Summary report of a workshop held at the Granlibakken Conference Center
Lake Tahoe, California
July 17-22, 2005

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Executive Summary

The science and management of aquatic ecosystems is inherently interdisciplinary, with issues associated with hydrology, atmospheric science, water quality, geochemistry, sociology, economics, environmental science, and ecology. Thus, research and management of aquatic ecosystems must be interdisciplinary to be most effective, but such truly interdisciplinary work is often difficult to implement. Interdisciplinary modeling is a useful approach for managing and understanding aquatic ecosystems, but there are several impediments to the implementation of successful interdisciplinary modeling of aquatic ecosystems, including (1) different spatial and temporal scales that specific disciplines are concerned with; (2) differences in degrees of uncertainty of data and models; (3) lack of awareness of what modeling options are available in an interdisciplinary sense; (4) difficulties in communication between disciplines, where different terminology and perspectives can get in the way of discussing common issues or concerns; and (5) scientists and modelers need to be educated and trained about interdisciplinary approaches.

To address these impediments, a workshop was held to develop a curriculum for a graduate-level course with an overall objective of engaging interdisciplinary discourse in modeling aquatic ecosystems. Twenty-one (21) faculty members and twenty-three (23) graduate students were chosen to participate in the workshop, which was held at the Granlibakken Conference Center at Lake Tahoe on July 17-22, 2005. Participants were provided a unique opportunity to interact with experts in various fields of aquatic ecosystem modeling and related disciplines.

The workshop consisted of a series of 50-minute lectures that provided brief overviews of models in different disciplines or covered interdisciplinary modeling topics such as issues of scale, uncertainty and errors. The workshop resulted in materials that can be distributed as a collection via an internet website so that instructors who wish to teach this course at any institution for higher learning will have background materials and a recommended curriculum.

Based on evaluations and key observations made during the workshop, it is recommended that multiple instructors teach this course. Not only would it be extremely difficult to teach this course as a single instructor due to the number of topics covered and the level of expertise needed in multiple disciplines, but it would also be difficult to evaluate students and grade assignments completed by students using models from various disciplines. Web resources should continue to be developed, ultimately resulting in a virtual textbook that would be a resource for instructors who wish to teach this type of course at any institution of higher learning.
1. Introduction

The science and management of aquatic ecosystems is inherently interdisciplinary, with issues associated with hydrology, atmospheric science, water quality, geochemistry, sociology, economics, environmental science, and ecology. Addressing water resources issues in any one discipline invariably involves effects that concern other disciplines, and attempts to address one issue often have consequences that interact with existing issues or concerns, or create new ones (Jørgensen et al. 1992; Lackey et al. 1975; Straskraba 1994) due to the strongly connected nature of key processes (Christensen et al. 1996). For example, in reservoir management, peak hydropower demands can be met by altering discharge quantities several times over the course of a day, yet these fluctuations can affect downstream channel morphology due to hydraulic and physical processes, and both the changed channel morphology and hydraulic characteristics can create habitat limitations for downstream species that become a concern for biologists. In-reservoir water levels can also fluctuate greatly with this type of operation and can have effects on recreational issues and in-reservoir habitat (Cantor 1985; Flug 1997; Stanford et al. 1996; Takeuchi et al. 1998) because of changes in hydrodynamic processes that affect thermal regimes, nutrient cycling, and trophic dynamics (Saito 1999).

Given the interdisciplinary nature of the issues, it follows that interdisciplinary approaches to addressing them should be productive (Gordon et al. 2004). Reports by the U.S. Geological Survey (USGS) and the National Science Foundation (NSF) have noted that the complex nature of natural ecosystems and environmental science issues are not adequately addressed by narrowly focused disciplinary approaches (NSF 2000; USGS 1999). While those observations were about natural ecosystems and environmental science in general, a recent study focused on water concerns by the National Research Council (NRC) similarly noted that the integrated nature of society’s water issues across physical, chemical, biological, and social sciences highlights the limitations of using strictly discipline-based approaches to address them (NRC 2004).

Thus, it is clear that research and management of aquatic ecosystems must be interdisciplinary to be most effective, but such truly interdisciplinary work is often difficult to implement. One of the ways to approach the diversity of needs in managing and understanding aquatic ecosystems is to employ mathematical modeling. Models based on available scientific knowledge and theories can be used to bridge the gap between the ability to scientifically predict with reasonable certainty, and the need to make decisions. If models are recognized as valid, they can increase understanding, facilitate communication, and assist in decision-making (Thomann 1998). Models are a key component of the paradigm of adaptive management, where deliberate management changes are used as experiments (Hilborn et al. 1995). This approach increases scientific knowledge while taking steps to satisfy multiple needs. Models are extremely useful for testing alternative management scenarios and predicting outcomes with limited data and within a condensed time frame. As an example, Saito (1999) used a linked modeling approach to investigate the effects of revised dam operations on the upstream reservoir ecosystem at Shasta Lake. Several researchers have advocated linked modeling approaches in aquatic ecosystem modeling (Crockett 1994; DeAngelis and Cushman 1990), in part because a major advantage of this approach is that well-accepted models for specific processes can be used. At Shasta Lake, a two-dimensional hydrodynamic and water quality model (CE-QUAL-W2) was linked with a bioenergetics model and a food web-energy transfer model. This approach exploited the strengths of engineering and ecological modeling methods and addressed concerns that none of the models could have addressed alone: 1) CE-QUAL-W2 could not have addressed quantitatively the impacts to fish; and 2) the bioenergetics and food web models could not have examined how spatial variability of temperature patterns and phytoplankton availability might change due to reservoir operations (Hanna et al. 1999; Saito et al. 2001).

Despite the strengths of interdisciplinary modeling approaches, there are several impediments to the implementation of successful interdisciplinary modeling of aquatic ecosystems, including (1) different spatial and temporal scales that specific disciplines are concerned with (Nilsson et al. 2003); (2) differences in degrees of uncertainty of data and models (Crockett 1994; Minns et al. 1996), and (3) lack of awareness of what modeling options are available in an interdisciplinary sense. All of these are intertwined with (4) difficulties in communication between disciplines, where different terminology and perspectives can get in the way of discussing common issues or concerns (Cullen 1990; Nicolson et al.
Research and applications to address impediments (1) and (2) are needed, but in order for such activities to happen, people are needed who are educated and trained about interdisciplinary approaches (Nicolson et al. 2002; NSF 2000; USGS 1999). Thus, a workshop was held to develop a graduate-level course with an overall objective of engaging interdisciplinary discourse in modeling aquatic ecosystems. The successful implementation of the curriculum will specifically address the impediments identified above by introducing students to models that are available in different disciplines and how such models might be applied together to address aquatic ecosystem issues, addressing issues of variability and uncertainty in implementing interdisciplinary approaches, and giving students experience in working in interdisciplinary teams to apply interdisciplinary modeling approaches to increase knowledge about aquatic ecosystems.

The intellectual merit of the workshop includes development of a much-needed course that provides students with enhanced knowledge about the availability of models for aquatic ecosystems in different disciplines, how such models might be applied together to address aquatic ecosystem issues, and the experience of working in interdisciplinary teams to apply interdisciplinary modeling approaches to increase knowledge about aquatic ecosystems. These students will then be better-prepared for professional or academic careers in which they interact with peers from other disciplines to address real-world aquatic ecosystem issues. Students taking this course should gain an appreciation for modeling in other disciplines and should be able to work well on an interdisciplinary team because they will have a better understanding of the language used and the issues associated with other disciplines.

2. Background

A 1990 report by the NRC on the hydrologic sciences noted that courses in hydrology at academic institutions typically spanned a range of departments and programs because of its interdisciplinary nature (NRC 1990). However, if ‘interdisciplinary science’ is defined as a cumulative approach that integrates individual disciplines (USGS 1999), courses that address interdisciplinary issues and give students skills for interacting in an interdisciplinary manner are relatively rare, despite the evident need for such courses. In its workshop on enhancing integrative science in 1998, the USGS advocated the value of developing well-designed courses that exposed students to the value of collaboration beyond traditional discipline-specific training (USGS 1999). An example of such an integrative course that has recently been implemented is a team-taught course at the University of Miami offered jointly through the Departments of Biology and Civil, Architectural and Environmental Engineering on water and nutrients in plants and ecosystems (BIL 591/CAE 695). Modeling is being used as an integrating aspect of this course (DeAngelis, personal communication).

When a search for graduate-level courses focused on interdisciplinary modeling approaches for aquatic ecosystems was done in 2004, no such course was found at an institution of higher learning in the United States, although there are some multi-disciplinary modeling courses available (Table 2.1). A query regarding interest in such a course resulted in affirmative responses from several institutions, indicating a clear need for this type of course (Table 2.1). Several programs did emphasize the interdisciplinary nature of their curriculum and research (e.g., Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA); Tufts University’s Water: Systems, Science, and Society Interdisciplinary Ph.D. and M.S. Program; University of Idaho’s Ecohydraulics Research Group; University of Texas San Antonio’s Center for Water Research; University of California, Davis’ Graduate Group in Hydrologic Science; University of South Florida’s Center for Modeling Hydrologic and Aquatic Systems; University of Tennessee’s Institute for Environmental Modeling).
Table 2.1. Examples of interdisciplinary modeling courses offered at some academic institutions as of October 2004

<table>
<thead>
<tr>
<th>Institution</th>
<th>Interdisciplinary modeling courses</th>
<th>Interest in proposed course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornell University</td>
<td>CEE 620 <em>Water Resources Systems I.</em> Introduction to water resource systems and the development and application of optimization and simulation models for assisting individuals responsible for regional water resources planning and management. Includes a segment on water quality models and integrating ecology with hydrology for restoration of degraded water resource systems.</td>
<td>Y</td>
</tr>
<tr>
<td>Tufts University</td>
<td>CEE-151 <em>Engineering Systems: Deterministic Models.</em> An introduction to the use of systems theory and modeling in the study/design of complex deterministic engineering, economic, environmental and social systems. Topic include network models, including PERT/CPM, economic analysis, optimization, linear and dynamic programming. Practical treatment is stressed; applications and projects involve several areas, including civil and environmental engineering and engineering psychology. CEE-152 <em>Engineering Systems: Stochastic Models.</em> An introduction to network models in the study/design of engineering, economic, environmental, and social systems with an emphasis on systems exhibiting random behavior. Topics include basic network models, Markov chains, queuing theory, reliability analysis, and genetic algorithms. Practical treatment is stressed; applications and projects involve several areas, including civil and environmental engineering.</td>
<td>Y</td>
</tr>
<tr>
<td>University of California, Berkeley</td>
<td>ERG 202 <em>Modeling Ecological and Meteorological Phenomena.</em> Modeling methods in ecology and meteorology; stability analysis; effects of anthropogenic stress on natural systems.</td>
<td></td>
</tr>
<tr>
<td>University of California, Davis</td>
<td>No such course offered</td>
<td>Y</td>
</tr>
<tr>
<td>University of California, Los Angeles</td>
<td>No such course offered</td>
<td>Y</td>
</tr>
<tr>
<td>University of Maryland, Baltimore County</td>
<td>No such course offered</td>
<td>Y</td>
</tr>
<tr>
<td>University of South Australia</td>
<td>No such course offered</td>
<td>Y</td>
</tr>
<tr>
<td>University of South Florida</td>
<td>Advanced Hydrologic Modeling: Integrated ground water and surface water</td>
<td></td>
</tr>
<tr>
<td>University of Tennessee</td>
<td>CS594/EEB504 <em>Computational Science for Natural Resource Management.</em> Topic coverage includes data structures and databases for geographic data, including metadata; basic modeling methods for spatial analysis of data; decision support tools including those with explicit spatial components and associated optimization approaches; peer-to-peer computing and applications; grid-computing and applications; linked physical and biotic models of natural systems (new course to be offered Spring 2005)</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.1 (cont.). Examples of interdisciplinary modeling courses offered at some academic institutions as of October 2004

<table>
<thead>
<tr>
<th>Institution</th>
<th>Interdisciplinary modeling courses</th>
<th>Interest in proposed course</th>
</tr>
</thead>
</table>
| Utah State University  | CEE 5690/6690  *Natural Systems Engineering*. Students are presented with a typical real world water resource system that has competing demands for instream and out-of-stream water allocations. This system is used as a framework for examining physical, chemical, and biological impacts and application of state-of-the-art assessment tools. Impacts and methods for their assessment are discussed in terms of legal, institutional, and regulatory settings in which they are applied. Students are exposed to commonly used assessment tools in applied multi-disciplinary impact assessments which cover topical areas such as hydrology, water quality modeling, instream flow assessments, riparian and channel maintenance flow techniques, and wildlife modeling techniques, and how these particular assessment methods are planned, applied, and interpreted.  
CEE 6720/5720  *Natural Systems Modeling*. Students are exposed to hands on application of commonly applied assessment tools for modeling impacts to aquatic ecosystems with a focus on stream environments, including the application of mass balance modeling of water resource systems, hydraulics, fish habitat, channel maintenance and riparian species, and water quality modeling. Emphasis is placed on understanding modeling limitations, data requirement needs, selection of appropriate applications, and interpretation of results. |

3. The Workshop

3.1. Overview

The workshop was organized by Dr. Laurel Saito, Assistant Professor at the University of Nevada Reno (UNR), and Ms. Heather Segale, a graduate student at UNR. In addition to Dr. Saito and Ms. Segale, twenty-one (21) faculty members and twenty-three (23) graduate students (Appendix A) participated in the Interdisciplinary Modeling for Aquatic Ecosystems Curriculum Development Workshop. The workshop was held at the Granlibakken Conference Center at Lake Tahoe on July 17-22, 2005. Participants were provided a unique opportunity to interact with experts in various fields of aquatic ecosystem modeling and related disciplines. Faculty participants gave lectures on modeling topics in their particular disciplines or on relevant topics associated with curriculum development or interdisciplinary modeling of aquatic ecosystems. Graduate students were competitively selected from 31 applications based on recommendations by faculty participants, use of modeling in research, and plans for pursuing an academic or teaching career. Selected students enrolled in a graduate level course for one or three credits, and provided valuable feedback on the types of educational approaches and lecture content that are most effective for fostering learning about interdisciplinary approaches and issues.

Funding for this workshop was provided by the National Science Foundation (NSF) through a grant from the Geosciences Directorate. Preliminary funding was also provided by the Nevada Experimental Program to Stimulate Competitive Research (EPSCoR)’s Advanced Computing in Environmental Science (ACES) Program, which is also funded through NSF. We are thankful to NSF and ACES for providing the
funding necessary for the workshop and to all of the attendees who participated to support the vision of this project.

3.1. Workshop Goals and Expected Outcomes

The overall goal of the workshop was develop a graduate-level course with an overall objective of engaging interdisciplinary discourse in modeling aquatic ecosystems. This course will address the five impediments to successful interdisciplinary modeling of aquatic ecosystems by 1) introducing students to models that are available in different disciplines and how such models might be applied together to address aquatic ecosystem issues; 2) addressing issues of variability and uncertainty in implementing interdisciplinary approaches; and 3) giving students experience in working in interdisciplinary teams to apply interdisciplinary modeling approaches to increase knowledge about aquatic ecosystems. Expected outcomes of the workshop included feedback on lecture content and approaches that are most effective for teaching interdisciplinary modeling for aquatic ecosystems; materials that can be distributed as a collection via an internet website so that instructors who wish to teach this course at any institution for higher learning will have background materials and a recommended curriculum; and directions for future course development and implementation. In addition, the workshop provided an important networking opportunity for participants, as well as an educational opportunity across disciplines for both lecturers and students.

3.2. Graduate-level Course at Workshop

A graduate-level course was held in conjunction with the workshop with an overall objective of engaging interdisciplinary discourse in modeling aquatic ecosystems. Students were introduced to models that are available in different disciplines and how such models might be applied together to address aquatic ecosystem issues; were presented with issues of variability and uncertainty in implementing interdisciplinary approaches; and gained experience in working in interdisciplinary teams to apply interdisciplinary modeling approaches to increase knowledge about aquatic ecosystems. Successful students in the course were to accomplish the following course objectives: 1) discuss the philosophy of modeling; 2) become aware of models in different disciplines that address water issues; 3) work in interdisciplinary teams to explore issues and approaches associated with interdisciplinary modeling; 4) participate in discussions of curriculum development for a graduate-level course on interdisciplinary modeling of aquatic ecosystems; and 5) summarize two or more lectures with additional literature review for development of course materials to be distributed on the course website (students in 3-credit option only). Student assignments included completion of the evaluation surveys for each lecture presented, daily participation, and preparation of a presentation and proposal for Model Exercise #2 (described later in this report). The course syllabus is presented in Appendix B.

3.3. Workshop Activities

Dr. Saito and Ms. Segale coordinated with the Digital Library for Earth System Education (DLESE) throughout the planning and implementation phases of the workshop. Reading materials and lectures were made available to participants prior to the workshop on a DLESE ‘Swiki’ internet site (http://swiki.dlese.org/aquamod/). This collection includes information about the workshop, lecture materials, and required and suggested readings provided by experts in each discipline or topic. In addition, all lecturers except those presenting case studies submitted pre-lecture information that included approaches typically used for modeling aquatic ecosystems in their respective discipline; a list of key books or references that provide a good background for models in the discipline; the kind of data input that is typically required for models in the discipline; the kind of data output that can be generated by models in the discipline; the spatial, organismal, and temporal scale at which models typically operate in the discipline; common assumptions made with models in the discipline; and what uncertainties are typically present in models in the discipline (see Appendix C).

All participants (except for two who lived nearby and commuted daily) stayed at Granlibakken to promote interaction between participants and provide an opportunity for networking. Students were paired with roommates to further promote interaction. Meals were also shared as a group.
The workshop consisted of a series of 50-minute lectures that provided brief overviews of models in different disciplines or covered interdisciplinary modeling topics such as issues of scale, uncertainty and errors (Table 3.3.1). These 50-minute lectures were each followed by a 10-minute break. In addition, there was an initial icebreaker on the first day, three modeling exercises, one field trip, and several discussions related to curriculum development. Case study presentations were provided during dinner. A binder was provided to all participants that included copies of PowerPoint lectures, lecture summaries, and recommended reading materials.

3.3.1. Lectures

Syntheses of participant lectures can be found in Appendix D and lecture materials are available on the workshop website (http://swiki.dlese.org/aquamod/). Overall, lecturers packed a tremendous amount of information into their 50-minute allotted time slots, with all lectures being rated as ‘moderate help’ to ‘very much help.’ Although all lecturers used PowerPoint, there were a variety of lecture styles. For example, some lecturers included audience participation that ranged from asking questions of the audience (e.g., hydrologic/watershed modeling, water quality modeling) to actually performing a small demonstration or visualization (e.g., data and models, issues of scale). Some lectures presented no equations, while others presented one or two key equations (e.g., flow and transport modeling, water quality modeling), and others presented numerous equations (e.g., groundwater/surface water modeling, ecological systems modeling). Frequent comments on almost all lectures indicated that in a regular course, more than one lecture would be needed to cover the material adequately, and examples of model applications and an associated exercise or computer laboratory would be very useful to enhance the lecture material. For most of the lectures, some participants wanted to see more detail on the material presented, while others became lost if too much detail was presented. In many lectures, participants felt that more discussion could have been provided about how models from a particular discipline could be applied in interdisciplinary modeling. Several of the lectures included a list of useful web resources, and many participants thought this type of information should be provided for all lectures.

3.3.2. Model Exercises

Three model exercises were done during the workshop: 1) a qualitative pairing of models from two different disciplines; 2) development of a proposal for an interdisciplinary modeling project addressing an aquatic ecosystem issue at Lake Tahoe; and 3) actual coupling of models using the Modular Modeling System (MMS).

3.3.2.1. Model Exercise #1 (July 17, 2005; see Appendix E)

The purpose of this exercise was to qualitatively examine issues in linking models between two specific disciplines. Participants were assigned into five groups that consisted of two faculty ‘experts’ from different disciplines, and additional faculty and student participants. For the exercise, groups were instructed to focus on either 1) an existing or possible ‘real-world’ application for linking models for the two disciplines, or 2) the design of a model exercise to be used for educational purposes to show how models from the two disciplines could be linked. Groups were asked to discuss the following questions and post the responses on flip charts: a) How could the two disciplines represented within this group be linked in a modeling exercise?; b) Provide an example(s) of a possible real-world need for linking these models; c) What are the limitations of linking these models?; d) What constraints exist for each of the models, and for the combined models?; and e) Are there other questions or issues that are of importance? Graduate students were responsible for taking notes during the discussion (Task 1) and reporting back to the other workshop participants (Task 2).
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Activity</th>
<th>Instructor(s)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday, July 17, 2005</td>
<td>2:00-2:45</td>
<td>Student registration with UNR Extended Studies</td>
<td>Neuberger</td>
<td>Outside Lake Room</td>
</tr>
<tr>
<td></td>
<td>3:00-3:30</td>
<td>Welcome; introductions; format</td>
<td>Saito/Segale</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>3:30-6:00</td>
<td>Model exercise 1: Model linkage discussions</td>
<td>All</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>6:00-6:30</td>
<td>Key observations for the day</td>
<td>All</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>6:30-8:00</td>
<td>Dinner; case study presentation</td>
<td>Schladow</td>
<td>Cedar House</td>
</tr>
<tr>
<td>Monday, July 18, 2005</td>
<td>8:00-8:50</td>
<td>Hydrologic/watershed modeling</td>
<td>Tootle</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>9:00-9:50</td>
<td>Snow hydrology modeling</td>
<td>Dana</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>10:00-10:50</td>
<td>Flow and transport modeling</td>
<td>Pohll</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>11:00-11:50</td>
<td>Water quality modeling</td>
<td>Warwick</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>1:00-1:50</td>
<td>Philosophy of modeling</td>
<td>Jenkins</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>2:00-2:50</td>
<td>Data and models</td>
<td>Biondi</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>3:00-3:50</td>
<td>Uncertainty/errors in models</td>
<td>Leavesley</td>
<td>Lake Room</td>
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<td></td>
<td>4:00-4:50</td>
<td>Issues of scale</td>
<td>Grismer/DeAngelis/Saito</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>5:00-5:30</td>
<td>Key observations for the day</td>
<td>All</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>6:30-8:00</td>
<td>Dinner; case study presentation</td>
<td>Saito</td>
<td>Cedar House</td>
</tr>
<tr>
<td>Tuesday, July 19, 2005</td>
<td>8:00-8:50</td>
<td>Groundwater/surface water modeling</td>
<td>Grismer</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>9:00-9:50</td>
<td>Statistical modeling</td>
<td>Panorska</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>10:00-10:50</td>
<td>Economics modeling</td>
<td>Braden</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>11:00-11:50</td>
<td>Atmospheric modeling</td>
<td>Grubišić</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>1:00-4:00</td>
<td>Model exercise 2: Field trip to Incline Creek watershed</td>
<td>Susfalk</td>
<td>Off site</td>
</tr>
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<td></td>
<td>4:00-5:00</td>
<td>Model exercise 2: Students work in interdisciplinary groups</td>
<td>Susfalk</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td></td>
<td>Faculty subset: discuss dissemination of workshop materials and outcomes</td>
<td>Saito</td>
<td>Townhouse</td>
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<tr>
<td></td>
<td>5:00-5:30</td>
<td>Key observations for the day</td>
<td>All</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>6:30-8:00</td>
<td>Dinner; case study presentation</td>
<td>Welty</td>
<td>Cedar House</td>
</tr>
<tr>
<td>Wednesday, July 20, 2005</td>
<td>8:00-8:50</td>
<td>Water resources systems modeling</td>
<td>Loucks</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>9:00-9:50</td>
<td>Ecological systems modeling</td>
<td>DeAngelis</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>10:00-10:50</td>
<td>Ecological modeling (algae)</td>
<td>Fritsen</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>11:00-11:50</td>
<td>Ecological modeling (fish)</td>
<td>Beauchamp</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>2:00-4:30</td>
<td>Model exercise 3: combine models from two disciplines</td>
<td>Leavesley</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>4:30-5:00</td>
<td>Key observations for the day</td>
<td>All</td>
<td>Lake Room</td>
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<tr>
<td>Thursday, July 21, 2005</td>
<td>8:00-8:50</td>
<td>MMS modeling</td>
<td>Leavesley</td>
<td>Lake Room</td>
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<tr>
<td></td>
<td>9:00-9:50</td>
<td>GIS modeling</td>
<td>Merwade</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>10:00-10:50</td>
<td>Advanced electronic resources (ACES/DLESE)</td>
<td>Grubišić/Olds</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>11:00-11:50</td>
<td>Collaborative inter-institutional teaching</td>
<td>Merwade</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>2:00-3:30</td>
<td>Model exercise 2: Presentations of modeling approaches by student groups</td>
<td>All</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>4:00-5:30</td>
<td>Discussion of utility of modeling exercises, improvements for curriculum</td>
<td>All</td>
<td>Lake Room</td>
</tr>
<tr>
<td></td>
<td>6:30-9:00</td>
<td>Dinner on the Tahoe Gal</td>
<td>All</td>
<td>Off-site</td>
</tr>
<tr>
<td>Friday, July 22, 2005</td>
<td>8:00-12:00</td>
<td>Discussion of course structure</td>
<td>All</td>
<td>Lake Room</td>
</tr>
</tbody>
</table>
The workshop participants were organized into five groups with the following paired disciplines (note: discipline pairings were revised from the planned pairings due to the absence of some of the faculty members for this exercise):

- Group 1: Physical/hydraulic modeling and fish community modeling
- Group 2: Water resource systems modeling and bioenergetics (fish) modeling
- Group 3: Snow hydrology modeling and water quality modeling
- Group 4: Economics modeling and water quality modeling
- Group 5: Atmospheric modeling and algal production modeling

The results of Model Exercise #1 (Appendix F) indicated that the exercise facilitated dialogue between different disciplines and introduced some concepts that came up frequently during the rest of the workshop such as model uncertainties, issues of scale, and data limitations. Participants thought the structure of Model Exercise #1 was very valuable, well-suited to its purpose, and should be included in the beginning of a course. The exercise generally worked well as conducted; however, it could be expanded beyond the current scope to include more in-depth aspects of modeling. It would be important to have experts in the various fields participate in the class exercise as was done for the workshop to keep the group discussions on track and within the realm of reality versus hypotheticals. Both the initial ice-breaker and model exercise provided a great opening activity for this workshop and would be recommended for future workshops or adapted for a semester-long course.

3.3.2.2. Model Exercise #2 (July 19-21, 2005; see Appendix G)

Model Exercise #2 was designed to promote interaction between students in different disciplines to plan out an interdisciplinary modeling project. The project focus was on an interdisciplinary issue pertaining to Lake Tahoe. The entire group (i.e., faculty and student participants) participated in a field trip to the Incline Creek watershed, which has been studied as a representative watershed for the Lake Tahoe region. Dr. Susfalk prepared a background document describing the region and watershed. On the field trip, participants had the opportunity to see some of the features of the area and discuss field data that could be collected to support modeling efforts.

Students were assigned to work in interdisciplinary teams to develop a proposal that included a monitoring plan, what models will be used and how they will be applied together, and a rough budget. Proposals were presented to the workshop participants on the last afternoon of the workshop (July 21, 2005) as 15-minute presentations. Students selected one of the following topics for the exercise and were instructed to work together as an interdisciplinary team to complete the assignment:

- Topic 1: Design a project to address the impacts of global warming on the aquatic ecosystem of Lake Tahoe
- Topic 2: Design a project to address the effects of riparian restoration on the aquatic ecosystem of Lake Tahoe
- Topic 3: Design a project to address the effects of urbanization on the aquatic ecosystem of Lake Tahoe
- Topic 4: Design a project to address total maximum daily load (TMDL) development or revision for Lake Tahoe (group chooses the constituent(s) that will be addressed)

Each student group was instructed to prepare a 10-15 page single-spaced proposal (including tables and figures) that included 1) a statement of problem that the group can feasibly address given the expertise of the team members; 2) a description of the modeling approach that will be used to address the problem; 3) data needs to support the modeling, including a monitoring plan; and 4) a preliminary ballpark budget for the project. After the exercise had been assigned, revised guidelines were provided to the students for completing the assignment that made the inclusion of a budget optional, but required the inclusion of a project timeline. The groups worked with faculty members as they developed the proposals.

Participants thought that this exercise was effective in illustrating the problems and opportunities afforded by interdisciplinary approaches. In a semester-long course, it would be beneficial to expand the scope
and time period for the project. Participants pointed out that in the real world, issues are raised, and team members with appropriate skills to address that issue are selected. Ideally, then, the interdisciplinary teams for this exercise should be driven by the question of interest, but if this is not possible, students should pick teams and topics out of a list of potential topics and/or present a proposed topic as an early assignment. It may not be necessary to include the proposal component of the assignment (specifically the budget component). It may also be worthwhile to require students to learn a suite of models and then use the models to test a hypothesis. Finally, students can link models either theoretically (with flowcharts) or using something like MMS to put models together.

3.3.2.3. Model Exercise #3 (July 20, 2005)

This model exercise was designed by Dr. Leavesley and Dr. Saito to allow participants to gain hands-on experience with linking two models together using the Modular Modeling System (MMS). In this exercise, participants loaded the MMS software (and associated CYGWIN compiler) onto their laptop machines. See http://wwwbrr.cr.usgs.gov/projects/SW_precip_runoff/mms/ for details and instructions. Unfortunately, due to the short time frame available and technical difficulties experienced during the installation of the software, there was very limited time remaining to complete the bulk of the exercise.

This exercise illustrated some of the difficulties involved in implementing hands-on modeling exercises in a course that covers the complexities of interdisciplinary modeling. Although workshop participants consistently suggested incorporating modeling exercises in their lecture evaluations, this exercise demonstrated that time, planning, and the correct software and hardware are needed to implement such exercises successfully. Most participants felt that inclusion of an exercise similar to this one was necessary for a semester-long course, but participants suggested conducting this exercise in a computer lab with the MMS software pre-installed. Troubleshooting for potential technical problems should occur prior to the exercise. The class could start by working with a single model that they have already discussed throughout the course, and add additional models into the MMS compiler as they are presented. In addition, if MMS is used, the general lecture on MMS should be presented prior to the exercise in order to help students understanding the exercise better. To facilitate timely implementation of the exercise, Dr. Leavesley prepared step-by-step instructions for installing the model and executing the exercise. A participant suggested that instead, showing a conceptual flow chart could be helpful because the step-by-step approach did not force participants to think through what they were doing. Another participant noted that this exercise provided a ‘reality-check’ on how much time it would take to work with various models in an interdisciplinary context.

3.3.3. Key Observations

At the end of each day of the workshop, participants were asked to provide their key observations. Key observations included points about the workshop itself, interdisciplinary modeling issues, specific lectures, the type of course that should be offered, course curriculum recommendations, and other related items. The bulleted comments and notes from the daily key observation discussions are available in Appendix H. These observations are discussed in appropriate sections of this report.

4. Workshop Evaluation

Workshop participants were given multiple opportunities for providing input regarding the workshop and proposed future course. Individual lectures and model exercises were evaluated (see Appendix D). Participants were also asked to complete pre- and post-workshop surveys using the Student Assessment of Learning Gains (SALG) tool available at http://www.wcer.wisc.edu/salgains/ website. Overall results from the pre-workshop survey are available in Appendix I and from the post-workshop survey in Appendix J. Students were required to complete all surveys for course credit, but everyone was encouraged to complete these evaluations.
4.1. General Comments Related to Workshop

In general, most participants truly enjoyed the opportunity to participate in the workshop. They appreciated the organization of the workshop (rated 4.7 out of a possible of 5), the conference facilities at Granlibakken (4.5), lodging facilities at Granlibakken (4.4), food at Granlibakken (4.4), the informal style of lectures, the good group of participants, and the lecture information form and workshop materials. The dinner on the Tahoe Gal was rated at 4.1. Comments included “I learned a lot,” “the workshop was truly interdisciplinary,” “students were also interdisciplinary and represented a good cross section,” and “it was useful to look through pre-workshop materials.” Participants also appreciated the good interaction, enthusiasm, and faculty willingness to work with students.

Negative comments included student complaints about the intense format, time limitations, and the lack of time for more inquiry-based hands-on learning. Recommendations included changing the lecture information form to include information about how the disciplinary models are used in an interdisciplinary manner and information about boundary conditions. Another suggestion was that the workshop could have included a panel discussion of specialists who are already teaching in interdisciplinary modeling. A few participants requested afternoon snacks and PowerPoint presentations set for better printing (i.e. grayscale rather than color).

4.2. Comparison of Pre-Workshop and Post-Workshop Assessment

The SALG survey asked participants to rate the degree to which various elements of the course helped them to learn the material and how well they felt they understood the material. Participants were asked to rate these items on a scale from 1 to 5 (Table 4.2.1), with numerical values equating to the following rankings:

(1) Strongly disagree
(2) Disagree
(3) Neutral
(4) Agree
(5) Strongly agree

Table 4.2.1. Summary of additional question items from SALG survey

<table>
<thead>
<tr>
<th>Evaluation Question</th>
<th>Pre-Workshop Evaluation Average Rating (n = 24)</th>
<th>Post-Workshop Evaluation Average Rating (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am excited about interdisciplinary modeling for aquatic ecosystems.</td>
<td>4.5 Agree</td>
<td>4.3 Agree</td>
</tr>
<tr>
<td>I am confident about my ability to do interdisciplinary modeling of aquatic ecosystems.</td>
<td>3.7 Agree</td>
<td>3.6 Agree</td>
</tr>
<tr>
<td>I am comfortable with addressing issues of uncertainty in modeling.</td>
<td>3.6 Agree</td>
<td>3.5 Agree</td>
</tr>
<tr>
<td>I am comfortable with addressing issues of spatial and/or temporal scale in modeling.</td>
<td>3.7 Agree</td>
<td>4.1 Agree</td>
</tr>
<tr>
<td>I am comfortable with linking models from different disciplines in modeling water-related issues.</td>
<td>3.4 Neutral</td>
<td>3.6 Agree</td>
</tr>
<tr>
<td>I am interested in using interdisciplinary modeling to address water-related issues.</td>
<td>4.5 Agree</td>
<td>4.4 Agree</td>
</tr>
<tr>
<td>I am interested in teaching a course in interdisciplinary modeling for water-related issues.</td>
<td>3.1 Neutral</td>
<td>2.8 Neutral</td>
</tr>
</tbody>
</table>
The results did not vary significantly from pre-evaluation to post-evaluation. In some cases, the level of “confidence” lowered slightly, due in part to a better understanding of the complexity of available models and interdisciplinary modeling.

4.3. Achievement of Workshop Expectations

Most of the participants felt that the workshop successfully introduced important concepts, provided valuable resources, and had a lot of relevant information about interdisciplinary modeling. Several participants noted that they learned what they had hoped or even more than they expected. In particular, the scope of participants’ knowledge about the range of models in different disciplines was enhanced. Many participants felt they learned a lot about the benefits and difficulties of interdisciplinary modeling, issues involved in linking models, and potentials for interdisciplinary collaboration. Some thought the binder of workshop materials, the workshop website, and the personal contacts made at the workshop were useful resources for future use. Many felt that in addition to the lectures and model exercises, discussions between faculty and students (both formal and informal) were very helpful. Students commented that the faculty participation was excellent and added value to the learning experience.

The majority of participants stated that the workshop/course met all of their expectations. However, several respondents noted that the workshop was rushed and too technical. Additionally, some respondents had hoped for more hands-on experience with the models and more information about how to actually integrate models. In addition, it was noted that a definitive approach to teaching the course at a university and how that would occur logistically was not finalized.

4.4. Effective Aspects of the Workshop

Participants found the organization of the workshop and the disciplinary lecture format to be effective and helpful, especially with the adherence to the 50-minute lecture and 10-minute break format (although one participant commented that they would have preferred a less structured environment to allow more ‘free flow’ of ideas). The quality of the lectures, the opportunities for discussion, the case studies and the chance to network with experts in various fields were also noted as effective aspects of the workshop. Even though a few participants had a difficult time absorbing all of the information, the consensus was that the workshop format and organization of lectures was effective. Students appreciated the opportunities to interact closely with a diverse faculty group. Feedback indicated that Model Exercise #1 was the most effective exercise included because of the interaction of small groups of faculty and students. Most found Model Exercise #2 to also be effective overall, but might have needed to be modified to make it more effective for the workshop.

While the schedule was notably “ambitious” and some found the workshop “too intensive,” there were minimal aspects of the workshop that were not considered helpful. A few participants commented that some of the lectures were too specific and the time taken for discussion was the least helpful. One respondent felt that the field trip “took too much time relative to the benefits.” In addition, while Model Exercise #3 was not considered very effective for the workshop, many felt that it could be very effective if modified for a course.

5. Modeling Observations

During the daily discussions of key observations (Appendix H), comments were made regarding issues concerning interdisciplinary modeling for aquatic ecosystems. Interestingly, most of these comments were made during the first two days of the workshop, after which key observations mostly focused on curriculum development. Some of these observations were focused on specific aspects of a lecturer’s presentation, but some general comments noted that it is important to first identify the purpose or objective of the modeling; there is not a common standard of model accuracy across disciplines; the concept of an appropriate ‘currency’ that will work across multiple scales will help to facilitate interdisciplinary modeling; data collection is important and should be considered in collaboration with model planning; disciplines have similar problems but different approaches for dealing with uncertainty,
lack of data, data problems, etc.; and it is important to have leadership in doing interdisciplinary modeling work.

6. Evolving Curriculum

One of the goals of the workshop was to gather suggestions for the most effective way of offering a course on interdisciplinary modeling for aquatic ecosystems in terms of format, content, and approach. Suggestions were solicited throughout the workshop during daily discussions of key observations (Appendix H), in the post-evaluation workshop survey (Appendix J), and in curriculum development discussions on the last two days of the workshop.

6.1. Need for Permanent Course

There was general agreement that a permanent, semester-long course on interdisciplinary modeling should be developed. Participants were asked for a show of hands regarding whether they believe that there is a need for a course on interdisciplinary modeling. Of the 35 participants who voted on this question, 94% (n=33) said “yes” there should be such a course, 6% (n=2) said “no,” and the remainder of participants did not vote because they either could not decide or were unsure of the course direction (n=2), or they were absent (n=7).

Based on these responses and the SALG survey responses, the majority of participants considered it essential to offer a similar course for graduate students to learn problem solving from an interdisciplinary viewpoint because interdisciplinary approaches are increasingly needed in research and applications, the course would provide a means of bringing together different disciplines (for example, hydrologists, ecologists, and sociologists), and the class would help students appreciate commonalities and differences among modeling disciplines. Those who were not in favor of developing a permanent course explained that they would prefer a more general course such as a seminar, they had concerns that a lot of redundancy might occur with this class and introductory modeling classes in each discipline, or they were “not ready to commit to an answer until specifics of the course are known.”

6.2. Recommended Course Objectives and Scope

Participants pointed out that the key starting point for designing a course should include the determination of a statement of scope and defining course objectives. Is the purpose familiarity with multiple fields, expertise in a few specific models, or an exploration of the overlap between various disciplines? Should students gain expertise in how to run models in each field? Is the course an interdisciplinary modeling course or a course on interdisciplinary models? Should the course attempt to accomplish both objectives or possibly be separated into two courses? While there was considerable discussion, the group was unable to reach consensus regarding course objectives because students and lecturers from various backgrounds had different ideas about the level of depth they would like to see in such a course. During the daily key observations and curriculum development discussions, several items were repeatedly mentioned as things that should be covered in a course or were recurring themes throughout the disciplinary lectures: 1) basic issues of scale, uncertainty, etc. are common to all disciplines and should be covered before going into specific disciplines; 2) students in the course will have varying levels of knowledge about models being discussed; 3) the course should be multi-instructor and would require a lot of coordination; 4) there needs to be a balance between providing useful information and overwhelming students by overloading the course with too much information. These issues were reflected in the five course models that were ultimately proposed:

Option 1: Fundamentals/General Principles of Interdisciplinary Modeling: This course model emphasis was to be light on modeling specifics, but heavy on generalities. Students would learn general modeling theory such as differential equations, genetic algorithms, game theory, and stability (numerical) issues, but in a general, non-discipline-specific context. Students would also learn core material and common concepts of modeling including scale, uncertainty, data collection, parameterization, goodness of fit, and skills for working as a team.
Option 2: Modular Course: For the first one-quarter to one-third of this course model, students would learn common core material, or concepts that are common to any modeling exercise such as scale, uncertainty, data collection, parameterization, and goodness of fit issues. Generic interdisciplinary modeling issues could also be covered. This section of the course would be followed by a disciplinary portion of the course that would be taught by various faculty members with optional disciplinary modules within the context of the overall course. For example, there could be a groundwater modeling module, or an economics modeling module, or a water quality modeling module. Students would take one of these modules. Finally, there would be a team project in which students would collaborate on an interdisciplinary project, with each student being the resident expert on the models in the disciplinary module he/she completed. Students could teach each other about their respective inputs/outputs and parameters so that models could be successfully coupled. All students in the course would thus apply a model and complete a team project in this course model.

Option 3: Survey of Interdisciplinary Models (i.e. The “Shopping Cart”): In this course model, students would learn about different types of models and the broad array of models that are currently available. This course would allow students to experience interdisciplinary modeling, but would not fully investigate the deeper details of any one specific model. Students would participate in conceptual exercises like Model Exercise #1 where they couple models in terms of example problems that could be addressed, the data needed for these models, inputs, outputs, and the limitations and uncertainty involved with such a project. Thus, students would learn to work together as a group, but might not necessarily learn how to use other models outside of their discipline.

Option 4: Seminar Series of Case Studies: Students would hear about specific projects and case studies that use modeling to solve water resources problems. As a general seminar, students would not need to know the specifics about other disciplines or specialties, but they would learn about models available in other disciplines so that they could think about modeling in their own disciplines in new ways. Students could discuss research questions from multiple fields where models could be used to address or simulate the problems presented. Another possible focus for such a course could be to have students learn how to network well with people in other disciplines, but this would need to be facilitated if the course were mostly a seminar format.

Option 5: The Art of Modeling: This course model was based on a course taught by Dr. Loucks at Cornell University. Students are exposed to and gain skills in the art of modeling by being introduced to a variety of problems (e.g., engineering design and management, public health, ecosystems/natural resources management, business, chemistry, physics) and using a variety of simulation and optimization methods. In regards to interdisciplinary modeling in particular, students would gain skills in stakeholder visioning and presentation, as well as getting along with different personality and discipline types (e.g., engineers, ecologists, politicians, funders, etc.).

These various options for the course were put to a vote to try to assess the preferences of the group (Table 6.2.1). A majority of respondents preferred the Fundamentals/General Principles of Modeling option, with a total of 66% in favor of such a course. This was followed by the Modular Option (46% in favor) which would provide general fundamental information along with specialty instruction in particular modeling disciplines. Both of these options could be oriented around a course that did not have a topical theme (for example, aquatic ecosystem modeling). However, subsequent discussion indicated that centering the course on a topical theme might be preferable to a fundamentals course with no topical theme (see discussion under Recommended Course Specifications).
### Table 6.2.1. Vote tallies of 5 proposed course models

<table>
<thead>
<tr>
<th>Course Option:</th>
<th>Student Vote:</th>
<th>Faculty Vote:</th>
<th>Combined Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What kind of course would you want to take?*</td>
<td>What kind of course would you want to teach?</td>
<td>n=35</td>
</tr>
<tr>
<td></td>
<td>n = 21</td>
<td>n = 14</td>
<td></td>
</tr>
<tr>
<td>Fundamentals / General Principles of Modeling (including general modeling approaches)</td>
<td>62 % (13 votes)</td>
<td>71% (10 votes)</td>
<td>66% (23 votes)</td>
</tr>
<tr>
<td>Modular Option</td>
<td>48% (10 votes)</td>
<td>43% (6 votes)</td>
<td>46% (16 votes)</td>
</tr>
<tr>
<td>Survey of Models</td>
<td>24% (5 votes)</td>
<td>29% (4 votes)</td>
<td>26% (9 votes)</td>
</tr>
<tr>
<td>Seminar Series of Case Studies</td>
<td>29% (6 votes)</td>
<td>0% (0 votes)</td>
<td>17% (6 votes)</td>
</tr>
<tr>
<td>The Art of Modeling</td>
<td>33% (7 votes)</td>
<td>29% (4 votes)</td>
<td>31% (11 votes)</td>
</tr>
</tbody>
</table>

*Note: Students were instructed to assume they had not already participated in this workshop. Percentages do not total to 100% in each column because each respondent was allowed to vote for two different options if desired.*

### 6.3. Recommended Course Specifications

Although workshop participants were unable to reach a consensus on the overall course objectives, most participants did agree on the following characteristics of a course on interdisciplinary modeling for aquatic ecosystems:

- The course should be a semester- or quarter-long course
- The course should be cross-listed across different departments
- The course should be an upper level graduate course
- The course could not be taught by a single instructor and should include team teaching
- The course should be described in such a way as to attract various students with various backgrounds (i.e. both engineering students and ecology students)
- Pre-requisites for the course should include a course in statistics and at least one modeling course (in any discipline) so that students are already familiar with typical modeling issues, assumptions, uncertainties, etc.
- This course would not supplant traditional disciplinary modeling courses but would instead become a capstone course for students truly interested in modeling

There was also some discussion about requiring calculus or geographic information systems (GIS) for this course, but no consensus was reached.

In terms of format, there was a general consensus among the participants that the permanent course should be organized with lectures and some degree of labs or exercises. The labs or exercises should relate the lectures to real-life situations and could include linking models across disciplines. About one-third to one-half of participants thought a regular lab should be included with the lectures to reinforce topics and issues that were covered in the lectures as well as provide hands-on experience with the
models. There was also a proposal that the lab component could be optional. Another alternative suggested would have lectures with required readings or articles and homework assignments that are done on the computer. A couple of participants indicated that they thought a lab component would not add very much to the class because students tend to learn the minimum amount necessary to get by, or it would deter some students from taking the class if there was a perception that students would be forced to learn the ins and outs of models outside of their discipline.

Many agreed that the course should have “aquatic ecosystems” as the unifying theme, although some suggested that the course might benefit from having alternative emphases such as atmospheric/hydrologic modeling, fire behavior/forest ecology modeling, evolution/population ecology modeling, or general interdisciplinary modeling without a technical focus. Of 35 attendees present, 60% (n=21) preferred that the course have a focus on aquatic ecosystems, while 31% (n=11) preferred a more general focus for the course. One participant recommended limiting the topics to the basic interactions of hydrology, water quality and aquatic ecosystem science. Another participant recommended covering general information about modeling, followed by an exercise that allows students to “operate an off-the-shelf interdisciplinary model in a simplistic project.” Students, or student groups, could then present model development and outcomes.

6.4. Recommended Topics

Most of the topics covered in the workshop were considered appropriate for a semester-long course, with the possible exception of topics associated with curriculum development (e.g., collaborative inter-institutional teaching; advanced electronic resources). Participants did have some specific recommendations about material that should definitely be included (or not included) in a permanent course.

6.4.1. Modeling Basics and Common Issues

Most participants thought that early in the course, the basics of modeling should be covered before going into information about specific disciplines. A presentation of introductory information is necessary because students will be coming from different backgrounds and therefore speaking different languages. All of the terms commonly used by modeling professionals should be defined, including inputs and outputs, scales, boundaries, data needs, data collection strategies, validation, calibration, limitations, uncertainty and error propagation. To introduce the main concepts, course instructors should start with conceptual models and flowcharts showing the inputs and outputs of various models.

The introductory terms and definitions could be presented by including an exercise similar to Model Exercise #1. Participants stated that they “enjoyed the first exercise,” especially “the process of having different disciplines get together to discuss modeling.” This was a “good way to start off the course.” While most participants agreed that the general, fundamental modeling concepts should be presented first, one respondent thought that this fundamental information “should be mixed in with the lectures on specific disciplines” by starting with a light overview of the general concepts and then go back to the fundamentals in more depth once students have some more experience.

Other introductory information that should be incorporated into the course includes modeling principles, a history of model development, and how models have evolved within each discipline. Statistics and basic mathematical modeling principles were mentioned as topics that could be brought more to the forefront. It is also critical to first identify the purpose and objectives for any modeling exercise and keep student groups focused so that projects do not head off into tangential and unmanageable projects.

Additionally, a conversation about how models can be interpreted or misinterpreted is necessary to put the role of modeling into context. Examples of the successful use and unsuccessful use of models would be useful for highlighting the potential for misuse of model results (i.e., “a fool with a tool is still a fool”).
6.4.2. Lectures in Different Disciplines

Participants discussed the issue of the extent of disciplinary material to present, with opinions ranging from very broad and general coverage to much more in-depth emphasis. The challenge lies with finding the balance between wanting to know everything, and the reality that achieving this would be impossible. Some participants reminded others that while disciplinary knowledge can be very useful, it is impossible for us to know everything in all disciplines.

The general consensus was that when models are introduced, lecturers should include not only the main concepts, but also specific models, example uses for each model, and references. References should include citations or websites for more detailed information, case studies, articles and links to freeware, if available. Not only may this more detailed information be useful to students, but in the case of a team-taught course, students may also need resources to follow-up after the lecturer has left.

Lecturers should also be explicit about the assumptions used within each discipline. Each discipline may take different approaches for dealing with uncertainty, lack of data, data problems such as data at wrong scale, and choosing the appropriate scale. Ideally, each disciplinary lecture should provide examples (case studies, real-world projects, past results) and hands-on experience with a model in their discipline. Lectures should also present future potential research questions from multiple fields along with stability (numerical) issues.

It would also be great to weave a common theme throughout the course to tie all of the lectures together. This could be a single water body (e.g., Lake Tahoe), or a particular case study issue (e.g., Lake Tahoe sedimentation).

In terms of the order of presenting disciplinary topics, one respondent recommended starting with the “big picture” of atmospheric and watershed modeling and presenting each discipline successively moving into smaller scale topics such as surface water modeling, fish, and algae. Another way to describe the proposed order would be to present the hierarchy of disciplines from atmospheric to hydrologic to ecologic to economic in the context of the typical structure of an interdisciplinary model.

One respondent noted that “too many topics were covered in the workshop to fit into a one-semester course and still allow the students to learn much in depth. [A permanent course] would too easily turn into a survey course.” This respondent preferred a more focused course that concentrated on how to combine hydrology, water quality, and aquatic ecosystem science, with occasional outside lectures on peripheral topics.

6.4.3. Team Organization and Involvement

A discussion about a “typical modeling team” provides an opportunity for a class to go into some depth about the roles of modeling programmers, managers, monitoring needs, data collection and stakeholders. Associated social issues related to model development and use in management decisions should be approached. The importance of leadership (by modelers and those presenting model output to stakeholders) cannot be understated. In the field of modeling, working with people with large egos can sometimes make the field difficult. When planning the modeling project, teams should consider the model first before the data collection plan is determined.

6.4.4. Data Collection

In order to build and run a model, data are needed to input into the model. While designing the conceptual model or linked models, students will realize what data will be needed. Thus, it is important to consider monitoring and data collection strategies when planning a modeling project so that modeling teams do not end up with data that are not useful or missing data that would have been useful. With interdisciplinary modeling, this can be even more important when considering the coupling of models that
may operate at different scales. It is important for students to discuss how they might choose an appropriate scale for data collection in order to "match boundaries" between models.

With every modeling project, there is always a problem with the lack of good data. The reality is that one can never have enough data. Students should discuss the difficulty of the collection of "good" data. Indeed, it is important for students to get exposure to field data collection so that they have a sense of how difficult it is to collect "good" data and thereby learn about issues of accuracy.

6.4.5. Characteristics of Models to be Used in the Course

There was some discussion of the appropriate characteristics of models to be used and introduced in a course on interdisciplinary modeling. A pervasive theme throughout the workshop was that hands-on applications or demonstrations of models would be useful for a course. Thus, it would be useful to develop computational examples that could be used at different points in the course. For example, Dr. Fritsen created several STELLA modules to demonstrate dynamic equilibrium and other systems-level concepts that he uploaded to the Aquamod website. Physical models could also be used to illustrate concepts (e.g., use a bucket of water to look at water-in/water-out for a basic systems-level understanding). All agreed that students should have varying levels of knowledge and familiarity with each discipline, so models should have an appropriate level of complexity and there would be a challenge in determining appropriate computer languages to work in (e.g., Matlab versus R). Some suggested that there should be a programming language component to the class and it would be useful to have students learn the mechanical side of models and take some time to fumble through code. It was recommended that open source models should be used where possible so that students could have access to the models without paying huge costs. In some cases, ‘pre-packaged examples’ could be used, as many popular models have tutorials or example applications for training purposes. Regardless, a list of open source software should be provided with websites for downloading these models.

6.4.6. Additional Modeling Issues or Topics That Should Be Covered

Participants suggested that it would be useful to have discussions and exercises regarding how to quantify data and model uncertainty and how to deal with it. Another participant suggested that at least one or two lectures should be included regarding the importance of an historic perspective in setting up, using, and testing models. In addition, there should be lectures on testing and calibrating models in both disciplinary and interdisciplinary contexts. A point was made that students often learn as much or more when models do not work, so lecturers should not refrain from providing examples of failed projects. These topics could also lead into discussions of the role of models in adaptive management. There could be some discussion or debate of the advantages and disadvantages of one-way versus two-way versus cyclical modeling combinations. Another suggestion was to have someone from the US Army Corps of Engineers’ Hydrologic Engineering Center do a guest lecture to talk about applications of their software. Along the same lines, the inclusion of relevant case studies to show what is actually being done with models talked about in class would be useful. An overall survey of available models would be useful. Emphasis on working in interdisciplinary groups should be included.

Other topics or issues that were suggested for inclusion in this course included: the language (jargon) or modeling in different disciplines; data management (i.e., finding and choosing data sources, downloading data, preparing data sets, looking at data, data analysis, what to do about missing data, evaluating the quality of data); how to perform trouble-shooting; how to evaluate error propagation; and determining boundary conditions.

6.4.7. Modeling Issues or Topics That Should Not Be Covered

Some respondents stated that “there were no aspects of this workshop that, given the greater amounts of time that would be available in a full-length course, should not be included.” Others suggested removing the proposal and presentation aspects of Model Exercise #2. Some other suggestions about approaches or issues to avoid were ‘black box’ or ‘canned’ models, providing too much detail on individual models,
introducing unwieldy models (such as HSPF) or models outside each student’s discipline, and programming or diving into the mechanics of models.

6.4.8. Revised Course Outline

Based on the input received during the workshop, a possible revised outline for future workshops or courses on this topic would be as follows:

- General introduction to models and modeling
- Model exercise 1: Model linkage discussions
- Philosophy, history, and ethics of modeling
- Data and models
- Issues of scale
- Statistical modeling
- Uncertainty/errors in models
- Interdisciplinary teamwork and involving stakeholders
- Model exercise 2: Students begin work in interdisciplinary groups
- Hydrologic/watershed modeling
- Snow hydrology modeling
- Flow and transport modeling
- Water quality modeling
- Groundwater/surface water modeling
- Economics modeling
- Atmospheric modeling
- Water resources systems modeling
- Ecological systems modeling
- Ecological modeling (algae)
- Ecological modeling (fish)
- GIS modeling
- MMS modeling
- Model exercise 3: combine models from two disciplines
- Student presentations

6.5. Team Teaching

There was a consensus that a course on interdisciplinary modeling would be best if taught by multiple instructors. This would require coordination and buy-in from faculty, their respective department heads, and college deans. A lead instructor would be needed to coordinate the various lecturers, but there should be shared responsibilities amongst several instructors for teaching the classes, fairly grading assignments, and conducting lab exercises. A commitment on the part of the multiple instructors to attend all lectures even if they were not lecturing would be important. The course could be taught on multiple campuses through communication portals such as Access Grid Nodes that allow video conferencing and real-time technology transfer. In this case, there should be a local campus leader at each participating campus. Obviously, team teaching would require a lot of coordination, but it would also provide an opportunity for faculty to demonstrate effective interdisciplinary interaction to students.

The Modular Course option that was discussed earlier (see Section 6.2) would require an additional aspect of coordination to offer the disciplinary modeling courses in the same semester or quarter at the same time, especially if the disciplinary courses already exist and are currently taught at different times.

6.6. Textbook

There was general agreement that a virtual textbook would be a suitable alternative to a printed textbook. This option would provide the most flexibility and provide the simplest way to ensure that the information
did not become out-of-date before making it into print. The existing web resource (http://swiki.dlese.org/aquamod/) is the first step towards development of a virtual textbook. Any textbook developed should "be about modeling in general and have an on-line component that could be updated regularly" to stay on top of new technology and information. Another participant suggested a "reference manual" and "not a full-blown textbook," and another suggested "I would not pursue this avenue immediately and wait to see how the class develops over the next few years. Use the website and its various future iterations to guide what is placed in the textbook." Several participants thought revolving the contents around a unifying theme (for example, Lake Tahoe) would provide a more readable and useful textbook.

One issue with a virtual textbook is the need for faculty/staff hours to keep it up-to-date. Revisions could occur annually or on an as-needed basis. There would need to be some process for submissions and for review. One option would be to assign a "chapter editor" for each topic. Editors would be responsible for reading submissions, reviewing proposed changes or additions, and determining if the information is appropriate for inclusion. The website (or DLESE "Collection") would require use of name and password to allow a gate-keeper to track changes.

Additionally, an index and table of contents would need to be developed. This could be tackled further down the road. Funding for such a venture could be sought from or in cooperation with individual institutions, NSF and/or DLESE.

6.7. Suggestions for Website Collection of Resources

The proposed scope of web collection is "to provide a resource for instructors wishing to teach this type of course on Interdisciplinary Modeling for Aquatic Ecosystems." Participants agreed that for each topic, the following items will be included: brief description of the lecture topic; lecture objective; lecture information sheet covering scale issues, inputs, outputs, assumptions, limitations, and boundary conditions; list of key definitions; lecture summary; lecture PowerPoint presentation; model overview with a list of frequently-used models; links to web resources (i.e., models, user manuals, data sets, freeware models, etc.); proposed model exercises or student assignments; case studies; and references. In the future, video-taped lectures could be posted on the website. Many of these materials are already available on the temporary DLESE website (http://swiki.dlese.org/aquamod/) and could easily be converted onto a permanent website. This site could be hosted at UNR and provide a resource for instructors to develop lectures and use exercises.

7. Dissemination of Workshop Materials and Outcomes

A subset of the faculty group gathered together to discuss dissemination of the workshop materials and outcomes. The primary suggestions for publicizing the workshop/course were 1) present the results at conferences, 2) journal publications, 3) brief synopsis in newsletters; and 4) other venues.

Conferences: Dr. Saito and Ms. Segale will assemble a "canned presentation" that will be available for any faculty present at the workshop to use. The following conferences were recommended as venues to disseminate information about the course development and lessons learned from the workshop:

- American Ecological Engineering Society (AEES), April 2006, Berkeley - Grismer
- American Geophysical Union (AGU), December 2005, San Francisco – Grismer
- American Geophysical Union (AGU), Spring 2006, Baltimore – Welty
- American Society of Limnology and Oceanography (ASLO), June 2006, Victoria – Saito
- American Water Resources Association (AWRA)
- California Society for Ecological Restoration (SERCAL)
- Ecological Society of America (ESA)
- Environmental and Water Resources Institute (EWRI), May 2006, Omaha – Saito
- Federal Interagency Modeling, April, 2006, Reno – Saito and Leavesley
Journal Publications: The following journals should be contacted about publishing a paper on the results from this workshop:

- American Water Resources Association, JAWRA Special Feature
- Ecological Engineering
- Ecological Modelling
- Ecology
- An education journal such as GS Sciences Education Journal – Grismer and Segale
- Universities Council on Water Resources (UCOWR)

Publication in Newsletters: A brief synopsis (3 - 4 pages) could go into the following newsletters to promote the course curriculum and workshop materials:

- EOS “Transactions” Hydrology section – Welty and Saito
- Frontiers in Ecology – DeAngelis
- American Water Resources Association (JAWRA) Impact
- ASLO “Dialogue”

Other Venues:

- Cyber Seminar in the Spring – Saito
- Digital Library for Earth System Education (DLESE) – Olds

8. Next Steps

Dr. Saito and Ms. Segale are currently finalizing the collection of course curriculum materials for interdisciplinary modeling for aquatic ecosystems for submission to DLESE. It is expected that resources that will be developed for distribution through the website include lectures (including background material, PowerPoint slides (if available), links to relevant publications or other websites, etc.), modeling exercises, and lab or field exercises. When the course website is finalized, DLESE will post an announcement of this site through its “News and Opportunities Section.” An email listserve has been established for ongoing communication and feedback about the curriculum.

Dr. Saito will offer a course on Interdisciplinary Modeling for Aquatic Ecosystems in the spring of 2007 as a regular semester course. The course will be team-taught by multiple instructors and will include collaborative teaching methods for presenting the topics and grading the assignments. It is expected that this course will be held every other year as a 700-level (i.e., second-year graduate student only) course. The course will have a regular University of Nevada, Reno (UNR) course number. Discussion has begun on the possibility of a multi-campus collaboration in offering the course jointly between UNR, Desert Research Institute, and the University of California at Davis (UCD). Such a course could be held during the summer at Lake Tahoe at UCD’s new Tahoe Environmental Research Center.

9. References


Appendices

Appendix A: Participant List
Appendix B: Course Syllabus
Appendix C: Pre-Workshop Lecture Information
Appendix D: Synthesis of Lectures and Exercises [includes short synthesis of each lecture/exercise]
Appendix E: Model Exercise #1 Directions
Appendix F: Model Exercise #1 Results
Appendix G: Model Exercise #2 Directions
Appendix H: Notes from Key Observation Discussions
Appendix I: Pre-Workshop Assessment Survey and Survey Results
Appendix J: Post-Workshop Assessment Survey and Survey Results