – increasing access

- Develop tools for :

  o Discovery and accessing model components and data

  o Meta model and data entry and retrieval

  o Visualization of multidimensional data

  o Automatic construction of audit trails

d) Creating a web service market supported by e-infrastructure

- Resolve IT security and certification issues

- Create and advance the model and data cloud

- Create/advance a registry of IEM components in the cloud

- Develop web-based demonstrator applications

- Create modeling platforms which include market places

e) Creating the ability to assess uncertainty and pass it down the model chain

- Develop tools for monitoring and debugging model chains

- Develop methods and tools for describing and exchanging uncertainty

- Develop techniques for computing ensemble statistics

f) Establishing an IEM culture based upon best practice

- Survey existing best practice across the community (compare and contrast)

- Create more sessions at professional meetings so that best practice can be identified

- Encourage the creation of open source software and so remove barriers to the use of best modeling components

3.3   Application vision, goals and activities

A summary of the discussions of the science area can be found on iemHUB at
https://iemhub.org/resources/283.

3.3.1 Vision

IEM will support robust and defensible decision-making providing for a range of users producing results in an appropriate form, using readily available data and models.

The end users to whom this vision applies to are likely to be:

- Government (central and local)

- Regulators and enforcers

- Industry (including the insurance and financial sectors) both for its own purposes and on behalf of others

- NGOs

- Scientists

- Students of all ages

- The general public

3.3.2 Goals

The breakout groups identified the following goals:

a. Providing modeling platforms – to make data, models and tools readily available

b. Establishing show-case projects to demonstrate the added value of integrated modeling

c. Producing descriptions of the uncertainty associated with results

d. Developing systems to manage and maintain an audit trail of integrated model runs

e. Engaging stakeholders

3.3.3 Activities

To achieve the goals the breakout groups proposed the following activities for each goal:

a) Providing modeling platforms

- Encourage the development of modeling platforms where researchers can develop linkable modeling components, research process interactions, and teach and provide a learning environment for students

- Encourage the development of platforms that provide a shop window for modeling components where end users and potential vendors can view potential modeling components with a view to use or commercialization

- Work to achieve a critical mass of linkable components

- Develop a searchable modeling component catalogue

- Consider the possibility of data, modeling components and results as web services

- Consider integrated modeling for mobile devices and the cloud

b) Establishing of show case projects

- Encourage establishing setting up of as wide a range of show-case projects, with the following attributes, when and where possible:
  - Address a real world problem with which users can identify
  - Require integrated modeling in the process of finding a solution
  - Define the scenarios to be explored
  - Consider how to evaluate the benefits of integrated modeling
  - Identify the processes involved
  - Identify the process interactions

- Choose models to represent the processes

- Translate the process interactions into model linkages

- Make non-linkable models linkable

- Link the models

- Run the scenarios

- Analyze the results

- Evaluate the benefits of integrated modeling

- Create a catalogue of show case projects containing one page summaries.

- Example show case projects:

  - Scenario analysis

    - Impact of medical plans for treating epidemics on waste water treatment and water supplies

    - Chesapeake Bay

    - Energy/water/food security

    - Impact of agricultural policy

    - Impact of proposed new sewage treatment plant

    - Impact of climate change on frequency and cost of flood damage

  - Post-event audit

    - Hurricanes - Katrina - New Orleans

    - Oil spills - Deep Water Horizon

    - Floods – Pakistan

  - Emergency planning

    - San Francisco

c) Capturing uncertainty associated with results

- Apply and evaluate methods of characterizing uncertainty

- Apply and evaluate methods for passing information about uncertainty down the model chain

- Understand how stakeholders react to uncertainty

- Develop methods for displaying uncertainty

d) Managing and maintaining audit trails for integrated model runs

- Establishing a methodology for approaching problems that requires integrated modeling to find a solution

- Automating the recording of the information required to be in the audit trail

e) Engaging stakeholders

- Develop participatory modeling

- Develop models for 'citizen science'

- Develop integrated modeling games

    o Develop a 'Black Swan X-box game'

    o Develop linkable versions of SPLASH and Sim City.

- Develop mobile apps as easily useable front ends to complex integrated models

3.4 Organization/Community vision, goals and activities

A summary of the discussions for the science area breakout can be found on the iemHUB at https://iemhub.org/resources/380.

3.4.1 Vision

IEM community is open (sharing), efficient, transparent and collaborative to advance science and technologies to make effective environmental decisions, for issues requiring trans-disciplinary approach, for societal benefits.

3.4.2 Goals

The break out groups identified the following goals:

a. Establish an inclusive IEM CoP that: (1) Recognizes realistic goals; (2) Exists as the communication platform; (3) Attracts funding and (4) Operates under clear definition of contributions from each member/ member organization

b. Create an e-infrastructure that (1) Provides a single catalogue of components (models, data, tools); (2) Supports (access to) HPC & cloud computing; (3) Broadcasts funding opportunities for IEM; and (4) provides links to IEM practitioners and experts

c. Comprehensive IEM Education Plan encompassing technical workforce, users and public.

d. Reach common agreed upon standards model linking and data sharing.

e. Funding for both operations of CoP and projects in IEM is readily available and coordinated across organizations

f. Implement information outreach that secures user buy-in, identifies & engages stakeholders and shares success stories

3.4.3 Activities

To achieve the goals the break out groups proposed the following activities for each goal:

a) Establish an inclusive IEM CoP that: (1) Recognizes realistic goals; (2) Exists as the communications platform; (3) Attracts funding; and (4) Operates under clear definition of contributions from each member/ member organization:

- Develop a governance structure

- Identify and involve existing organizations and initiatives to establish connections

- Identify lessons learned from growing similar CoPs to achieve critical mass

- Develop newsletters and workshops to promote development of community

b) Create an e-infrastructure that (1) Provides a single catalogue of components (models, data, tools); (2) Supports (access to) HPC & cloud computing; (3)Broadcasts funding opportunities for IEM; and (4) provides links to IEM practitioners and experts

- Develop, populate and maintain an IEM "content" database that can be accessed by multiple portals → iemHUB

- Develop a technical steering committee for the iemHUB

c) Comprehensive IEM Education Plan encompassing technical workforce, users and public.

- Technical Workforce:
  - o Develop training, curricula material, courses and workshops for IEM/ systems analysis
  - o Identify educators affiliated with IEM (1-3 years)
  - o Develop online tutorials for the IEM community (1-3 years)
  - o IEM summer school for graduate students (3-5 years)
  - o Set of "How to…" notes for different aspects of IEM.

- Users:

  - Develop a speaker series for the user community to the IEM community (1-3 years)

  - Either identify an existing journal or create a new journal to provide a venue for IEM (1-3 years)

  - Develop a personnel exchange program for end-user community and development/modeler organizations

- Public:

  - IEM games for K-12 (young adults) to demonstrate inter-related disciplines are needed to address key environmental problems

d) Reach common agreed upon standards model linking and data sharing.

- Create a working group at OGC to reuse/improve standards for IEM

- Establish a standards committee to develop IEM standards and protocols

- Conduct an assessment study to demonstrate the financial benefits of using standards – "what would xyz-system cost today, if standards abc would have been used?"

- Encourage organizations to require the use of standards for the projects they fund

e) Funding for both operations of CoP and projects in IEM is readily available and coordinated across organizations

- Develop a cost-benefit, return on investment, net current value financial justification for investment in IEM

f) Implement information outreach that secures user buy-in, identifies & engages stakeholders and shares success stories

- High quality promotional material making an irresistible case for IEM

- Define benefits of IEM/community approach to IEM

- Identify and engage potential users/stakeholders by offering specific solutions to known problems

4 Day Three – summary of roadmaps and development and implementation plans

4.1 Projects

Participants agreed it was imperative to build quickly on the success of the workshop by initiating projects that would yield results in the short- to medium-term, as well as projects that would require longer collaboration.

Projects to be initiated immediately fell in the following categories:

- Creating short exchanges of staff between organizations to "cheerlead" to inject enthusiasm into the process of adopting IEM

- Identifying required standards

- Converting *de facto* standards into recognized standards (e.g., making the OpenMI into an OGC standard)

- Building a catalogue of integrated modeling components

- Setting up small pilot/demonstration projects

- Building a set of summary sheets describing integrated modeling projects

- Increasing the number of linkable modeling components

Potential collaborative projects were also identified. These are detailed in Appendix 4 and are available on the iemHUB at https://iemhub.org/groups/iemsummitproj.

4.2 Community governance

Noha Gaber (US EPA) led a discussion on reaching consensus on governance of the Community of Practice for Integrated Environmental Modeling (CIEM). Participants agreed that the CIEM should serve as the body to facilitate communication, coordination and collaboration in the IEM community, and that it was important for the community to develop appropriate governance and funding mechanisms to keep the CIEM operational and able to meet its goals. Participants discussed the CIEM mission statements and defining characteristics. There was general agreement that modest resources would be required to sustain an IEM secretariat, charged with CIEM's day-to-day operations such as promotion, organizing and running meetings, web site maintenance and outreach. Significant resources would be required by the collaborative

opportunities and any resulting projects -- present and future -- set up to overcome the challenges.

There was consensus that CIEM should be a not-for-profit, umbrella organization and the term 'a community of communities' was mentioned. It would not acquire or distribute funds, but instead seek to influence funding agencies and help member organizations find and/or generate funding for research and operations. A t team was formed to finalize the CIEM charter and develop its governance structure and funding plan. In addition to the funding required to maintain the CIEM, participants identified other funding needs, namely projects to address challenges related to the science, technology and application of IEM.

5 Summary and the way forward

The meeting was remarkable in a number of ways. Right from the start, it was clear that this was a key meeting for the future of IEM, happening at just the right time. Despite coming from very different backgrounds, all the participants realized that common challenges were faced and that collaboration was the only way forward. The meeting offered a clear consensus that, with more collaboration, the rewards offered by integrated environmental modeling (IEM) for society and industry would be enormous. The greatest challenge will be turning IEM from its present state -- something used by researchers -- into an operational tool for anyone.

The meeting convened model developers, users, and science and resource managers from the US and Europe. Over three days, they reviewed the state-of-the-art and sketched a vision of where IEM might go in the next 20 years. They then identified challenges to attaining the vision and developed an outline of a Roadmap to overcome them. The meeting concluded with establishing collaborative opportunities and projects to accelerate the development of IEM. Developing and implementing the Roadmap was recognized as key to IEM's future.

"Next steps" to continue the progress made at the meeting were summarized by Denis Peach (BGS) (see https://iemhub.org/resources/288):

- Document the Roadmap,

- Publish the Roadmap in the Journal of Environmental Modeling and Software,

- Implement projects to enhance communication, co-ordination and collaboration in integrated environmental modeling,

- Establish the presence of the IEM community with research organizations (NERC, NSF), European Commission and industry (IT and Re-Insurance).

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7 Glossary

AI   Artificial Intelligence: approach that uses computers to simulate human thought

API   Application Programming Interface: A set of rules and definitions that software use to communicate with each other, e.g. OpenMI and its implementation.

Black Swan   A low probability high-impact event with negative consequences

BGS   British Geological Survey (www.bgs.ac.uk)

CCA   Common Component Architecture US DoE funded high-performance computer based model linking system

CSDMS   Community for Surface Dynamic Modeling Systems (see csdms.colorado.edu)

FCO   UK Foreign and Commonwealth Office (see www.fco.gov.uk)

FRAMES   Framework for Risk Analysis in Multi-Media Environmental Systems see http://www.epa.gov/athens/research/modeling/3mra.html

Future Proof   System that is flexible to be able to cope with changes either foreseen or unforeseen.

Integrated modeling   The process of bringing a set of modeling components together to create a system whose purpose is to understand and or predict how a set of interacting processes will respond in given circumstances.

Integronster   An integrated modeling system that is too unwieldy to achieve its aims.

Model   A model engine set up to model a specific situation, e.g. water moving down the Rhine or Mississippi; the impact of the switch to biofuel production on global food supplies; the effect of climate change on the Golden Plover population in the UK .

Modeling component   An element in a modeling system that has functionality. Can be a process model, visualization tool, database, etc.

Model engine   The generic description of a process. It is most commonly used to refer to the program code in a model which simulates the process, e.g. water flowing down a channel; the transformation of rainfall into runoff; the behavior of a plant or animal; the response of farmers to agricultural policy; etc..

Model integration   The process of enabling modeling components to exchange data.

Model interface   The means by which a model can receive data from or make data available to other modeling components.

NRCS National Resource Conservation Service (see www.nrcs.usda.gov)

OMS   Object Modeling System: a framework for linking models can be linked see for example http://acwi.gov/sos/pubs/2ndJFIC/Contents/M09_Olaf_ExtendedAbstract.pdf

OpenMI   Open Modelling Interface: An EC funded model linking standard (see www.openmi.org)

US EPA   United States Environmental Protection agency (see www.epa.gov)

USDA United States Department of Agriculture (see www.usda.gov)

US DoE   United States Department of Energy (see www.energy.gov)

USGS   United States Geological Survey (see www.usgs.gov)

8 Appendices

Appendix 1: Original proposal to the FCO

GLOBAL PARTNERSHIPS FUND 2010-11: US SIN BID

<u>**Lead Post:**</u>

<u>**Title of project:**</u> Developing UK-US Collaboration on Integrated Environmental Modelling

<u>**Activity**</u>

Explain what type of activity you are proposing e.g. workshop, visit, and who would be involved (e.g. which UK or US universities).

Type of activity: Workshop

Attendees: Key players from UK, US and Europe from government agencies, industry and academia and communities of practice including funding agencies.

We are working on the actual list of invitees but they will be drawn from the following organisations:

Government	Industry	Academia	Communities of practice (CoP)
US participants and international			
US EPA	Microsoft	NSF funded Community of Universities for the Advancement of Hydrologic Science Inc (CUAHSI)	Open Geospatial Consortium (OGC)
US ACE	Google	NSF funded Community for Sediment Dynamics Modelling System (CSDMS)	Integrated Environmental Modelling CoP
USGS	ESRI		International Environmental Modelling Systems society
NOAA			Inter-agency Multi Media Modelling Group
NASA			
USDA			
NSF			
UK participants			
DEFRA	HR Wallingford	NERC (HQ, BGS & CEH)	AGI
DFID	VITALIS	EPSRC	BSI
EA	ESRI (UK)	ESRC	DAEM
LWEC partners	Atkins	Virtual Observatory Consortium	OpenWeb
Met Office	Halcrow		InformaTec

Government	Industry	Academia	Communities of practice (CoP)
	Willis Re		
SEPA	Arup		
European and other participants			
EC RTD	DHI	OpenMI Association	EurAqua
EEA	Deltares		
INSPIRE			EuroGeo Surveys
JRC			

Objective

Explain what you are trying to achieve by the activity e.g. link together UK-US centres of excellence to develop new collaborations.

The objectives of the workshop are to:

- To bring together key players across US, UK and Europe
- Identify potential opportunities created by recent advances in integrated modelling and develop their application for researchers, funding agencies, industry and government
- Inclusively and collaboratively present those opportunities in a shared vision for the future
- Develop and agree a strategy for achieving the vision
- Set out a road map

Background

Explain the background to the activity – what has led you to propose it, what work has already taken place etc.

Assessing the sustainability of proposed policies is challenging because it requires the ability to understand and predict the response of multiple interacting processes. Models are utilised in many cases; these effectively encapsulate knowledge and use it for prediction. However, most models represent a single or small group of processes. The sustainability challenges that face us now require the prediction of many that interact. These processes will not be confined to a single discipline but will often straddle many – social, economic and environmental. Consider a relatively simple question, "What will be the impact of the medical plans for managing a 'flu pandemic on river water quality and could the plans cause a further health hazard?" It spans medical planning, the spread of disease through the population, the absorption of drugs by the body and the hydraulic and chemical processes in sewers, sewage treatment works and rivers. The question can be nicely addressed using the present stateoftheart of integrated modelling. We have models of the processes and interface standards allow them to be linked to each other and to datasets. We can therefore answer the question, though at this stage with a large measure of associated uncertainty. The answer will also come with the important proviso that we had thought to ask it.

To achieve our present ability to link or integrate models and hence to model and predict more complex processes, the first and crucial step was to produce a generic open solution to enabling models to exchange data. The most recent attempt is that of the NERCled HarmonIT consortium. Their solution comprises a standard interface, the OpenMI, which can link relevant models to each other and to other modelling components. Once adopted, it transforms the ease with which models can be linked and run. It has been widely tested, especially in the US, by government agencies and major science programmes.

It is now clear that there are very strong parallels between the evolution of Google Maps and Sat Nav from paper maps and the path that the development of integrated modelling could follow.

However, from paper maps to Google Maps took 40 years. The lesson from that experience is that a selforganising community of practice and appropriate early funding could greatly shorten the time it will take for integrated modelling to become operationally useful to science, industry and policy makers. It is useful to remember here that GIS has grown from nothing to a billion dollar industry; it doesn't require great imagination to see that the potential earnings from integrated modelling could be far greater.

The purpose of this workshop is to set out the opportunities in research and in the market and develop a plan for what must be done to realise those opportunities.

Expected outputs/outcomes

List the outcomes you expect from the activity e.g. proposals submitted for funding, report, papers etc.

- A short statement of the vision
- An outline strategy for achieving the vision
- A road map

The science aim is to improve our ability to understand the whole earth system

The policy aim is to improve our ability to develop policies that are more likely to be sustainable

The commercial aim is to create a new industry comparable to that of GIS

Stakeholders

List the US and UK stakeholders, indicate what contact you have had with them and what contribution they will make to the project (in cash or in kind)

Those listed above.

<u>GPF Funding required</u>

Set out what funding you require from GPF in £s – breakdown as much as possible into e.g. flights, hotel costs, admin costs etc.

Item	Quantity	Duration	Unit cost GBP	Cost GBP
Airfares inc. travel to airport	8		£800.00	£6,400.00
Hotel (Qty people x nights)	8	7	£150.00	£8,400.00
Room hire				£3,000.00
Tea, coffee, light refreshments	25	5	£10.00	£1,250.00
Secretarial assistance				£500.00
Printing, posters, minor items, etc				£250.00
				£19,800.00

Roger Moore

pp. Dr Denis Peach

Chief Scientist, British Geological Survey

Natural Environment Research Council

Appendix 2: Agenda and running order

Day 1:   **Tuesday December 7, 2010: Laying the groundwork for roadmap development**

7:30-8:30	**Summit Registration**

8:30-8:45	**Welcome to the Summit**
	
	    Matt Larsen
	
	    Associate Director for Water, US Geological Survey
	
	Introduction to the Summit
	
	    Roger Moore, Open MI Association, UK
	
	    Who are we (demographically)? Why are we here? What will we do? What will we produce?

8:45-10:15	**Ice-breaker: Introductions of Summit Participants and Participating Organizations** **Facilitator: Nathan Schwagler**
10:15-10:30	**Introduction to Integrated Environmental Modeling: Drivers and Philosophy** **Speaker: Pierre Glynn, US Geological Survey**
10:30-10:45	**Coffee Break**
10:45-12:15	**The State of the Art and Practice of Integrated Environmental Modeling** **Speaker: Alexey Voinov, iEMSs** IEM is a discipline whose focus is the science, engineering, and community of integrated environmental systems analysis.

	Presentation: A summary view of the current IEM landscape including : • Characteristics and examples of problems requiring IEM • Characteristics and examples of IEM solutions • Strengths and weaknesses of current IEM solutions **Facilitated Discussion:** The output from this discussion will be a consensus view of the current IEM landscape. This information will form the basis for establishing a vision for the future of IEM and communicating with the Managers on Day 3. **Facilitators: David Fortune, Open MI Association and Nathan Schwagler** **Rapporteur: Bert Jaegers, Deltares**
12:15-1:15	**Lunch**
1:15-3:00	**Where We Are Going? A Vision for the Future of IEM** **Roger Moore, Open MI Association, UK** The IEM landscape includes four important layers; science, technology, application, and organization/community. The vision for the future of IEM is presented as a series of IEM-based activities placed in the context of these layers. For example, within the science layer a vision statement for IEM may be: *In education we envision undergraduate and graduate degree programs in integrated environmental modeling, integrated environmental assessment, and trans-disciplinary environmental decision making.* The vision statements collectively represent a comprehensive view of the roles IEM will play daytoday in the context of environmental assessment. Each layer/activity may represent the primary focus of a segment of the IEM community, but no activity should be designed or implemented without due consideration of all layers (i.e., the larger context of IEM and environmental assessment). **Presentation:** A strawman vision statement for IEM will be presented. This is a high level view of the world of IEM in a 5to10year time frame.

	Facilitated Discussion: The output from this discussion will be a consensus of the vision for the future of IEM. This vision statement will be used in subsequent sessions as statements of intent that will require us to articulate and prioritize the challenges to achieving the vision and to develop specific organization/community-based strategies (roadmaps) for navigating the future landscape of IEM. **Facilitators: Gerry Laniak, USEPA and Nathan Schwagler** **Rapporteur: Andrew Hughes, British Geological Survey**
3:00-3:30	**Coffee Break**
3:30-5:00	**The challenges ahead for IEM** **Pierre Glynn, US Geological Survey** To achieve the vision for IEM will require significant advances in each of the major layers of IEM (science, technology, application, and organization/community) and in the integration across layers. This session will focus on reaching a common understanding of the most important challenges that face IEM. For example, challenges related to organization/community may include : • Establishing cross-organizational research, development, and application strategies • Facilitating community-wide involvement and collaboration It will also be important to describe and document the interdependencies among the challenges and the vision statements. This will ensure that as the roadmap is developed that challenges are addressed in an integrated holistic context. **Presentation:** A strawman list of the science, technology, application, and organizational challenges associated with implementation of the vision will be presented.

	Facilitated Discussion: The intent of the discussion is to refine the list, define the interdependencies, and develop a consensus prioritization. This list will form the input to discussions focused on solutions and the IEM roadmap to the future. At this point the groundwork has been laid to pursue development of a roadmap for IEM. **Facilitators: Gene Whelan, USEPA and Nathan Schwagler** **Rapporteur: Noha Gaber, USEPA**

Day 2:   **Wednesday December 8, 2010: Developing the roadmap**

8:30-9:00	**Welcome to Day 2: Charge to Participants** **Facilitator: Nathan Schwagler and Shane Sasnow**
9:00-10:30	**Development of an Integrated Modeling Science and Technology Roadmap :** **Breakout Segment 1** **Breakout 1: Integrated Modeling Science** **Facilitators: Thomas Nicholson, NRC and Mary Hill, USGS** **Breakout 2: Integrated Modeling Technology** **Facilitators: Michiel Blind, Deltares and Peter Gijsbers, Deltares (USA)** **Breakout 3: Integrated Modeling Applications** **Facilitators: Andrew Hughes, BGS and John Rees, NERC** **Breakout 4: Organization/Social Aspects of Integrated Modeling** **Facilitators: Candida West, USEPA and Noha Gaber, USEPA**
10:30-11:00	**Coffee Break**
11:00-12:30	**Development of an Integrated Modeling Science and Technology Roadmap :**

	Breakout Segment 2
	Breakout 1: Integrated Modeling Science
	Facilitators: Thomas Nicholson, NRC and Mary Hill, USGS
	Breakout 2: Integrated Modeling Technology
	Facilitators: Michiel Blind, Deltares and Peter Gijsbers, Deltares (USA)
	Breakout 3: Integrated Modeling Applications
	Facilitators: Andrew Hughes, BGS and John Rees, NERC
	Breakout 4: Organization/Social Aspects of Integrated Modeling
	Facilitators: Candida West, USEPA and Noha Gaber, USEPA
12:30-1:45	**Lunch**
1:45-3:15	**Development of an Integrated Modeling Science and Technology Roadmap : Breakout Segment 3**
	Breakout 1: Integrated Modeling Science
	Facilitators: Thomas Nicholson, NRC and Mary Hill, USGS
	Breakout 2: Integrated Modeling Technology
	Facilitators: Michiel Blind, Deltares and Peter Gijsbers, Deltares (USA)
	Breakout 3: Integrated Modeling Applications
	Facilitators: Andrew Hughes, BGS and John Rees, NERC
	Breakout 4: Organization/Social Aspects of Integrated Modeling

	Facilitators: Candida West, USEPA and Noha Gaber, USEPA
3:15-3:45	**Coffee Break**
3:45-5:15	**Development of an Integrated Modeling Science and Technology Roadmap : Breakout Segment 4**
	Breakout 1: Integrated Modeling Science
	Facilitators: Thomas Nicholson, NRC and Mary Hill, USGS
	Breakout 2: Integrated Modeling Technology
	Facilitators: Michiel Blind, Deltares and Peter Gijsbers, Deltares (USA)
	Breakout 3: Integrated Modeling Applications
	Facilitators: Andrew Hughes, BGS and John Rees, NERC
	Breakout 4: Organization/Social Aspects of Integrated Modeling
	Facilitators: Candida West, USEPA and Noha Gaber, USEPA
7:00	**Workshop Dinner**

Day 3:   Thursday December 9, 2010: Defining the next steps

8:30-9:00	**Integrated Management and Modeling – the driving forces**
	Speaker: Denis Peach, Chief Scientist, British Geological Survey
9:00-10:30	**Presentation of Roadmaps**
	Integrated Modeling Science
	Presenters: Thomas Nicholson, NRC and Mary Hill, USGS
	Integrated Modeling Technology

	Presenters: Michiel Blind, Deltares and Peter Gijsbers, Deltares (USA) **Integrated Modeling Applications** **Presenters: Andrew Hughes, BGS and John Rees, NERC** **Organization/Social Aspects of Integrated Modeling** **Presenters: Noha Gaber, USEPA**
10:30-11:00	**Coffee Break**
11:00-12:30	**Development of Prioritized Project Proposals** **Facilitator: Nathan Schwagler**
12:30-1:30	**Lunch**
1:30-3:00	**Development of Implementation Plans** Participants will form smaller groups of collaborating organizations to develop project concept notes
3:00-3:30	**Coffee Break**
3:30-5:00	**Making it Happen** Mechanisms for organizational collaboration and support for the community of practice on integrated environmental modeling **Facilitator: Nathan Schwagler**
5:00-5:30	**Wrap-up and Next Steps**

Appendix 3: Workshop participants

Name	Organization	Country	Email
Steven Ackleson	Department of Defense, Office of Naval Research	USA	steve.ackleson@navy.mil
Todd Anderson	Department of Energy	USA	Todd.Anderson@science.doe.gov
Daniel Barrie	National Oceanic and Atmospheric Administration	USA	Daniel.Barrie@noaa.gov
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Nicholas Clesceri	National Science Foundation	USA	nclescer@nsf.gov
Olaf David	US Department of Agriculture	USA	olaf.david@ars.usda.gov
Pat Deliman	US Army Corps of Engineers	USA	Patrick.N.Deliman@usace.army.mil
Michael Ellis	British Geological Survey	UK	mich3@bgs.ac.uk
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David Fortune	OpenMI Association	UK	david.fortune@microdrainage.co.uk
Noha Gaber	US Environmental Protection Agency	USA	gaber.noha@epa.gov
Gary Geller	National Aeronautics and Space Administration	USA	gary.n.geller@jpl.nasa.gov
Kurt Gerdes	Department of Energy	USA	Kurt.Gerdes@em.doe.gov
Gary Geernaert	Department of Energy	USA	Gerald.Geernaert@science.doe.gov
Peter Gijsbers	Deltares (USA)	Netherlands	Peter.Gijsbers@deltares-usa.us
Pierre Glynn	US Geological Survey	USA	pglynn@usgs.gov
Jan Gregersen	Hydroinform	Denmark	Gregersen@HydroInform.com

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Mary Hill	US Geological Survey	USA	mchill@usgs.gov
Andrew Hughes	British Geological Survey	UK	aghug@bgs.ac.uk
Warren Isom	Willis Re:	USA	warren.isom@willis.com
Bert Jagers	Deltares	Netherlands	bert.jagers@deltares.nl
Billy Johnson	US Army Corps of Engineers	USA	Billy.E.Johnson@usace.army.mil
Robert Kennedy	US Army Corps of Engineers	USA	Robert.H.Kennedy@usace.army.mil
Holger Kessler	British Geological Survey	UK	hke@bgs.ac.uk
Rob Knapen	Alterra	Netherlands	Rob.Knapen@wur.nl
Gerry Laniak	US Environmental Protection Agency	USA	laniak.gerry@epa.gov
Matt Larsen	US Geological Survey	USA	mclarsen@usgs.gov
David Maidment	Consortium for the Advancement of Hydrological Sciences, Inc	USA	maidment@mail.utexas.edu
Justin Marble	Department of Energy	USA	Justin.Marble@em.doe.gov
Michael McDermott	US Geological Survey	USA	mmcdermo@usgs.gov
Roger Moore	OpenMI Association	UK	rvm@ceh.ac.uk
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Thomas Nicholson	Nuclear Regulatory Commission	USA	Thomas.Nicholson@nrc.gov
Jørgen Bo Nielsen	DHI	Denmark	jni@dhigroup.com
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Onno Roosenschoon	Alterra	Netherlands	Onno.Roosenschoon@wur.nl
Mattia Santoro	National Research Council	Italy	santoro@imaa.cnr.it
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Todd Swannack	US Army Corps of Engineers	USA	Todd.M.Swannack@usace.army.mil
Stanislav Vanecek	DHI	Czech Republic	S.Vanecek@dhi.cz
Roland Viger	US Geological Survey	USA	rviger@usgs.gov
Alexey Voinov	International Environmental Modelling and Software Society	International	voinov@itc.nl
Candida West	US Environmental Protection Agency	USA	west.candida@epa.gov
Jim Westervelt	US Army Corps of Engineers	USA	James.D.Westervelt@usace.army.mil
Gene Whelan	US Environmental Protection Agency	USA	whelan.gene@epa.gov
Ming Zhu	Department of Energy	USA	ming.zhu@em.doe.gov

Appendix 4: Potential collaborative projects

Project Title	Lead(s)	Team Members	New/Ongoing
Open Standards for Model Interoperability	Alexey Voinov	Roland Viger Rob Knapen David Fortune Michiel Blind Jorgen Bo Nielsen Gabriel Olchin Quillon Harpham USEPA TBC Onno Roosenschoon	New
Sensitivity Analysis/ Uncertainty: Data to Predictions	Mary Hill	Simon Smart Angelica Gutierrez-Magness Christa Peters-Lidard Quillon Harpham (as a link to other groups at HR Wallingford) Sim Reaney Mike Ellis (addressing similar things at BGS) Gabriel Olchin Peter Gijsbers (as a link to Deltares)	New
Community of Practice on Integrated Environmental Modeling Organizational Structure	Noha Gaber	Candida West Denis Peach Andrew Hughes John Rees Michiel Blind Scott Peckham Roger Moore Alexey Voinov Mike Ellis Onno Roosenschoon Roland Viger Gerry Laniak	New

		Jorgen Bo Nielsen	
Environmental Virtual Observatory Pilot (EVO-P)	Sim Reaney	Quillon Harpham Roland Viger Jan Gregersen Michiel Blind (as a link to Delatres: Gerben Deboer)	Ongoing
Ecomodeling for/ by Ecologists	Todd Swannack Jim Westervelt	Alexey Voinov	Ongoing
Indicators for Water, Land-Use and Species	Gary Geller	Simon Smart Quillon Harpham Brenda Rashleigh Roland Viger Stefano Nativi Sim Reaney Bert Jaegers (on behalf of colleagues) Onno Roosenschoon (on behalf of colleagues)	Almost new
OGC Web Services IEM Pilot Project	Luis Bermudez	Onno Roosenschoon Stanislav Vanecek Peter Gijsbers Roger Moore Roland Viger Quillon Harpham Jan Gregersen Holger Kessler (connect to BGS team) Scott Peckham Roger Moore	New
Benchmarking IEM Methodologies and Technologies		Peter Gijsbers Olaf David Jorgen Bo Nielsen Jan Gregersen Roland Viger Gene Whelan David Fortune Bert Jaegers Scott Peckham	New

		Roger Moore Rob Knapen Quillon Harpham	
Java OpenMI Collaboration	Rob Knapen	Holger Kessler (as a link to BGS Java Developers)	New
Development of a Dynamic Environmental Sensitivity to Climate Change Model	Mike Ellis	Candida West Bert Jaegers	Almost New
Chernobyl Cooling Pond	Tom Nicholson	Boris Faybishenko Billy Johnson Sim Reaney Quillon Harpham Bert Jaegers	Developing
Linkage of Watershed, Hydrodynamic and Large Open Water Models	Pat Deliman	David Fortune Bert Jaegers Quillon Harpham	
Data Access Tools	Kurt Wolfe Rajbir Parmar Andrew Hughes John Rees	Jorgen Bo Nielsen Sim Reaney Jan Gregersen	New
British Geological Survey Open Environmental Modelling Platform	Holger Kessler	Rob Knapen Jan Gregersen Bert Jaegers (Link to geo colleagues at Deltares and alternative application of technology goals)	Ongoing
Education Curriculum	Gene Whelan Olaf David Scott Peckham	Billy Johnson Gabriel Olchin Tom Nicholson Andrew Hughes Sim Reaney Holger Kessler Todd Swannack Quillon Harpham Alexey Voinov	New
Case-study analyses of requirements for IEM success	Pierre Glynn	Warren Isom Peter Gijsbers Bob Kennedy Michiel Blind	New

		Jorgen Bo Nielsen	
		Fluid Earth & Quillon Harpham	

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