Fusing Science and Solutions

CUAHSI’s Third Biennial Colloquium on Water Science and Engineering
Boulder, CO
July 16 - 18, 2012
Acknowledgements
CUAHSI Members
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UCAR & NCAR Maps
  - Area Map
  - Center Green Conference Room Maps
Plenary Speaker Biographies
  - Roger Pielke, Jr., University of Colorado at Boulder
  - Thomas Dunne, University of California, Santa Barbara
  - Soroosh Sorooshian, University of California, Irvine
Invited Speaker Abstracts
Poster Abstracts
Information on Boulder
  - Boulder Map(s)
  - Dining Guide
Acknowledgements

CUAHSI would like to acknowledge the contributions, support and assistance from the following organizations and individuals:

The National Science Foundation. This meeting is being supported, as part of a cooperative agreement with CUAHSI – NSF/EAR-0753521.

University Consortium for Atmospheric Research (UCAR) for providing facilities and logistical support. In particular Larry Winter, NCAR Deputy Director, for authorizing sponsorship of the meeting, David Gochis, NCAR Research Application Laboratory, and The Institute for Integrative and Multidisciplinary Earth Studies, for serving as the official meeting host. Additionally, Debbi Griffin, Karen Griggs and Shanna Zakas, for meeting planning and facilities support.

Jim McNamara, for leading the organization of the meeting and technical content. Adam Ward and Jay Zarnetske for their contribution to the graduate student program and the session conveners: Martyn Clark, David Tarboton, Todd Rasmussen, Adam Milewski, John Selker, Larry Murdoch, Peter Troch, and Ken Potter.

CUAHSI Member Institutions for their continuing support. CUAHSI Corporate Affiliates for their support of CUAHSI and water science.

Aquatic Informatics, Inc.

Kisters – Pioneering Technologies

Sea-Bird Scientific

And, the CUAHSI staff, Jessica Annadale, Lisa Gray, Jonathan Pollak, Jennifer Arrigo and Kayla Berry for their efforts in organizing and managing this meeting.
Acknowledgements

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• Past Chair
º Chair-elect

Image credit: Program cover photo – Aaron Packman, Northwestern University
# CUAHSI Members

## Institutional Members

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<th>AK</th>
<th>University of Alaska - Fairbanks</th>
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## Affiliate Members

| IL | Eastern Illinois University - Illinois State University - University of Illinois |
| MA | Smith College |
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| NC | RTI International |
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| CAN | CIMA Research Foundation |

| DNK | University of Copenhagen |
| GBR | Centre for Ecology and Hydrology |
| ITA | ITA |
Detailed Schedule
## 2012 CUAHSI BIENNIAL DETAILED SCHEDULE

### Sunday, July 15, 2012

<table>
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<tr>
<th>TIME</th>
<th>SESSION</th>
<th>ROOM</th>
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<tbody>
<tr>
<td>4:00-6:00PM</td>
<td>Graduate Student Reception</td>
<td>Mesa Lab</td>
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<td>(Transportation will be provided to Mesa Lab leaving Center Green Campus at 3:30PM, with return trips to Center Green and conference hotels)</td>
<td>Tree Plaza</td>
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### Monday, July 16, 2012

<table>
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<tr>
<th>TIME</th>
<th>SESSION</th>
<th>ROOM</th>
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<tr>
<td>8:30-8:45AM</td>
<td>General Opening &amp; Welcoming Remarks</td>
<td>Auditorium</td>
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<td></td>
<td>Richard Hooper, Executive Director, CUAHSI</td>
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<td>Witold Krajewski, University of Iowa, CUAHSI Chair</td>
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<td>Jim McNamara, Boise State University</td>
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<tr>
<td>8:45-9:45AM</td>
<td>Keynote: Roger Pielke, Jr., University of Colorado at Boulder - “Policy Relevant Science: A Minefield where Uncertainty, Ignorance and Policy Meet”</td>
<td>Auditorium</td>
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<tr>
<td>8:30-6:00PM</td>
<td>Posters Available for Viewing</td>
<td>1210, Lobby</td>
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<tr>
<td>9:45-10:00AM</td>
<td>Break</td>
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<tr>
<td>10:00-12:00PM</td>
<td>Session 1: Bridging the Gap between Models and Observations</td>
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<td>10:00</td>
<td>Moderator: Martyn Clark</td>
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<tr>
<td>10:00</td>
<td>Peter Troch – “Hydrologic Analysis of Catchment Behavior through Process-based Modeling”</td>
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<td>10:30</td>
<td>Mark Seyfried – “Natural Constraints on Modeling”</td>
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<tr>
<td>11:00</td>
<td>Enrique Vivoni – “The Challenge of Distributed Hydrologic Models Supported by Observations”</td>
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<tr>
<td>11:30</td>
<td>Andy Wood - “Operational River Forecasting: Practice, Challenges, and Opportunities for Hydrologic Prediction Research”</td>
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<td></td>
<td>Discussion</td>
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<td>10:00-12:00PM</td>
<td>Session 2: Data, Model and Information Sharing Solutions</td>
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<td>10:00</td>
<td>Moderator: David Tarboton</td>
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<tr>
<td>10:00</td>
<td>Anthony Aufdenkampe – “The Integrated Data Management System for Critical Zone Observatories”</td>
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<tr>
<td>10:30</td>
<td>Fred Ogden – “Petascale Hydrologic Modeling - Needs and Challenges”</td>
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<td>11:00</td>
<td>Dan Ames – “HydroDesktop as an Entry Point for Access to and Combination of Data from Multiple Sources Using the CUAHSI HIS”</td>
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<td>11:30</td>
<td>David Tarboton – “HydroShare: An online, Collaborative Environment for the Sharing of Hydrologic Data and Models”</td>
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<td></td>
<td>Discussion</td>
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## 2012 CUAHSI BIENNIAL DETAILED SCHEDULE

**12:00-2:00PM**  
Lunch  
Lobby

**2:00-4:00PM**  
**Session 3: Learning from Disasters**  
**Moderator: Adam Milewski**  
2:00 **John England** – “Floods and Society: Lessons from Extremes”  
2:30 **David Yates** – “Drought and Heat in the Southwestern U.S.: Perspectives from Paleo, Recent and Future Conditions”  
3:00 **David Kreamer** – “Water and Sanitation in the Developing World – Can Hydrophilanthropy Adequately Address the Quiet, Persistent Disaster?”  
3:30 **Paul Hsieh** – “Application of Science in Stopping the Deepwater Horizon Oil Spill”  
Discussion

**2:00-4:00PM**  
**Session 4: Large-scale Experiments 1**  
**Moderator: John Selker**  
2:00 **Gordon Grant** – “Achieving Criticality: Challenges and Prospects for the Critical Zone Observatory (CZO) Network”  
3:00 **Jie Liu presenting on behalf of Chunmiao Zheng** – “An Overview of the Heihe River Basin Ecohydrological Research Initiative in Northwestern China”  
3:30 Discussion

**2:00-6:00PM**  
Mixer and Poster Session with Author(s) Present  
Lobby

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**Tuesday, July 17, 2012**

**7:30–8:15AM**  
Registration  
Lobby

**8:15-8:30AM**  
Maura Hagan, NCAR Deputy Director  
Auditorium

**8:30-9:45AM**  
Plenary: “Reds” Wolman Lecture - Tom Dunne, University of California, Santa Barbara - “The Evolution of Floodplain Complexity”  
Auditorium

**8:30-6:00PM**  
Posters Available for Viewing  
Lobby

**9:45-10:00AM**  
Break  
Lobby

**10:00-12:00PM**  
**Session 5: Large-scale Experiments 2**  
**Moderator: John Selker**  
10:00 **Roger Bales** – “The Southern Sierra CZO as a Template for the American River Hydrologic Observatory”
2012 CUAHSI BIENNIAL DETAILED SCHEDULE

10:30  David Goodrich – “Experimental Watersheds as a Platform for Food security and Sustainability Research: The Long-Term Agricultural Research (LTAR) Network”

11:00  Danny Marks – “Networking Hydrologic Observatories for Large-scale Climate Change Assessment: Is It Possible?”

11:30  Discussion

10:30-12:00PM  Session 6: Advances in Community Modeling
Moderator: Larry Murdoch

10:00  Martyn Clark – “A New Hydrological Model Extension Package for the Weather Research and Forecasting System”

10:30  Don Cline – “Towards a National Water Modeling System”

11:00  Jon Goodall – “Making Hydrologic Models Interoperable, Reproducible, and Easy to Share”

11:30  Reed Maxwell – “Large Scale, High-resolution Simulations of Continental North America with the Integrated, Parallel, ParFlow Hydrologic Model”
Discussion

12:00-2:00PM  Lunch  Lobby

2:00-4:00PM  Focus Group Activities
Focus Group Activity – CUAHSI HIS
Focus Group Activity – Community Perspectives on Field Observatories

3:00PM  Break

4:00-5:00PM  Poster Session with Author(s) Present  1210, Lobby

5:00-6:00PM  Reception & Banquet Dinner
Mesa Lab
Tree Plaza
(Transportation will be provided to Mesa Lab leaving Center Green Campus at 4:30PM, with return trips to conference hotels after dinner)

6:00-8:00PM  Film Showing - “Last Call at the Oasis”  Mesa Lab Auditorium

8:00-10:00PM  Post-film Reception
(Transportation will be provided from Mesa Lab to conference hotels)
## 2012 CUAHSI BIENNIAL DETAILED SCHEDULE

### Wednesday, July 18, 2012

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<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>7:30–8:30AM</td>
<td>Registration</td>
<td>Lobby</td>
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<tr>
<td>8:30-9:45AM</td>
<td><strong>Plenary: Eagleson Lecture - Soroosh Sorooshian</strong>, University of California, Irvine - “Hydrologic Forecasting and the Relative Role of its Three Pillars: Models, Observations and Parameterization”</td>
<td>Auditorium</td>
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<td>9:45-10:00AM</td>
<td>Break</td>
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<td>10:00-12:00PM</td>
<td><strong>Session 7: Coevolution of Hydrologic and Geomorphologic Systems</strong></td>
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<td>10:00</td>
<td>Anne Jefferson – “Timescales of Drainage Network Evolution are Driven by Coupled Changes in Landscape Properties and Hydrologic Response”</td>
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<td>11:00</td>
<td>Taehee Hwang – “Ecosystem Processes at the Watershed Scale: Co-evolution of Hydrology, Forest Canopy, and Geomorphic Systems”</td>
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<td>11:30</td>
<td>Discussion</td>
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<td>10:00-12:00PM</td>
<td><strong>Session 8: Water Resource Sustainability</strong></td>
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<td>10:00</td>
<td>David Hyndman – “Climate Change and Sustainability: Quantifying Impacts to Water, Soil, and Crop Yields”</td>
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<td>10:30</td>
<td>David Goodrich – “An Essential Ingredient for Water Resources Sustainability: Integration of Science and Decision Making”</td>
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<td>11:00</td>
<td>Ken Potter – “A Survey Tool to Inform the Translation of Hydrologic Science to Practice”</td>
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<td>Discussion</td>
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<td>Lunch</td>
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### Workshops

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<tr>
<td>12:00-5:00PM</td>
<td>Predictions Under Change (PUC) Workshop</td>
<td>Kelly Caylor</td>
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<td>1:00-5:00PM</td>
<td>Graduate Student &amp; Early Career Development Workshop</td>
<td>Jay Zarnetske and Adam Ward</td>
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<td>1:00-5:00PM</td>
<td>CUAHSI Hydrologic Information System: Using HIS and HydroDesktop Workshop</td>
<td>Jonathan Pollak and Jeff Horsburgh</td>
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<td>2:00-5:00PM</td>
<td>Distributed Optical Fiber Temperature Sensing Workshop</td>
<td>Foothills Lab2 1003</td>
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<td>Conveners: John Selker and Scott Tyler</td>
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<td>7:30–8:30AM</td>
<td>Registration for Workshops</td>
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<td>8:00-1:00PM</td>
<td>The NCCP and NevCAN: Infrastructure for Acquiring and Accessing</td>
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<td>Climate Change Data in Nevada</td>
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<td>Convener: Michael McMahon</td>
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<tr>
<td>8:00-5:00PM</td>
<td>Predictions Under Change (PUC) Workshop</td>
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<td>Moderator: Kelly Caylor</td>
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<td>9:00-5:00PM</td>
<td>Bringing Data and Modeling Driven Geoinformatics Modules into the</td>
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<td>Convener: Venkatesh Merwade and Ben Ruddell</td>
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Tuesday, July 17, 2012

2:00-4:00PM

Focus Group Activities

CUAHSI Hydrologic Information System (HIS) 1212

HIS Applications 2:00-3:15PM

2:00PM Introduction – CUAHSI and HIS Team
   • Alva Couch

2:10PM Community/User Presentations
Community Members and HIS Users are invited to share their experiences with short presentations on their research using HIS. Confirmed presenters as of July 11th:
   • Kathleen McKee
   • Chris Graham
   • John McEnery
   • Jon Goodall

2:40PM Discussion
Community members are invited to engage the presenters and the CUAHSI HIS team members on their impressions of the current HIS technology. We appreciate feedback on the strengths, weaknesses, and opportunities for improvement in the current system. Are there certain features you would like to see? What would make HIS more useful in your research? Are there certain data sources, types of searches, etc. that you feel would be particularly valuable?

Future Development of HIS 3:15-4:00PM

3:15PM Presentations
Members of the CUAHSI HIS research team will share short presentations on the planned future developments of the HIS System.
   • Jeff Horsburgh
   • David Tarboton
   • Ray Idaszak

3:35PM Discussion and Feedback
Development of new web based data sharing functionality, expansion of the system to additional data types, and the future of HIS
Community Perspectives on Field Observatories - Agenda

Plenary Session
2:00PM Background and Rationale
- New Solicitation for Critical Zone Observatories (12-575)
- How can CUAHSI help those preparing proposals?
  - Directory of existing field sites (LTER, USFS, ARS, USGS)
  - Summaries of past recommendations
- How should network considerations influence site selection?
- Outcomes of this effort
  - Letter to Director of NSF on Community Perspectives
  - Community resources for teams preparing proposals

Topics for Discussion
2:30PM Funding for CZOs: How should NSF allocate $8M/yr?
**NOTE: The Neuse River design considered an operating budget of $3M/yr and a capital budget of $10M for a five-year period when Hydrologic Observatories were being discussed.**
- Is $1M/yr/site sufficient to achieve scientific breakthroughs
- Does the community want 8 sites funded at $1M/yr?
- What about a different distribution of $8M (1 site @ $3M/yr, 1 site @ $2M/yr, 3 sites @ $1M/yr)? Can we get more than 3x the science at 3x the cost?
- What capital is required for instrumentation? Is that a limiting factor in accomplishing scientific objectives?

3:00PM CZO’s as science projects and community facilities
- How do we reconcile Principal Investigator needs to execute scientific study while serving as a community facility?
- Is the LTER model adequate for community use of sites?
- Consider the following aspects of community use and suggest policies:
  - Data Access
  - Data Comparability across sites
  - Site Access

3:30PM Forming a network of CZOs
- CZOs are selected individually based upon scientific merit of the proposed study. Should site characteristics be a factor in site selection to encourage diversity of sites?
- Can networks be defined only by stated hypotheses?
- Can we achieve consensus on a set of hypotheses to be used for network design?
- Should a network be considered only after selection of the initial 8 CZOs?
Plenary Session
4:00-4:15PM  Next Steps
- Selection of Steering Committee
- Community Review Process
- Target Date for letter to Director: December 1, 2012
Plenary Speaker Biographies
Roger Pielke, Jr., University of Colorado at Boulder

Fellow of the Cooperative Institute for Research in the Environmental Sciences (CIRES), Director of the Center for Science and Technology Policy Research at University of Colorado at Boulder

Roger A. Pielke, Jr. joined the faculty of the University of Colorado in 2001. He is currently Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in the Environmental Sciences (CIRES). At CIRES Roger serves as the Director of the Center for Science and Technology Policy Research. He also served as the Director of Graduate Studies for the University's Graduate Program in Environmental Studies from 2002-2004. Roger's current areas of interest include understanding the relations of science and politics, technology policy in the atmospheric and related sciences, use and value of prediction in decision making, and policy education for scientists. In 2000, Roger received the Sigma Xi Distinguished Lectureship Award and in 2001, he received the Outstanding Graduate Advisor Award by students in the University of Colorado's Department of Political Science. Before joining the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research.

Soroosh Sorooshian, University of California, Irvine

Director of the Center for Hydrometeorology & Remote Sensing

Soroosh Sorooshian is the Director of the Center for Hydrometeorology & Remote Sensing (CHRS) and Distinguished Professor of Civil & Environmental Engineering and Earth System Science Departments at UC Irvine. Prior to 2003 he was a faculty at the University of Arizona for 20 years. His area of expertise is Hydrometeorology, water resources systems, climate studies and application of remote sensing to hydrology and water resources issues with focus on arid and semi-arid zones.

He is a member of the US National Academy of Engineering (NAE); Member of the International Academy of Astronautics (IAA); Associate Fellow of The Academy of Sciences for developing countries (TWAS). He is a Fellow of a number of societies including, AGU, AMS, AAAS, and IWRA, among others. Dr. Sorooshian is the Past Chair, Science Steering Group (SSG) of Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP); U.S. Member of the Hydrology Commission for WMO; Emeritus member of UCAR Board of Trustees and NOAA Science Advisory Board; Past-President of AGU's Hydrology Section; member of several editorial boards and former editor of AGU's Water Resources Research. He has served on numerous advisory committees, including those of NASA, NOAA, DOE, USDA, NSF, EPA, and UNESCO as well as service to NRC including membership of the Space Study Board (SSB), Water Science and Technology Board (WSTB), and numerous committees. He has testified to both Senate and House sub-committees on earth observations from space and water resources issues.

Among his recent honors are, Recipient of the 4th Prince Sultan Bin Abdulaziz International Prize for Water Resources Management & Protection in 2010; recipient of the NASA Distinguished Public Service Medal, 2005, and AMS Walter Orr and Horton lectureships.
Thomas Dunne is a Professor of Environmental Science & Management and of Earth Science at the University of California Santa Barbara. He conducts field and theoretical studies in hillslope and fluvial geomorphology, and in the application of hydrology and geomorphology to landscape management and hazard analysis.

He obtained a B.A. in Geography from Cambridge University in 1964 and a PhD in Geography from The Johns Hopkins University in 1969. His doctoral research involved a field investigation of runoff processes under rainfall and snowmelt conditions in northern Vermont.

While working for the USDA Agricultural Research Service (1966-1969) and McGill University (1971-1973), he conducted research on the effects of topography, soil characteristics, and vegetation on runoff processes under rainfall and snowmelt in Vermont and subarctic Canada. While teaching at the University of Nairobi, Kenya (1969-1971), he initiated a long-running research interest in African environments, including experimental studies of runoff and erosion processes, and statistical studies and field surveys of the effects of land use on hillslope erosion and river-basin sediment yields. He continues to use data from the experimental studies to model sediment transport and hillslope evolution, one of his long-term research interests.

While teaching in the Department of Geological Sciences at the University of Washington (1973-1995), he studied landsliding and debris flows; drainage-basin sediment budgets in natural and managed forests; tephra erosion and debris-flow sedimentation on active volcanoes; and sediment transport and channel morphology in sand-bed and gravel-bed river channels. He also conducted several studies related to resource management, such as the impacts of gravel harvesting on the river-channel sedimentation and morphology; impacts of timber harvest on erosion and sedimentation; and effects of flow diversion and reservoir management on sedimentation.

Since moving to California he has studied hydrology, sediment transport, and floodplain sedimentation in the mainstem Amazon River of Brazil and in the Andes Range and adjacent floodplains of eastern Bolivia. He currently works with several graduate students, postdocs, and colleagues on sediment transport, channel change, oxbow lake production, and river temperatures in the Sacramento, Merced, and San Joaquin rivers in the Central Valley of California.
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Keynote
Monday, 8:30AM-9:45AM

Policy Relevant Science: A Minefield where Uncertainty, Ignorance and Politics Meet
Roger Pielke, Jr., University of Colorado at Boulder

It is no longer controversial for call for science to be more relevant to decision making. For instance, the theme of this CUAHSI biennial meeting is focused on “how to bridge gaps between science and solutions.” However, making science relevant to real world decisions can be a minefield, especially for research that deals with complex and non-stationary phenomena and decisions that involve high stakes and disputes over closely held values. On issues as important as those involving water, scientific knowledge must be a key consideration in decision making, but there are better and worse ways to incorporate science in how we choose to act. Consequently, how scientists choose to “bridge gaps” can make a big difference in real-world outcomes. This talk will explore several cases of the use and misuse of science in decision making, and raise a few perhaps counterintuitive lessons from that experience.

Session 1: Bridging the Gap between Models and Observations
Monday, 10:00AM-12:00PM

Hydrologic Analysis of Catchment Behavior through Process-based Modeling
Peter Troch, Department of Hydrology and Water Management, The University of Arizona

Developing predictive models of catchment response across physiographic gradients is an important yet difficult to achieve objective. Here we present a method that uses our current level of hydrological understanding, expressed in the form of a process-based model, to interrogate how climate and catchment characteristics interact to produce observed hydrologic response. The model uses topographic, geomorphologic, soil and vegetation information at the catchment scale and conditions parameter values using readily available data on precipitation, temperature and streamflow. It is applicable to a wide range of catchments in different climate settings. We have developed a step-by-step procedure to analyze the observed hydrologic response and to assign parameter values related to specific components of the model. We applied this procedure to 12 catchments across a climate gradient east of the Rocky Mountains, USA. We show that the model is capable of reproducing the observed hydrologic behavior measured through hydrologic signatures chosen at different temporal scales. Next, we analyze the dominant time scales of catchment response and their dimensionless ratios with respect to climate and observable landscape features in an attempt to explain hydrologic partitioning. We find that only a limited number of model parameters can be related to observable landscape features. However, several climate-model time scales, and the associated dimensionless numbers, show scaling relationships with respect to the investigated hydrological signatures (runoff coefficient, baseflow index, and slope of the flow duration curve). Moreover, some dimensionless numbers vary systematically across the climate gradient, possibly as a result of systematic co-variation of climate, vegetation and soil related time scales. If such co-variation can be shown to be robust across many catchments along different climate gradients, it opens perspective for model parameterization in ungauged catchments as well as prediction of hydrologic response in a rapidly changing environment.
Abstracts – Invited Speakers

Natural Constraints on Modeling
Mark Seyfried, United States Department of Agriculture – Agricultural Research Service

A common complaint among researchers is that, in spite of many years of model development and massive improvements, management tends to favor old, outdated and largely discredited models. Aside from the practical considerations, which are certainly valid but probably not determinant, many of the reasons for this resistance are not complimentary. Part of the resistance, however, is due to a suspicion that the models are overly complex and specialized using data beyond what they think is reasonable. While researchers tend to be very forthcoming about computational details (which managers generally do not appreciate), they tend to have little to say about the data needed for the models or the precision of the modeling results (things that managers tend to be more interested in). From a field science perspective, I think they have some legitimate concerns. Model parameter precision depends on the variability of that parameter in nature. This can vary enormously over time or location. This fundamental limitation is rarely mentioned in modeling work but would seem to be critical for establishing credibility.

The issue is acknowledged, at least indirectly. It is addressed in distributed models by reducing the cell or polygon size, with the expectation that smaller the areas are more homogeneous. This is no doubt true in general, but the benefits of increased resolution are rarely documented. A common result is that model resolution far exceeds the data resolution, giving false sense of how variability is represented on the landscape. Similarly, the high demand for data for more sophisticated models often results in the use of poor quality data. This too is rarely acknowledged but rather it seems that the assumption is that data are somehow cleansed after it has been used as model input. We use a combination of long-term soil data and intensive monitoring using fiber-optic distributed temperature sensing to illustrate these points. In this case, the data were collected at the Reynolds Creek Experimental Watershed, a long-term research site. We also illustrate modeling strategies that more explicitly accommodate different levels of precision within the same simulation. A more explicit consideration of the data impacts on simulation results may improve the acceptance level among some managers and have the additional benefit of a better understanding of model results.

The Challenge of Distributed Hydrologic Models Supported by Observations
Enrique R. Vivoni1,2

1School of Earth and Space Exploration, Arizona State University, Tempe, AZ
2School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ

After several decades of development and applications, distributed watershed models are now common tools in hydrologic research and increasingly used in practice. Unfortunately, the sophistication of these tools has not been accompanied by comparable levels of observational data collection. Ultimately, predictions from distributed watershed models need to be verified to build confidence in their ability to simulate the past and subsequently the future, under changing conditions. This talk will describe our efforts to develop, apply and test a distributed watershed model for semiarid regions in the southwestern United States and northwestern Mexico. We will provide examples from forested mountain, semiarid desert and subtropical shrubland systems which all have marked seasonality due to winter snowfall and the summer North American monsoon. Our previous efforts include comparisons to eddy covariance data, distributed soil moisture patterns and runoff observations, among others. After building model confidence, we explore the underlying patterns, processes and mechanisms in the distributed simulations to identify emergent behavior. The intent of this synthesis stage is to infer generalizable features of the hydrologic system that may help explain the observed data and build predictive capacity for other settings. We also discuss prospects for improved joint use of distributed
Abstracts – Invited Speakers

watershed models and distributed observations from ground, aerial and satellite platforms.

**Operational River Forecasting: Practice, Challenges, and Opportunities for Hydrologic Prediction Research**

Andrew Wood, NOAA/NWS Northwest River Forecast Center, Portland, OR

NOAA/NWS River Forecast Centers perform hydrologic analysis and modeling to make streamflow predictions on a daily basis for the entire US. These forecasts serve purposes ranging from emergency flood risk management to reservoir and water infrastructure management for regional water supply allocations, and entail direct and active interactions with users throughout the water sector. RFC predictions leverage the efforts of over 100 career forecasters drawn from fields such as meteorology, engineering and hydrology, and are supported by researchers at the NWS Office of Hydrology and other NWS laboratories. Most RFC forecasts are generated using the lumped Snow17 and Sacramento models via a process that combines automated and manual, subjective components. These forecasting models and the basic elements of the practice have not changed substantially in the last decade, and several research publications have suggested that skill of RFC forecasts is not evolving in pace with advances in the research community. One element, however, has changed: the decades-old legacy platform for forecasting, the NWS River Forecast System (RFS), has recently been replaced by the Community Hydrologic Prediction System (CHPS), which is built on a modern, flexible and extensible software architecture. This presentation illustrates the current RFC forecast practice, described CHPS, and explores the question of whether and how the CHPS transition can facilitate an evolution in RFC forecast practice. Notable efforts, priorities and opportunities to close science gaps between RFCs and the hydrology research community will also be discussed.
Abstracts – Invited Speakers

Session 2: Data, Model and Information Sharing Solutions
Monday, 10:00AM-12:00PM

The Integrated Data Management System for Critical Zone Observatories
Anthony K. Aufdenkampe, Mark W. Williams, Ilya Zaslavsky, David G. Tarboton, Kerstin A Lehnert, Jeffrey S. Horsburgh, Emilio Mayorga

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The Critical Zone Observatory (CZO) program is an NSF-supported multi-institutional, collaborative effort to advance scientific understanding of environmental interactions in the critical zone, which extends from bedrock to the atmospheric boundary layer and spans multiple scales and disciplines. An integrated CZO information system that facilitates seamless analysis of hydrology, geochemistry and geomorphology data within and across six CZO sites is being developed. This is comprised of easy to use tools for site data managers to publish their quality controlled data and tools for scientists to identify and access data of interest so that they can use data from multiple sites to address cross discipline and cross CZO hypotheses. It is based on the following principles: (1) building on the experience of environmental observatory projects and leveraging CI development efforts from neighboring disciplines; (2) relying on community standards for data exchange and on state-of-the-art data cataloguing, discovery, integration and visualization tools; (3) preserving the autonomy and minimizing requirements on individual research sites, while creating centralized CI components that achieve cross-CZO integration and are scalable and extensible; (4) ensuring that CZO data are available both in a human-readable form at individual CZO sites and via web services from the centralized components of the system.

The current prototype is designed as an evolving, operational system capable of supporting data integration at different interoperability levels: from common dataset-level metadata, which enables data discovery and retrieval regardless of the type or domain system that manages it, to compatible semantics, which ensures that metadata can be unambiguously interpreted in a cross-disciplinary setting, to compatibility at the levels of service interfaces and information model encodings, such as those standardized by the Open Geospatial Consortium, which enables flexible programmatic access to the data from analysis and modeling applications.

The prototype builds on infrastructure components developed mostly within the CUAHSI Hydrologic Information System project, and is designed to extend to geochemical and other data being collected by CZOs. At this early stage, the CZO Central discovery system currently indexes about 90 resources, including services and display files, while brokering web service access to over 15 million hydrologic observations collected at CZOs.
Petascale Hydrologic Modeling - Needs and Challenges
Fred L. Ogden1*, Craig C. Douglas2, Scott N. Miller3, Ye Zhang4

1Dept. of Civil & Architectural Engineering, Univ. of Wyoming
2Dept. of Mathematics, Univ. of Wyoming
3Dept. of Ecosystem Science and Management, Univ. of Wyoming
4Dept. of Geology and Geophysics, Univ. of Wyoming

In recent decades, computational models have been developed to solve point-scale process models using physics-based or conceptual approaches. The integration of these processes across space-time has been limited by computational power to either high-resolution over small spatial domains, or coarse resolution over large spatial domains. These modeling approaches have lead to improved understanding at both small and large scales, but have required parameterization of important phenomenon, and the corresponding lack of model sensitivity to changes and uncertainties in parameter values. The CI-WATER project aims to develop a peta-scale modeling approach to simultaneously allow simulation of high-resolution processes such as snow melt, vegetation dynamics and runoff generation at the scale of an individual hillslope, while integrating over large areas using an unstructured grid. The CI-WATER High Performance Computing (HPC) model, which is being developed in cooperation with the US Army Corps of Engineers, Engineer Research and Development Center, and the NCAR Research Applications Laboratory, will include needed physics-based process modules and parameters to simulate future change with a minimum of conceptualizations. Significant challenges exist, however. The ultimate objective of the model development is to simulate large watersheds such as the Upper Colorado River above Lake Powell (287,000 km²). This will require generation of an unstructured mesh with over 10^7 nodes, coupling with remote sensing, modeled, and/or space-time interpolated forcing data, linkage of multi-physics flow process solvers, and parameter assignment and estimation using a reasoning engine. Optimization of the model mesh, visualization of inputs and and model outputs as well as coupling with data from diverse sources represent further challenges. The CI-WATER HPC model architecture and initial tools are discussed, as well as development activities and data linkages.

HydroDesktop as an Entry Point for Access To and Combination of Data from Multiple Sources Using the CUAHSI HIS

Discovering and accessing hydrologic and climate data for use in research or water management can be a difficult task that consumes valuable time and personnel resources. Until recently, this task required discovering and navigating many different data repositories, each having its own website, query interface, data formats, and descriptive language. New advances in cyberinfrastructure and in semantic mediation technologies have provided the means for creating better tools supporting data discovery and access. In this paper we describe a freely available and open source software tool, called HydroDesktop, that can be used for discovering, downloading, managing, visualizing, and analyzing hydrologic data. HydroDesktop was created as a means for searching across and accessing hydrologic data services that have been published using the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS). We describe the design and architecture of HydroDesktop, its novel contributions in web-services based hydrologic data search and discovery, and its unique extensibility interface that enables developers to create custom data analysis and visualization plug-ins. The functionality of HydroDesktop and some of its existing plug-ins are introduced in the context of a case study for discovering, downloading, and visualizing data.
HydroShare: An online, Collaborative Environment for the Sharing of Hydrologic Data and Models

David Tarboton*, Utah State University; Ray Idaszak, RENCI; Dan Ames, Idaho State University; Jeff Horsburgh, Utah State University; Jon Goodall, University of South Carolina; Larry Band, University of North Carolina; Venkatesh Merwade, Purdue University; Alva Couch, Tufts University; Jennifer Arrigo, CUAHSI; Richard Hooper, CUAHSI; David Valentine, San Diego Supercomputer Center

HydroShare is an online, collaborative environment being developed for the sharing of hydrologic data and models to expand the data sharing capability of the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS). The development of HydroShare has just started, as a five-year project supported by the NSF Software Infrastructure for Sustained Innovation program (www.nsf.gov/si2/). The goal of HydroShare is to enable scientists to easily discover and access data and models, retrieve them to their desktop or perform analyses in a distributed computing environment that may include grid, cloud or high performance computing model instances as necessary. They will then be able to publish outcomes (data, results or models) back to the system, sharing with whom they choose and use the system as a platform for collaboration. HydroShare will build on and draw upon elements from a number of existing systems. CUAHSI HIS is an Internet based system comprised of hydrologic databases and servers connected through web services as well as software for data publication, discovery and access. HIS's flexibility in storing and enabling public access to similarly formatted data and metadata has created a community data resource from public and academic data. Hydroshare will broaden the classes of data accommodated, and expand capability to include the sharing of models and model components. Hydroshare will use content management and science gateway functionality, such as from HUBzero to support community interactions. HydroShare will use distributed data management middleware, such as the integrated Rule-Oriented Data System (iRODS) to perform rule based background actions that filter and develop metadata catalogs and provide automated translation and parsing for the enhanced classes of data HydroShare supports. HydroShare is expected to provide new opportunities for information integration that transforms the way hydrologic knowledge is created and applied.
Abstracts – Invited Speakers

Session 3: Learning from Disasters
Monday, 2:00PM-4:00PM

Drought and Heat in the Southwestern U.S.: Perspectives from Paleo, Recent and Future Conditions
David Yates, UCAR

Evidence suggests that the Colorado River Basin has exhibited prolonged dry periods over the last several millennium, although the variability of climate over the recent period is dramatic unto itself. Studies have suggested that even with a 20% reduction in annual Colorado River flow due to “climate change” relative to historic flows, management practices could mitigate impacts, although analysis of impacts often only consider reservoir depletion. This study looks at the broader implications of severe drying on southwestern water supplies, using an integrating model of water and energy for the region.

Water and Sanitation in the Developing World – Can Hydrophilanthropy Adequately Address the Quiet, Persistent Disaster?
David Kreamer, University of Nevada, Las Vegas

Major societal upheaval can result from the scarcity of clean water. During the period 1968 – 1975, a drought in Sub Sahelian Africa killed 200,000 people and millions of herd animals, but the effects lasted much longer. There were shifts in population, and the economy of the region (8 countries) was devastated for decades. Loss of livestock and agriculture resulted in many thousands of children sustaining brain damage from inadequate nutrition. The United Nations has recently estimated that 1.1 to 1.2 billion people do not have access to clean drinking water, and 2.5 billion people were still without improved sanitation in 2010 with about 1.1 billion practicing open defecation. The UN has also noted that future water shortages could promote international conflict, and Ban Ki-moon, UN Secretary General, notes that "Access to sanitation is deeply connected to virtually all the Millennium Development Goals, in particular those involving the environment, education, gender equality and the reduction of child mortality and poverty".

The response to this persistent ongoing challenge is often hydrophilanthropic efforts to increase clean water supply and sanitation, by a plethora of organizations including government based groups, educators, and non-government organizations (both faith-based and non-faith based). These groups have varying motivations, funding sources, competencies, and experience. Sometimes efforts of the best-intentioned hydrophilantropists can do more harm than good in local communities, specifically, sowing the seeds of unrest and future conflict. Solutions to clean water shortage and sanitation problems in the Developing World can be top-down including:

- Defining Acceptable Risk for Populations and Ecosystems,
- Numerical, Concentration-Based Standards and Action Levels for a broad spectrum of specific contaminants should be developed (beyond World Health Organization - WHO is limited),
- Initiating Risk Based Remediation based on Improved Site Characterization,
- Strengthening Natural Protected Areas,
- Hydrogeological and Water Quality Data Storage information systems and archiving should be unified, not miss important parameters, and be readily available,
- Addressing chemical pollution at many sites, including consideration of small polluters, promotion of a common national vision on Monitored Natural Attenuation and Technical Impracticability, and establishment of early warning leak detection, tracers, and other methods
which could remove the need for remediation.

Solutions can also begin in the local communities (bottom-up) and include:

- Education and training – Community, Primary, University
- Holistic Sanitary Community Improvement
- Increasing Analytical and Technical Capability
- Wellhead Protection
- Improving Enforcement, coupled with uniform interpretation and implementation of regulations

Floods and Society: Lessons from Extremes
John F. England, Jr., Ph.D., P.E., Flood Hydrology Technical Specialist, United States Bureau of Reclamation

Many floods in the United States have resulted in damages, deaths, and other impacts to society over the past several decades. Overviews of particular flood events are presented, to provide a perspective on these disasters and lessons learned. Events such as the Northern California floods in 1997, Hurricane Katrina in 2005, Iowa floods in 2008 (among others) have been used to improve scientific investigations on extremes, and revisit planning and operations tools used in practice. Extreme weather and climate information are used to assess potential impacts to infrastructure and society in several areas, such as dam safety, flood control, water supply operations, and for risk-based decision making. Some examples that encompass short-term and long-term planning decisions include: hydrologic hazards for dam safety; evaluating flood control rule curves; examining options on additional reservoir storage; and flood forecasting. Extreme precipitation and weather-related phenomena are typically needed with the following characteristics: fine spatial (watershed) scales ranging from a few hundred to thousands of km²; fine temporal scales ranging from minutes to days (possibly seasons); and annual exceedance probabilities (AEPs) ranging from 1/50 to < 1/10,000. Spatial variability of precipitation within these orographic watersheds is high. Design flood planning methods in the United States have traditionally focused on frequency analysis of peak flows for floodplain management; and Probable Maximum Flood estimates for dams and nuclear facilities. Recent academic and Federal agency research is being used to examine potential changes to standard flood hydrology planning tools, and move to risk-based methodologies, and is highlighted. Additional needs on data, research to operations, and communication on extreme floods are noted. Ongoing challenges and opportunities are highlighted, include the lack of consensus on “extremes” and climate variability and change.

Application of Science in Stopping the Deepwater Horizon Oil Spill
Paul Hsieh, United States Geological Survey

Following unsuccessful attempts during May and June, 2010, to contain the Deepwater Horizon oil spill by methods such as the containment dome and top kill, and with the relief well not expected to be completed until September, plans were drawn up to install a capping stack on top of the Macondo well to shut the flow of oil. Such a shut in, however, was not without risks, stemming from concerns that the well casing might have been damaged during the initial explosion. The rising shut-in pressure could force oil to leak out of the damaged casing into the surrounding formation, initiating a hydraulic fracture that could breach the seafloor. This would result in a renewed and uncontrolled flow of oil into the Gulf of Mexico—a catastrophic development. When the Macondo well was shut in on the afternoon July 15, the shut-in pressure recovered to a level that indicated a leak was indeed possible. A decision will have to be made on whether to reopen the well the next day or to continue the shut in. Although an overnight modeling analysis supported a no-leak scenario, the result was subject to uncertainty. In the end, it was judicious decision making by senior government officials, supported by scientific analyses, that guided
Abstracts – Invited Speakers

the path to ending the environmental disaster. This presentation will discuss some of the challenges facing the scientist while participating in disaster response. The challenges include maintaining communication during chaotic times, analyzing real-time data in a matter of hours, and effectively presenting scientific results to decision makers.
Achieving Criticality: Challenges and Prospects for the Critical Zone Observatory (CZO) Network
Gordon Grant, United States Department of Agriculture, Pacific Northwest Research Station

The CZO program stands at an important juncture as a national scientific program and initiative. The first funding cycle for the first six sites will end in FY 13, and NSF has indicated that there will be an open competition for as many as 8 sites over the next 5 years. These recent developments, particularly at a time of overall Federal budget decline, signify a strengthening of NSF’s commitment and support of the CZO program. This support is largely due to both the successes to date as well as future prospects of the network. Successes include: 1) a fundamentally integrated research program that solicits and incorporates the perspectives, techniques, and analytical insights of a wide range of disciplines, including hydrology, geomorphology, biogeochemistry, soil and ecosystem sciences, and microbial biology; 2) a diversified portfolio of established sites, each of which supports a diversified portfolio of site-focused science, resulting in an explosion of studies on critical zone processes; 3) a demonstrated capacity on the part of at least some of the sites to balance the demands of an on-going observation and measurement program with the ability to respond quickly to scientific opportunities posed by natural disturbances; and 4) a well-equipped and intellectually vibrant “gymnasium” for training ground for the next generation of Earth scientists.

While these strengths strategically position the CZO network, with increased funding comes increased responsibilities, and the planned expansion of the CZO network plus other related developments, poses new challenges for the network. There are clear signals from NSF that the new solicitation will not just be an automatic renewal for the existing sites, but a refocusing and/or expansion of effort around key themes and foci that clearly link research to understand the critical zone with societally relevant issues of change and sustainability. While these questions have implicitly been a part of the existing network, they have not been fully developed to date. Beyond NSF, these challenges reflect expectations on the part of the larger science community, society at large, and the responsibilities inherent in the luxury of being able to do science at a time of rapid and unprecedented planetary change.

Several key challenges stand out if the CZO network is to meet these broadened expectations. Specifically, sites will need to: 1) expand development of integrated, comprehensive, and to the extent possible, quantitative conceptual models of how the critical zone functions and evolves at their location; 2) emphasize studies that specifically leverage the presence of the larger CZO infrastructure; 3) explicitly expand their focus to include observing, modeling, predicting, and explaining environmental change on societally relevant timescales (decadal to centurial); and 4) improve their capacity for keeping doors open to the broadest possible swath of the research community and play well with others, including other observatory programs.

Is the CZO program up to these challenges? How can it be improved? And is the observatory model the best one to meet the rising expectations for monitoring, explaining and predicting environmental change? These questions deserve our attention.
The NEON Observatory: A New Platform for Potential Long-term, Large-scale Hydrologic Observations and Experiments
Heather Powell, National Ecological Observatory Network (NEON)

The National Ecological Observatory Network (NEON) will provide researchers the opportunity to investigate continental-scale patterns by combining investigator-driven measurements with those of the Observatory. NEON is a national-scale research platform for analyzing and understanding the impacts of climate change, land-use change, and invasive species on ecology and features sensor networks, field-based sample collection, and experiments, linked by advanced cyberinfrastructure to record and archive ecological data for at least 30 years. NEON partitions the United States into 20 ecoclimatic domains. Each Domain hosts one, fixed Core Aquatic Site in a wildland area and one Relocatable site. Information on ecologically significant gradients will be captured as Relocatable sites move within a Domain over the course of the Observatory lifecycle. The Aquatic sites include both stream and shallow lakes that house automated, in-situ sensors for surface water chemistry; groundwater height, elevation and temperature; stream flow (velocity, discharge, and stage); and lake water elevation. Groundwater and surface water are also sampled regularly for selected chemical and isotopic parameters at each site. The design of the hydrologic and geochemical data collection will provide continuous, basic information on water and chemical fluxes in streams and lakes, and between groundwater and surface water. These data are intended to support investigator-driven modeling studies, experiments, and additional measurements.

In addition to the freely available data from the NEON Project, the managing authority for the Observatory is designed to manage other large-scale science projects for the research community. Thus, expanding and advancing the capabilities of any individual researcher or group of researchers to perform continental-scale science. The Observatory is constructed and will be operated by an independent 501(c)(3) corporation - NEON, Inc. NEON, Inc. is created to manage large-scale ecological observing systems and experiments on behalf of the scientific community. The company aim is to provide logistical, financial, engineering, and related resources for other large-scale research projects in the future.

An Overview of The Heihe River Basin Ecohydrological Research Initiative in Northwestern China
Chunmiao Zheng¹,², Guodong Cheng³, Bojie Fu⁴, Changqing Song⁵, Honglang Xiao³, Jie Liu¹*

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⁵Directorate of Geosciences, National Natural Science Foundation of China, Beijing, China

This presentation provides an overview of a major new research initiative supported by the National Natural Science Foundation of China for an integrative study of ecological principles, hydrological processes and socioeconomic considerations in the Heihe River Basin (HRB) in northwest China. The HRB is an inland watershed located at the center of the arid zone in East Asia, stretching from the Qilianshan Mountains in the south to the Gobi desert in the north bordering China’s Inner Mongolia Autonomous Region and Mongolia. The total area of the Heihe River Basin is approximately 130,000 km², covering a wide range of climatic, geographical, ecological and hydrogeological conditions, from the high-altitude alpine ecosystem with glaciers and permafrost in the upper HRB, to the intensively irrigated agricultural ecosystem in the middle HRB, to the fragile thinly vegetated desert ecosystem in the lower HRB. The
new research initiative builds on the existing observatory infrastructure and long-term ecohydrological datasets since the 1950s. It seeks to reveal the complex interactions across multiple spatiotemporal scales between the basin hydrologic cycle and diverse ecosystem functioning in a water-limited environment with about 60 new, well-coordinated research projects supported for the next five years. This new research initiative is in essence a grand ecohydrological experiment from which better understanding and new insights on integrated ecohydrological processes are to be gained so as to provide stronger scientific underpinning for sustainable water resource management that maximizes the economic benefits without irreparably damaging the ecosystem.
The “Reds” Wolman Lecture on Humans and Water
Tuesday, 8:30AM-9:45AM

The Evolution of Floodplain Complexity
Tom Dunne, Bren School of Environmental Science & Management, University of California, Santa Barbara

The floodplains of lowland rivers comprise valuable but hazardous landforms used by hundreds of millions of people for settlement, food production, industrial development, and ecosystem conservation. They are characterized by great complexity and dynamism of form and therefore of inundation regime. The most diverse valley floors are associated with migrating, flooding rivers, but many managed floodplains have been radically simplified. Understanding the origin of this dynamic complexity provides a basis for exploiting the desired services and minimizing risks to people. However, an enduring problem in geomorphology and hydrology is the difficulty of identifying causality and providing explanations of the formation and maintenance of extensive landforms with degrees of rigor attainable in laboratory experiments or at intensively monitored field sites. Developing such understanding requires a combination of measurements of processes at natural scale and mathematical modeling to generalize the necessarily sparse measurements.

The foremost driver of floodplain landform construction is the tendency for rivers to shift laterally through bend migration and also to form new channels through floodplain incision. Most research into these processes has emphasized the role of channel hydrodynamics on bend growth, neck cutoff, and oxbow lake production. However, the magnitude of sediment supply can also have an important influence on channel migration. The supply of bed material to a reach accelerates point bar growth, which increases the cross-channel acceleration of flow and intensifies bank erosion and bend growth. The vulnerability of floodplain surfaces to chute incision, which depends on point bar growth, floodplain texture, floodplain gradient, and vegetation cover, limits channel sinuosity and alters the average production rate and length of oxbow lakes. The form and rate of sedimentation in oxbow lakes and thus the length of time they survive as open water bodies before filling depends on the initial diversion angle of the cutoff (and therefore, on average, the sinuosity of the channel), and the relative supplies of bed material and wash load. These themes will be illustrated from studies of gravel-bed rivers and their floodplains in the Central Valley of California.
Abstracts – Invited Speakers

Session 5: Large Scale Experiments 2
10:00AM-12:00PM

The Southern Sierra CZO as a Template for the American River Hydrologic Observatory
Roger Bales\textsuperscript{1,*}, Branko Kerkez\textsuperscript{2}, Stephen Welch\textsuperscript{2}, Martha Conklin\textsuperscript{1}, Steven Glaser\textsuperscript{2}, Robert Rice\textsuperscript{1}, Danny Marks\textsuperscript{3}

\textsuperscript{1}Sierra Nevada Research Institute, University of California, Merced
\textsuperscript{2}Civil & Environmental Engineering, University of California, Berkeley
\textsuperscript{3}United States Department of Agriculture, Agricultural Research Service, Boise, ID

A basin-scale observatory in being developed in the main seasonally snow-covered portion of the American R. basin, which is over 2000 square kilometers in area, to make comprehensive water-balance measurements in support of research by multiple investigators. This basin-scale “instrument cluster” will consist of over 20 local sensor groups, following the design for a local sensor group, or “headwater-catchment-scale observatory” developed at the Southern Sierra Critical Zone Observatory (CZO). Each local instrument group will have 10-20 “sensor nodes” consisting of a snow-depth and temperature sensor, with solar radiation, soil moisture, soil temperature and sap flow measured at a subset of the nodes and local groups. All local groups will have a meteorological station, including precipitation measurements. Individual sensors within local sensor group will be deployed to measure the quantities of interest across variable aspect, slope and vegetation cover. Local sensor groups will be arrayed within the basin to measure attributes across the same variables, plus account for elevation and soil differences. The inter- and intra-group communications will be provided by a sophisticated wireless sensor network. Locations for the local sensor groups for measurement of snow depth and water equivalent was evaluated using rank-based clustering, which proved superior to random placement or geographic clustering. Rank-based clusters remained stable inter-annually, suggesting that rankings of pixel-by-pixel snow water equivalent exhibit stationary features that can be exploited by a sensor-placement algorithm. Locations of wireless-sensor nodes within each local sensor group follows a three-phase design procedure to overlay a wireless network onto strategically placed sensor nodes. An iterative procedure is necessary, with specific metrics for network performance, as network performance in vegetated, complex terrain can be much different from that in flat, open areas. Data and analysis from these catchment-scale and basin-scale observatories provides unprecedented, detailed accounting of water fluxes and storage, and insight into catchment-scale and basin-scale processes.

Experimental Watersheds as a Platform for Food security and Sustainability Research: The Long-Term Agricultural Research (LTAR) Network
Mark R. Walbridge\textsuperscript{1}, Steven R. Shafer\textsuperscript{1}, David C. Goodrich\textsuperscript{2,*}

\textsuperscript{1}Office of National Programs, Beltsville, MD
\textsuperscript{2}Southwest Watershed Research Center, Tucson, AZ

As the 21st century unfolds, agriculture will face a series of challenges—in the United States and globally—in providing sufficient food, fiber, and fuel to support a growing global population while our natural resources, environmental health, and available arable land decline and climate changes. The unprecedented nature of these challenges creates a growing sense of urgency for transformative changes in agriculture and land management to accelerate progress towards achieving sustainable agricultural systems that maximize production and economic return for producers, minimize
environmental degradation, and adapt to changing climate. Achieving such a transformation requires an improved understanding of the complexities of how agro-ecosystems function at multiple scales (i.e., fields to watersheds or landscapes). Long-term research and data collection are essential to achieving this understanding; at stake are the security and safety of our food production systems, our natural resources, and our environment. Over the past 10 years, there have been frequent calls for the creation of a Long-Term Agro-Ecosystem Research’ (LTAR) network, similar to the National Science Foundation’s Long–Term Ecological Research (LTER) network, to provide a sophisticated platform for research on the sustainability of U.S. agricultural systems. The U.S. Department of Agriculture’s Agricultural Research Service (ARS) currently maintains approximately 22 benchmark experimental watersheds and ranges that collect long-term data on agricultural sustainability, climate change, ecosystem services, and natural resource conservation at the watershed or landscape scale. Here we present a vision for how a subset of these sites could be used to form the core of an LTAR network. Each of these experimental watersheds and ranges measures a variety of physical and biological quantities for understanding watershed and range processes. Within these sites we envision poly-disciplinary coordination with plant, animal, ecological, and economic sciences to more fully understand the effects and feedbacks of agricultural production on these systems. The observation suite would be expanded and integrated for these additional functions. This would enable integrated environmental and economic evaluation of things like new cultivars developed to be heat and drought tolerant, biofuels production, or animals breed to thrive of new plant groups becoming dominate due to climate change. Eventually, such a network would link ARS sites with partner sites operated by universities, other research institutions, and (or) other Federal agencies to support poly-disciplinary research and funding efforts addressing regional- and national-scale questions using shared research protocols. Such a long-term agro-ecosystem research network would provide the knowledge to substantially improve both agricultural sustainability and the delivery of ecosystem services to a society that increasingly demands that agriculture be safe, environmentally sound, and socially responsible, in addition to being productive and economically viable.

Networking Hydrologic Observatories for Large-scale Climate Change Assessment: Is It Possible?
Danny Marks, USDA Northwest Watershed Research Center

A limited number of hydrologic observatories exist across North America, and only a few of these offer the long-term (greater than 35-year) data records required for assessment of the response of water and ecosystem resources to climate warming and change. The challenge hydrological science is to use data from our hydrologic observatories to characterize trends across larger regions, but this is a complicated and difficult undertaking. To extend measured and simulated states and conditions from hydrologic observatories across larger regions, we must first be able to directly compare conditions within and evaluate differences between observatories. Because data collection and measurement protocols are generally determined by site characteristics and observatory objectives, this can be a daunting problem. The difficulties and issues associated with this are presented and discussed.
Abstracts – Invited Speakers

Session 6: Advances in Community Modeling
10:00 AM - 12:00 PM

A New Hydrological Model Extension Package for the Weather Research and Forecasting System
D. Gochis¹, W. Yu¹, D. Yates¹, R. Rasmussen¹, M. Clark¹*, H. Kunstman², T. Rummler², B. Fersch²

¹National Center for Atmospheric Research
²Karlsruhe Institute of Technology

Over the last several years researchers from NCAR and the academic community have been making steady progress on developing a generic model-coupling framework for the regional Weather Research and Forecasting model (WRF) to enable rapid, extensible integration of distributed hydrologic models within the WRF modeling platform. The emerging coupling framework is a multi-model development and integration effort that leverages the modular, parallel computing architecture of the WRF. Effectively, we have developed a model driver/coupling architecture that enables the coupling of many different conceptualizations of the land surface including plant canopy formulations, terrestrial routing and groundwater formulations, and water management infrastructure formulations into WRF. The system has seamless stand-alone (i.e. offline) and coupled capabilities, is high performance computing (HPC) capable, is readily extensible and upgradable and is completely open source, distributed through NCAR to the academic community. The hydrological model extension package is scheduled to be released with the next version of WRF in 2013 as a separate extension package akin to ‘WRF-Chem’. This presentation will provide a structural overview of the new software package and provide results from several case study applications ranging from idealized experiments to real-world, coupled model forecast runs.

Towards a National Water Modeling System
Don Cline¹*, Jerad Bales², Bill Scharffenberg³, Witek Krajewski⁴

¹Chief, Hydrology Laboratory National Weather Service, National Oceanic and Atmospheric Administration
²Chief Scientist for Water, United States Geological Survey
³HEC-HMS Lead Developer Hyd. Engineering Center, Institute for Water Resources, United States Army Corps of Engineers
⁴University of Iowa, Chair, CUAHSI Board of Directors

Today we face a gamut of complex and often interrelated water resources challenges that will likely define both our generation of scientists and engineers and our future as a society. Three grand challenges serve as examples that demand comprehensive water prediction everywhere, all the time:

1) Reduce the occurrence of estuarine hypoxia everywhere along our coastline by a) tracking nutrient and sediment movement throughout watersheds nationwide, and b) providing actionable predictive information that allows managers to effectively and efficiently control sources and enables more effective legislation;

2) understand and seamlessly predict the full range of hydrologic extremes, from floods to droughts and from short-term to long-term, and their relationships to large-scale climate, land and water management practices and other drivers, and

3) ensure water security by a) predicting surface and groundwater availability in all watersheds to enable water users to determine the least-cost source and plan for droughts, b) predicting water flow and depth in all major and minor rivers to permit optimal operation of multiple-use...
Abstracts – Invited Speakers

reservoirs, facilitate navigation and fully inform flood fighting efforts on levees, and c) tracking and predicting movement of hazardous contaminants accidentally or deliberately released into the water supply to enable effective operation of control structures and issuance of emergency notifications.

Each of these examples challenges the state of the science and exceeds the capacity of any single organization to address. While diverse in scope, these challenges require at the core a new and highly integrative information, simulation and prediction system to enable a new national paradigm of collaborative water modeling for research and operations, focusing our collective intellectual and computational resources on these very difficult problems.

To foster the development of such a system, the Integrated Water Resources Science and Services (IWRSS) consortium, presently comprised of NOAA, the USGS, and the U.S. Army Corps of Engineers, has reached out to CUAHSI and other partners at the “First Scoping Workshop for the National Water Model”, April 9-11, 2012 in Chapel Hill, NC. From the workshop and subsequent discussions has emerged a conceptual multi-scale operational and research framework for a collaborative national water modeling system. This talk will discuss the need and vision for a community-driven National Water Modeling System, a process for scoping, design and implementation to achieve an initial capacity for the system in five years, and next steps.

Making Hydrologic Models Interoperable, Reproducible, and Easy to Share
Jonathan L. Goodall, University of South Carolina

Creating a community hydrologic model, no matter the approach taken, presents serious technical as well as scientific challenges. The software tools needed to enable community hydrologic modeling including the connections with other scientific and engineering disciplines are nontrivial and will require a deep and long-term collaboration with computer scientists and engineers to get right. In this talk I will cover some recent efforts in hydroinformatics as they relate to creating community hydrologic models organized around three themes. The first theme is model interoperability. Hydrologic models must be made so that they can be coupled with other models within the earth science and engineering communities to create larger models of interdisciplinary systems. Exactly how to achieve this model interoperability is a significant challenge for which there have been many different and competing ideas proposed. I will argue for a decentralized approach that emphasizes autonomy and specialization, but maintains standard interfaces and connections across components of a larger modeling system. The second theme is model reproducibility. By this I mean enabling those not directly involved in the modeling process to, with relative ease, recreate and confirm model predictions starting from source data, through data preparation steps, modeling assumptions, mathematical representations, model calibration, etc. Scientific workflows offer the potential for better documenting these steps, and I will discuss our efforts in this area as part of the NSF DataNet Federation Consortium (DFC) project using iRODS. The third theme is model sharing. By this I mean taking advantage of how the Internet enables social networks around hydrologic models and data, and how these social networks can aid in science and engineering progress. I will discuss the aims of the recently begun CUAHSI HydroShare project that target this specific need.
Large Scale, High-resolution Simulations of Continental North America with the Integrated, Parallel, ParFlow Hydrologic Model
Reed Maxwell1†*, Laura Condon1,2, Stefan Kollet3, Ian Ferguson2, John Williams1

1Colorado School of Mines
2United States Bureau of Reclamation
3Bonn University

Integrated hydrologic models are growing in application and show significant promise in unraveling connections between the surface, subsurface, land-surface and lower atmospheric systems. Recent advances in numerical methods, coupled formulation and computing power have all enabled these simulation advances. The modeling platform ParFlow, an integrated hydrologic model that has been coupled to land surface and atmospheric models will be presented along with a recent application of this model to a large, Continental-Scale domain in North America at high resolution that encompasses both the Mississippi and Colorado watersheds. Details will include techniques for model setup and initialization, in addition to results that focus on understanding fluxes, feedbacks and systems dynamics. Additional anthropogenic complications such as the effects of pumping, irrigation and urbanization will be discussed and a path forward for integrated simulations of the hydrologic cycle will be presented.
The Pete Eagleson Lecture on Hydrologic Science

8:30AM-9:45AM

Hydrologic Forecasting and the Relative Role of its Three Pillars: Models, Observations and Parameterization

Soroosh Sorooshian, Civil & Environmental Engineering and Earth System Science, Director, Center for Hydrometeorology and Remote Sensing (CHRS), The Henry Samueli School of Engineering, University of California, Irvine

To be responsive to the need for more effective management of water resources, engineers and scientists must utilize more sophisticated hydrologic prediction tools. Depending on the problems, the hydrologic information needed may range from hourly forecasts (i.e., in the case of flash floods) to seasonal to inter-annual (i.e., in the case of water resources systems such as reservoir operation), and to decadal to century (i.e., in the case of long range water supply planning and structural designs). While good progress has been reported related to both, “weather-scale” and “climate-scale” hydrologic predictions, many challenges face the research community attempting to extend the forecast lead time and accuracy.

Over the past half century and with the advent of digital computers, hydrologic models of various levels of complexity have been developed and continually refined and proposed. Progress towards development of more sophisticated and efficient parameter estimation methods have also been made and extensively reported in the literature. More recent advances we are witnessing are related to both space-based and in-situ observation tools to measure hydrologic fluxes at space-time resolutions required by the new generation of models.

However, despite of the progress in each of these three pillars of hydrologic forecasting, the improvements in the overall forecast quality is yet to reach the users expectations. Some recent results from a number of reported evaluation studies will be presented. Personal reflections based on over 3 decades of research and experience will shared with the goal of encouraging further discussion about the recent proposed strategies to advance hydrologic sciences.
Abstracts – Invited Speakers

Session 7: Coevolution of Hydrologic and Geomorphologic Systems
10:00AM-12:00PM

Timescales of Drainage Network Evolution are Driven by Coupled Changes in Landscape Properties and Hydrologic Response
Anne J. Jefferson, Department of Geology, Kent State University, Kent, OH

In diverse landscapes, channel initiation locations move up or downslope over time in response to changes in land surface properties (vegetation, soils, and topography) which control the partitioning of water between subsurface, overland, and channelized flowpaths. In turn, channelized flow exerts greater erosive power than overland or subsurface flows, and can much more efficiently denude and dissect the landscape, leading to altered flowpaths and land surface properties. These feedbacks can be considered a fundamental aspect of catchment coevolution, with the headward extent of the stream network and landscape dissection as prime indicators of the evolutionary status of a landscape.

Drainage network evolution in response to landscape change may occur over multiple timescales, depending on the rapidity of change in the hydrogeomorphic drivers. Climate and lithology may also modify the rates at which drainage networks respond to change in land surface properties. On basaltic landscapes, such as the Oregon Cascades, timescales of a million years or more can be necessary to evolve from an undissected landscape with slow, deep groundwater drainage to a fully-dissected landscape dominated by shallow subsurface stormflow and rapid hydrograph response in streams. This evolution seems to be driven by a slow change in land surface properties and permeability as a result of weathering, soil development, and mantling by low permeability materials, but may also reflect the high erosion resistance of crystalline bedrock. Conversely, rapid or near-instantaneous changes in land surface properties, such as accompanied the beginning of intensive agriculture in the southeastern Piedmont, can propagate into rapid (1-10 year) changes in channel network extent on clay-rich soils. Where agriculture has been abandoned in this region and forests have regrown, downslope retreat and infilling of extensive gully networks is occurring on decadal timescales.

Climate, Vegetation, Channelization, and Landsliding Interaction: Insights from Lidar Analysis and Theoretical Modeling
Paola Passalacqua1* and Colin P. Stark2

1Department of Civil, Architectural, and Environmental Engineering, University of Texas at Austin, TX
2Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY

The advent of high resolution topographic data is revolutionizing the study of geomorphic processes. For the first time, the topographic patterns of surface flow, channelization, and landsliding can be resolved over large areas at resolutions commensurate with the scales of the governing processes. Such data provide an exciting opportunity to quantify these patterns and to investigate their dependence on climate, land cover, anthropogenic disturbance, and geology. At the same time, recently developed tools allow the objective extraction of geomorphic features and related attributes from the enormous amount of information contained in lidar digital terrain models (DTMs). In this talk we will present how this powerful combination of new data and new methods can be exploited to deepen our understanding of hillslope-channel process and form, and to evaluate the dynamic interactions with vegetation, hydrologic response and anthropogenic disturbance. In particular, we will show results from the application of methods of automatic geomorphic feature extraction and morphological analysis to lidar DTMs across Japan in combination with ground validation at key watersheds. We will also discuss the results obtained with a theoretical model which highlights how runoff, landsliding, vegetation growth
Ecosystem Processes at the Watershed Scale: Co-evolution of Hydrology, Forest Canopy, and Geomorphic Systems
Taehee Hwang1,*, Lawrence E. Band1,2, T.C. Hales3, James M. Vose4, Christina Tague5

1Institute for the Environment, University of North Carolina at Chapel Hill
2Department of Geography, University of North Carolina at Chapel Hill
3School of Earth and Ocean Sciences, Cardiff University
4Coweeta Hydrologic Laboratory, USDA Forest Service
5Bren School of Environmental Science and Management, University of California at Santa Barbara

Water is not only a key substance for all life forms on earth, but also a key component of surface energy balance and a main driver of landscape development. Therefore, the co-evolution of catchments includes complex interactions among hydrology, ecosystem, and geomorphology at different time scales given climate and tectonic conditions. Vegetation mediates between short-term water flows and long-term landform developments by reducing soil water, runoff production, pore pressures and increasing slope stability of watershed systems. In this sense, ecosystem development effectively represents long-term adjustments of soil-vegetation system given climatic, geomorphic, and hydrologic settings. In this study, we estimated the spatio-temporal vegetation dynamics at different scales from several sets of remote sensing imagery in Coweeta Hydrologic Lab (NC, USA). Specifically, the large, local variability of meteorological and edaphic conditions in steep terrain provides a unique opportunity to diagnose ecosystem responses to the interaction of climate and landscape positions. First, we examined how hydrologic behavior at catchment outlets are related to observed spatial organization of vegetation assuming that observed vegetation patterns effectively represent partitioning between localized water use and lateral water flow along hydrologic flowpaths. Second, we explore how transient hydrologic behavior is constrained by current ecosystem carbon uptake and resulting dynamic vegetation growth during the clearcut and pine plantation experiments. Finally, we examine how hydrologic and canopy structural pattern impacts on slope stability and the transient development of landslide potential in steep forested catchments. This study revisits the concept of ‘ecologically optimum state of vegetation and soil in a given climate’ at the watershed scale, originally suggested by Eagleson (1982), and suggests how we can use emergent vegetation dynamics as a diagnostic tool to understand complex hydrology-ecosystem-geomorphology feedbacks within forested watershed systems.
Climate Change and Sustainability: Quantifying Impacts to Water, Soil, and Crop Yields
David Hyndman*, Bruno Basso and Anthony Kendall, Michigan State University

Climate change will affect the sustainability of water and food production. Changes in climate, land use, and population can be quantified by synthesizing remotely-sensed and GIS data using landscape hydrology models. The Integrated Landscape Hydrology Model (ILHM), is a water- and energy-balance physics-based model that can simulate regional hydrology at fine resolution with such readily available data. SALUS is a crop biophysics model that allows us to quantify the impact of changes in both climate and management on crop yields. We use these codes to simulate streamflows, groundwater levels, and crop yields across regional watersheds based on remotely sensed data including MODIS LAI, SRTM Digital Elevation, LANDSAT-derived land cover maps, and NEXRAD precipitation estimates, along with digitized soil survey maps, subsurface geologic maps, and station climate data. These are compared to several decades of measured streamflows, and groundwater levels, and county crop yields. We explore the relative importance of historic changes in land cover, climate, and land management practices on hydrology, and then simulate the impacts of projected changes in climate from the IPCC AR4 on water resources and crops. Through this analysis we examine sustainability of resources and future crop yields under different management strategies.

An Essential Ingredient for Water Resources Sustainability: Integration of Science and Decision Making
David Goodrich (and a cast of hundreds), Research Hydraulic Engineer, United States Department of Agriculture – Agricultural Resource Service Southwest Watershed Research Center, Tucson, AZ

Watersheds provide a number of critical ecosystem services which are essential to sustain human well being. Decision-makers and natural resource managers responsible for watershed management increasingly require sophisticated levels of expert findings and scientific results to make informed decisions. No single scientific discipline is typically capable of providing integrated solution for decision-makers and managers. Significant effort beyond the traditional scientific method is required conduct interdisciplinary science across the physical, ecological, and economic sciences. Even greater effort is required to effectively integrate this research with policy and decision makers. This presentation will provide an overview of the evolution of natural resources research in the San Pedro Basin in southeastern Arizona into a mature integrated science and decision-making program embodied in the Upper San Pedro Partnership. It will discuss the transition in project focus from science and research for understanding; through science for addressing a need; to integrated science and policy development. At each stage the research conducted became more interdisciplinary, first across abiotic disciplines (hydrology, remote sensing, atmospheric science), then by merging abiotic and biotic disciplines (adding ecology and plant physiology), and finally a further integration with the social and economic sciences with policy and decision-makers for resource management. Non-market ecosystem service valuation for multiple riparian attributes will also be presented as they aid decision makers weighing preservation and restoration expenditures. Lessons learned from this experience will be reviewed with the intent providing guidance to ensure that hydrologic and watershed research is socially and scientifically relevant and will directly address the needs of policy makers and resource managers for overall watershed sustainability.
A Survey Tool to Inform the Translation of Hydrologic Science to Practice
Ken Potter* and David Liebl, University of Wisconsin, Madison, WI

One of CUAHSI's primary mission elements is to translate scientific advancements into effective tools for
water management and policy. Scientific advancements are most likely to be translated into practice
when practitioners participate in selecting and framing scientific inquiry. In this spirit we have
developed a prototype survey of water resource practitioners to get their ideas on research needs and
ways to facilitate the translation of research into practice to address water resource management
challenges. We have tested this survey on the membership of the Wisconsin Association for Floodplain,
Stormwater, and Coastal Management. We will share the results of this survey and accept suggestions
on potential improvement of the survey tool.
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Advances in Community Modeling

1
Implementing a Catchment-Based, National-Scale Land Surface and River Transport Model
Zhao Liu1*, James S. Famiglietti1, 2, HyungJun Kim2

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In this study we characterize how accurately we can estimate river discharge, river depth and inundation extent using an explicit representation of the river network and a catchment-based hydrological and routing modeling system (CHARMS). Here we present a national-scale implementation of CHARMS that includes an explicit representation of the river network upscaled from the NHDPlus dataset. HUC8 (Hydrologic Unit Code) is chosen as the average catchment size (~3900 km²), and the main river channel in each catchment is extracted using the Strahler Stream Order from NHDPlus. We also derive empirical relationships between channel dimensions and drainage area to describe the river cross-sectional profile for several large regions of the country. Daily streamflow is generated and shows reasonable agreement with gage observations. River depth and floodplain extent associated with each river reach are also explicitly simulated. Results have implications for capturing the seasonal-to-interannual dynamics of surface water in climate models, and for assimilation of surface water altimetry, e.g. from the upcoming NASA SWOT mission.

2
Large Scale, High-resolution Simulations of Continental North America with the Integrated, Parallel, ParFlow Hydrologic Model
Reed Maxwell1*, Laura Condon1,2, Stefan Kollet3, Ian Ferguson2, John Williams1

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Integrated hydrologic models are growing in application and show significant promise in unraveling connections between the surface, subsurface, land-surface and lower atmospheric systems. Recent advances in numerical methods, coupled formulation and computing power have all enabled these simulation advances. The modeling platform ParFlow, an integrated hydrologic model that has been coupled to land surface and atmospheric models will be presented along with a recent application of this model to a large, Continental-Scale domain in North America at high resolution that encompasses both the Mississippi and Colorado watersheds. Details will include techniques for model setup and initialization, in addition to results that focus on understanding fluxes, feedbacks and systems dynamics. Additional anthropogenic complications such as the effects of pumping, irrigation and urbanization will be discussed and a path forward for integrated simulations of the hydrologic cycle will be presented.
Bridging the Gap between Models and Observations

A Nested Global-Local Hydrological Model for Large Scale Flood Forecasting Using Satellite Data: Bridging Across Scales
Amir AghaKouchak and Ali Mehran, University of California, Irvine

This paper aims to contribute to modeling hydroclimate extremes and understanding the complex Earth system processes using satellite data sets. A nested hydrological modeling framework is proposed for quasi-global flood forecasting using satellite data. The proposed modeling framework consists of two steps. Step 1: A 0.25 degree conceptual-probabilistic global hydrological model is proposed to identify areas with high probability of flooding. Step 2: A deterministic semi-distributed model, nested within the global, is suggested for detailed flood analysis in watershed (local) scale. The deterministic model includes a 250 meter river network for detained flood routing and streamflow analysis. Having a fully nested global-local model, the local model can be activated only for areas identified as high risk in the first step. Satellite-based precipitation, snow covered areas, evapotranspiration and soil moisture data, derived from multiple sensors, are used as input data. The simulated runoff using the presented model is validated with the Global Runoff Data Center measurements. The results indicate that the model can provide reasonable probability of flooding, and magnitude of peak flow. The model can be used to monitor global environmental changes due to large scale flooding events. Efforts are underway to use this model for an early flood warning system that can provide probability of flood events and their uncertainties.

Effect of Land-Use Land-Cover Data Resolution and Methods of Production on SWAT Model Predictive Ability
Kwasi Asante*, Jackson Cothren and John Van Brahana, University of Arkansas, Fayetteville, AR

The development of relatively new natural-gas exploitation technologies particularly horizontal drilling and hydraulic fracturing (fracking) has resulted in an increase in gas exploration and production activities in shale formations throughout the United States. The increase in activities has a corresponding impact on the overall land-use land-cover (LULC) change and ultimately affects the hydrology of the watersheds in which they occur. A key scientific tool for the study of LULC (in this research shale-gas exploration and production activities) impacts on the hydrology of a watershed is hydrologic modeling. However, factors such as the availability, quality, frequency and most importantly the scale of hydrologic monitoring data are known to affect the output results of such models. In this research, the effects of two LULC data of different resolutions (30 m and 2 m) classified with two image analysis techniques (the object-oriented image analysis and the traditional pixel-based maximum likelihood methods) on the storm-water runoff predictive ability of the soil and water assessment tool (SWAT) model will be studied.

The study area is the Little Red River watershed in north-central Arkansas which is located within the Fayetteville Shale play region. The impact on the predictive ability of the runoff models will be assessed through an evaluation of the calibrated models at the 95-percent prediction uncertainty level. The generalized likelihood uncertainty estimation (GLUE) method will be employed to determine the percentage of observed data that can be captured or accounted for by the best model simulation. Preliminary results with the low-resolution (30 m) LULC data model show that extensive and consistent manual calibration is required prior to any automatic calibration with the GLUE methodology. It is
expected that this study will contribute to literature concerning the choice and provision of data for hydrologic modeling thereby enhancing knowledge on bridging the gap between observation data and hydrologic modeling.

5

The Complex Interrelation of Surface- and Ground-Water in a Mantled-Karst Setting—Modeling Implications from the Savoy Experimental Watershed

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Interdisciplinary research at the Savoy Experimental Watershed (SEW) at the University of Arkansas has provided an increasingly complex characterization of what initially to us appeared to be a simple hydrologic site. After 15 years of intense studies, each which had a strong field component, we conclude that the hydrology is actually far from simple. This conclusion has tempered our enthusiasm for using models for predictive purposes outside the scale and range of antecedent hydrologic conditions for which they were developed. Although this position is a basic modeling tenet and seems obvious to us as hydrologists, it is a conclusion that is easy to lose sight of, as examples from our research site remind us.

The SEW site is characterized by near-horizontal soil horizons, regolith, and bedrock layers of variably pure limestone with chert. Macropores in the nonindurated layers and systematic jointing in the indurated limestone and chert beds allow focused recharge from precipitation and streamflow to move into and out of the subsurface rapidly, providing discrete points of recharge that can have telltale chemical and physical properties. These fast-flow pathways are imbedded within porous media that store and transmit flow at rates orders of magnitude less than preferred pathways. Horizontal zones in the regolith containing continuous chert layers provide vertical barriers to flow, and divert recharge from ephemeral streambeds to springs and seeps much further away than nearby resurgences. Rapid flow zones are surprisingly compartmentalized within nonindurated media, and they are not easily discernible using geomorphology or remotely-sensed image interpretation. Furthermore, recent geochemical research indicates that surface land management and surface flow is closely connected with nutrient transport along subsurface pathways and ecosystems, zones that were previously interpreted as having little impact on water quality. This has led us to become advocates of continuous high-frequency monitoring to understand catchment hydrochemistry. Most of this understanding was unknown until intensive, long-term interdisciplinary field studies under a wide range of hydrologic conditions had been conducted. Modeling prior to these studies yielded inaccurate interpretations.
Poster Abstracts

To more fully document and provide needed data on fluxes, hydraulic parameters, and calibration quantities for numerical testing of hypotheses, an accurate characterization of hydrologic budget components and water quality within all aspects of the flow system is being undertaken. Numerical simulation plays a valuable and well-respected role in our hypothesis testing and overall assessment of processes needing further study, and it serves as an important tool in our hydrologic toolbox. It is only one of many tools, however, and a refined, coherent study that draws on an interdisciplinary, interagency team of researchers working at a long-term research site is an essential first step. We conclude that long-term interdisciplinary study sites are an essential component to understanding the full hydrologic complexity of watersheds. Although SEW is a basin underlain by karst, it is our feeling that many basins in porous-media settings are likewise much more complex hydrologically than originally envisioned. This implies to us that we need to carefully evaluate all predictive modeling, particularly in light of assumptions and simplifications.

6
Using Lidar and Distributed Snow Modeling to Understand Small-scale Snow Variability
Patrick Broxton*, Adrian Harpold, Peter A. Troch, Paul D. Brooks, University of Arizona

Snow often provides an important, if not dominant, water input in topographically complex, mixed conifer environments. Understanding snow variability in these areas is important for estimating the timing and quantity of snow melt, which both affects management decisions, as many drinking water supplies originate as snow melt in these areas, as well as ecology, as vegetation health is closely tied to snow water input. Particularly important are processes that occur on the order of 10-100s of meters, as they can alter the amount of snow melt that enters the ground by as much as +/- 30%. At these small scales, vegetation exerts a significant influence on snow distributions due to interception and its influence on wind and energy. In this study, we model these influences using an energy balance snow model that is informed with LIDAR-derived estimates of canopy height and density, and evaluated with LIDAR-derived estimates of snow depth. We developed the model, which is called SnowPALM (Snow Physics and Lidar Mapping), to be parsimonious and computationally efficient enough to be able to make use of extensive very high resolution spatial data, yet still retain representations of important physical processes involving snow. The model has been evaluated at small (<1 sq. km.) study areas in the Jemez River Basin and the Boulder Creek Critical Zone Observatories at a 1 meter spatial resolution. These simulations demonstrate improvements from incorporating high resolution vegetation data into distributed snow models, and have allowed us to infer which processes (e.g. those related to wind or energy) are influential at each site. Understanding the influence of such small scale process on snow variably is essential given the ongoing changes in vegetation and climate.

7
Modeling the Time Scales of Ecohydrological Responses to Extreme Precipitation Events in Grasslands With and Without Woody Encroachment
Nate A. Brunsell¹*, J. Nippert²

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²Division of Biology, Kansas State University

Extreme weather events have profound impacts on water and carbon cycling. However, events of similar magnitude may have very different impacts depending upon the timing of the event in the phenological cycle. Here, we assess the impacts of extreme daily weather events including precipitation, maximum and minimum temperature using data collected from an annual burned watershed (C4 grassland) and a
Poster Abstracts

4-year burn regime (C4 grass with woody encroachment) on the Konza Prairie Long Term Ecological Research site in the central U.S. Utilizing long term weather and biomass collection data at the LTER site to examine the historical variability of extreme events and the impacts on annual carbon dynamics. Results indicate a strong sensitivity to spring precipitation and summer temperature. Using six years of eddy covariance data, we can isolate more of the biophysical mechanisms governing the responses to extreme weather events. Of particular interest is to assess the biophysical processes responsible for determining the response of water and carbon dynamics to extreme weather events. To examine the scales of responses, we employ a wavelet based information theoretic approach to quantify the timescales of response to environmental forcings both from the LTER data, as well as eddy covariance data and AGRO-BGC model simulations. These simulations help identify the timescales of interactions between precipitation, radiation, soil moisture and the resulting annual carbon and water cycling. Using the model output, we can identify discrepancies as a function of time scale to help aid model development by focusing on specific timescales. This helps to isolate both the ecological response and the model’s sensitivity to the responses as a function of burn regime and species composition. Developing a more thorough understanding of extreme events and the differential responses due to the timing and magnitude of the events will assist in the mitigation of future climate change.

8
Quantifying the Sensitivity of Snow Processes to Vegetation Parameters in the Variable Infiltration Capacity Model to Improve Accurate Modeling of Snow in Forested Watersheds
Susan E. Dickerson-Lange*, Dr. Jessica Lundquist, Department of Civil and Environmental Engineering, University of Washington

The mountain watersheds of the Pacific Northwest are expected to experience a drastic loss of snowpack and, consequently, summer water supply in the coming decades as a result of changing climate conditions. However, forests also affect the magnitude and melt rate of snowpack by intercepting falling snow and shading the snowpack from shortwave radiation and wind. Forest management therefore has the potential to mitigate some of the effects of climate change through maximizing snow retention on the landscape, but the optimal forest structure for this objective in the range of climate conditions seen in the Pacific Northwest is not known. Previous efforts to determine the net effect of forest structure on snow processes have been limited to plot-scale studies, with results across the region that lack transferability and have seemingly conflicting results.

In order to test the feasibility of forest management as a mitigation strategy at the watershed scale and across the region, an accurate modeling framework that represents the effect of forest structure on snow processes is needed. Particularly important for the purpose of forest management are comparisons across a variety of forest structures (e.g., dense second growth, old growth, thinned) rather than a binary perspective of clearcut versus forest. We quantify the sensitivity of snow metrics (peak SWE, ablation rate, and snow disappearance date) to vegetation parameters in the snow component of the Variable Infiltration Capacity (VIC; Liang et al., 1994) hydrologic model. Our results identify leaf area index (LAI) and percent of vegetation coverage as key vegetation parameters in the model that must be linked to measurable forest characteristics in order to ultimately determine optimal forest structure for snow retention under changing climate conditions.
Estimating Land-Atmosphere Moisture Exchange by Measuring Subsurface Displacements
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\(^2\)Civil Engineering Department, Georgia Tech, Atlanta, GA

Moisture flux across the land-atmosphere interface is an important part of the hydrologic cycle, but characterizing it remains challenging. We have developed a new measurement strategy with advantages compared to existing methods. The approach is to evaluate changes in water content in soil using a sensor that detects small vertical displacements in the underlying formations. An increase in moisture content increases the vertical stress in the subsurface causing vertical displacement that is proportional to the change in water content. The sensor can be emplaced at depths of a few m to hundreds of m or more, and it averages over an area that scales with the depth. This provides a method for measuring transient soil moisture change averaged over regions from a few square meters to dozens of hectares.

The instrument developed for this application is called a Sand-X, which is short for Sand Extensometer. It is designed for applications in unconsolidated material. The Sand-X is simple and relatively inexpensive, and it can be installed in a boring made with a hand auger or with a small drilling rig.

Field-scale studies are being performed in the vicinity of Clemson, SC, which is underlain by saprolite weathered primarily from biotite gneiss. Calibration is done by correlating displacement to known loads, such as measured rainfall or the weight of a person or vehicle. The calibration factor for one Sand-X installation is 440 nanometers of displacement/mm of water equivalent load, for example. The resolution of the instrument is in the range of tens of nm of displacement, so it appears to be capable of detecting changes of water content on the order of tenths of one mm when deployed in compliant material like saprolite. The current instruments are installed at a depth of 6 m, and they respond to load changes over an area roughly 35 m in diameter.

Recent data shows that rainfall causes an abrupt compressive displacement that correlates to measured precipitation. This signal is followed by a gradual extension at a rate of roughly 500 nm/da, which gives 1.15 mm of water/da using the calibration. Using 70% of pan evaporation gives an estimate of 1.4 mm/day for the average ET in February. It appears that the instrument can characterize ET rates between rainfall events.

Changes in barometric pressure cause displacements of up to 1 micron, and these signals interfere with interpretations of water content change. Barometric pressure is easily measured, and it appears to be feasible to remove the effects of this signal by convolving a response function derived from poroelastic effects beneath a half-space. Work on this data analysis technique is on-going and will be critical to achieving the full resolution of the instrument.

An exciting aspect of the technique is that it should be capable of characterizing a wide range of processes beyond changes of water content in soils. Erosion and deposition of sediment, melting of snow pack or melting of glaciers, mass loss during fire or mass gain during growth of biomass will change the vertical load in the subsurface. It could be feasible to characterize these processes over a range of scales by measuring displacements at different depths in the subsurface.
**10**

**Climate Change and the Ecology of Devils Hole, Death Valley National Park**

Mark B. Hausner\(^1\)*, Kevin P. Wilson\(^2\), D. Bailey Gaines\(^2\), Francisco Suárez\(^1, 3\), and Scott W. Tyler\(^1\)

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\(^3\)Pontificia Universidad Católica de Chile, Santiago, Chile

Devils Hole, a water-filled fracture in carbonate aquifer underlying Ash Meadows National Wildlife Refuge, is home to the only extant population of the endangered Devils Hole pupfish. A shallow shelf at the south end of Devils Hole plays a critical role in the ecosystem, providing a substrate for primary productivity, the best habitat in the system for pupfish spawning, and a site for daily foraging activities by pupfish. Because of its shallow depth and highly variable solar exposure, the shelf also experiences the greatest diurnal and annual swings in water temperature in the system. A hydrodynamic model of the shallow shelf is presented to simulate thermal convection in response to a number of energy fluxes, including climatic drivers such as air temperature and solar radiation. The model is particularly sensitive to changes in the ambient air temperature, and points towards a system that is susceptible to the expected impacts of climate change in the Southwest. Simulations of present-day conditions demonstrate seasonal and diurnal changes in the temperature of the water and the substrate in which adult pupfish spawn, eggs hatch, and larvae develop, and the simulated convection cells also have the potential to influence the oxygen dynamics, nutrient cycling, and food web of the ecosystem.

**11**

**Characterization of Nutrient Kinetics in a Spring-Fed North Florida Stream**

Wes Henson*, Water Institute, Agricultural and Biological Engineering, University of Florida
Grant Weinkam, Environmental Engineering Sciences, University of Florida
Chris Pettit, College of Sociology, Criminology, and Law, University of Florida
Joelle Laing, School of Natural Resources and Environment, University of Florida
Courtney Reijo, UF School of Forest Resources and Conservation

Management decisions often regulate nutrient loads in streams based on information from regional to basin-scale models which can be limited by sparse datasets. Research is needed to assess stream nutrient kinetics to better inform water managers of the assimilative capacity of streams and further assist in development of downstream protection values and total maximum daily loads (TMDLs). This study employs the Tracer Additions for Spiraling Curve Characterization (TASCC) method (Covino et al. 2010) to examine nutrient kinetics in a small spring-fed north Florida stream. Applied methodology investigates spatial and temporal variability in nutrient kinetics under various initial conditions associated with energy input fluctuations related to diurnal changes and the presence/absence of tree canopy coverage. The TASCC method provides an efficient way to fully characterize the stream reach nutrient uptake velocity and rate models through analysis of conservative (Cl) and reactive tracers (N, P). Overall, this study investigates the characterization of nutrient kinetics and provides a basis for further studies in a variety of stream systems.
12  
**Modeling Losses to Bedrock in a Mountainous Catchment by Focusing on Catchment Storage**  
Patrick Kormos*, Boise State University

Mountain catchments in the Western United States are important sources of regional aquifer recharge. Most of the 2.41 million acre-feet per year of potential groundwater recharge to the semi-arid Great Basin region occurs in the mountainous divides between basins. Deep percolation from catchment mass balance is considered to be an estimate of mountain block recharge to regional aquifers. On smaller scales, deep percolation is an important term in water mass balance studies, which attempt to estimate hydrologic states and fluxes in watersheds with fractured or transmissive bedrock. However, few studies estimate the magnitude of this water balance term and it is often considered negligible. The objective of this study is to estimate deep percolation by focusing on achieving a high degree of agreement between measured and modeled catchment storage. We introduce modeling methods much simplified compared to modern fully distributed physically based watershed models. We propose that watershed fluxes can be modeled well by accurately representing catchment storage. This study employs a detailed physically based snow accumulation and melt model to estimate distributed snow water input to the catchment, and a capacitance based soil storage model to estimate soil storage.

13  
**Evaluation of GRACE Performance Over Large Lakes Around the World**  
Huidong Liu*, Department of Earth Science System, University of California, Irvine

As the only tool which measures the mass change of water directly, GRACE provides an opportunity to validate the modeled lake water level using a coupled land surface model and lake-river routing model. We compared the mass change in lakes detected from rescaled GRACE data with the mass change calculated from the altimetry data, to analyze the ability of GRACE sensor in detecting the water storage change in large lakes around the world. A 1-degree lake mask is made to be consistent with the GRACE data resolution. A scaling factor is calculated for each lake using the given mask. After removing the hydrology signal from the surrounding area, the unscaled GSR-LAND-300KM GRACE data is multiplied by the scaling factor to estimate water mass changes in each lakes. In order to study the hydrologic behavior in different climate zones, we chose the Great Lakes, Lake Victoria, and Lake Baikal for case study. This study shows the potential of GRACE in capturing monthly water storage variations within lakes of areas of ~10000 km² or more.

14  
**Isotope Hydrology in High-frequency: A Field-deployable System for Continuous High-frequency Measurements of δ²H and δ¹⁸O in Multiple Water Flows**  
Luke Pangle*, Water Resources Program, Oregon State University

The temporal resolution of δ²H and δ¹⁸O measurements in isotope-tracer studies has limited our understanding of end-member contributions to runoff and water transit-time distributions in catchments. Recent work by Bermann et al. (2009) demonstrated how state of the art laser spectrometers and associated auto-sampling devices can be deployed for continuous high-frequency measurement of the stable-isotope composition of stream water. We expand on this previous work by introducing a new auto-sampling system that enables high-frequency measurement of multiple water flows in the field. The system utilizes a laser-absorption spectrometer (LGR Liquid Water Isotope Analyzer), a peristaltic pump with four flow channels, and a new flow-through auto-sampling tray. We deployed the system at a field site in Corvallis, OR, where we simultaneously measured the δ²H and δ¹⁸O
composition of precipitation, and the discharge from two lysimeters: one containing grassland vegetation and the other with bare soil. We used this new system to collect sub-hourly measurements of $\delta^2$H and $\delta^{18}$O for each water sources. To illustrate the advantage of these high-frequency data, we compared the range (i.e. information content) of $\delta^2$H values observed at high-frequency, versus $\delta^2$H values averaged over increasing flux depths (representing integrated samples at more coarse temporal resolution). The ranges of $\delta^2$H values observed in bare soil discharge, grassland discharge, and precipitation at the highest sampling frequency were 73, 111, and 20% greater than observed for samples representing an integrated flux of only 1 mm. This new level of information content in isotope time series can profoundly improve our estimates of end-member contributions to runoff and solute transport timescales in catchments, particularly when calculated by empirically fitting transfer functions and transit-time-distribution parameters to measured input and output data sets.

Where and Why do Models Fail? Perspectives from Oregon Hydrologic Landscape Classification
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A complete understanding of why rainfall-runoff models provide good streamflow predictions at catchments in some regions, but fail to do so in other regions, has still not been achieved. Here, we argue that a hydrologic classification system is a robust conceptual tool that is well equipped to characterize the success or failure of a rainfall-runoff model at regional scales. We use a spatially lumped rainfall-runoff model to predict daily streamflow at 88 catchments in Oregon and analyze its performance within the context of Oregon Hydrologic Landscape (OHL) classification developed by scientists at EPA. OHL classification is used to better understand the physio-climatic conditions that potentially favor high (or low) hydrologic predictability within Oregon. Results show that high predictability catchments (Nash-Sutcliffe efficiency NS > 0.75) are predominantly classified as having very wet climate, winter seasonality of water surplus (rain dominated), low aquifer permeability, and low to medium soil permeability. Most of these catchments are located in the western part of Oregon (west of the Cascade Mountain Range). Conversely, low predictability catchments (NS < 0.6) show propensity towards spring seasonality of water surplus (snow dominated), high aquifer permeability, and medium to high soil permeability. They are mainly located in the volcano-influenced regions near the High Cascades. Results suggest that poor characterization of snow processes and difficulty in estimating external gains and losses of deep groundwater are the primary reasons for low predictability in Oregon. We recommend that low predictability catchments must be dealt with on a case-by-case basis, where a combination of increased model complexity and additional input data is likely to improve streamflow predictions.

Error, Uncertainty, and Over-tuning: Addressing Calibration Biases in a Semi-arid Catchment
Catherine Shields*, Christina Tague, University of California, Santa Barbara

In hydrologic modeling, uncertainty in soil drainage parameters is a long-standing challenge. One approach to reducing this uncertainty is calibrating by comparing model output to observed data. However, calibration can also introduce error or bias. Weather conditions during the calibration period and uncertainty or error in the data used to drive the model or evaluate performance may bias parameter selection. In semi-arid environments, these uncertainties may play an especially large role in soil parameter calibration. Semi-arid regions experience extreme low and high flow events that are difficult to accurately measure, as well as a high degree of interannual climate variability. Finally,
estimating catchment-wide precipitation from point data is problematic. We present three alternatives to a “control” calibration of an ecohydrologic model, RHESSys, for a semi-arid catchment in Santa Barbara, CA, each designed to account for a suspected source of error or uncertainty. We test whether the parameters selected using these alternative approaches are substantially different from those selected using the control approach, and analyze changes in model performance between the control and alternative approaches. Two alternative approaches, incorporating interannual variability into evaluation of model performance and filtering the calibration period to remove periods of suspected error, result in substantially different pools of acceptable soil parameter sets when compared to acceptable parameter sets derived using the control method. Surprisingly, accounting for uncertainty in scaling of point precipitation data across an elevation gradient resulted in no significant changes in relative performance of parameter sets.

17
Carbonate Minerals: Unlikely Sources of Metals in Groundwater at Elevated pCO₂
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Injection of large amounts of carbon dioxide into deep geological formations – often referred to as geological carbon capture and storage (GCCS) - has been proposed as a climate change mitigation option. Large-scale injection operations are accompanied by concerns of CO₂ leakage from deep geological repositories and subsequent contact with shallower aquifers, such as underground sources of drinking water (USDWs). Dissolution of CO₂ in water results in elevated acidity. In a groundwater setting, increased acidity may lead to release of metals from aquifer material through desorption and mineral dissolution. Several previous studies attempted to simulate geochemical responses of freshwater aquifers to elevated pCO₂. In most of these studies, sulfide minerals are taken as likely sources of toxic metals. In addition, calcite is viewed solely as an acidity-buffering agent. Yet calcite is rarely found in pure form, and often contains a wide range of impurities in solid-solution. Dissolution of calcite is accompanied by release of these impurities from the calcite lattice. This holds true for dolomite minerals as well. We show through experimental work that dissolution of carbonate minerals is the likely mechanism responsible for elevated concentrations of metals in carbonate aquifers, where these minerals comprise the majority of the rock, even in the presence of sulfides. We also show that models that ignore co-release of metals with calcite dissolution can greatly underpredict metals input into USDWs at elevated pCO₂.
Bringing Research into Practice

18
Understanding the Social and Biophysical Influences on Urban Nutrient Pollution Due to Residential Impervious Surface Connectivity
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The presence of nutrient pollution in surface waters threatens biodiversity while undermining human use. In the U.S., efforts to meet water quality goals (e.g. “fishable and swimmable” waters) have for the past 20-years been increasingly focused on controlling non-point source nutrient pollution delivered via stormwater from agricultural and urbanized landscapes. Nutrient pollution (primarily phosphorous and nitrogen) has been associated with eutrophication of lakes and estuaries due to increased growth of phytoplankton. Further, elevated concentrations of nitrate in drinking water are toxic to humans.

The heterogeneity of urban landscapes – with fine-scale mixing of different vegetation, pavement, and buildings – challenges our attempts to advance understanding of the hydrology and biogeochemistry of nutrient pollution in urban environments. To surmount this challenge, it is necessary to employ an urban ecosystem approach rather than a strictly hydrological or biogeochemical approach. Such an ecosystem approach would fully consider the roles of both biophysical systems and social agents in producing urban landscape heterogeneity. Alberti (2009), in outlining a research agenda for urban ecology, suggests a guiding question for such an integrated approach: How do socioeconomic and biophysical variables influence the spatial and temporal distributions of human activities in human-dominated ecosystems? More recently, Pataki et al. (2011) has argued for the need of a “socio-ecohydrology” that brings together ecohydrology with social science approaches aimed at elucidating the role that institutional and individual decision-making as well as socioeconomic factors have on water management practices in urban ecosystems.

For my doctoral dissertation research, I seek to advance understanding of the relationship between residential stormwater management practices and the export of nutrient pollution in urban ecosystems. I pursue this objective using an interdisciplinary modeling approach that entails: (1) field observation and multilevel regression modeling of existing patterns of residential rooftop impervious surface connectivity to stormwater networks; (2) spatially explicit process-based ecohydrology modeling (RHESSys) of nutrient pollution loading that results from both baseline residential rooftop impervious connectivity and from disconnection scenarios (i.e. redirecting stormwater to lawns and rain gardens at various locations in a watershed). Here I present preliminary field data and modeling analyses of urbanized watersheds in Durham, NC, where managers are turning their attention to stormwater management on private residences, and where residential rooftops comprise a significant portion of impervious surfaces on private land.

My research will evaluate the utility of the of an intermediate complexity ecohydrology model for urban stormwater and ecosystem services management. Further, the interdisciplinary modeling approach I propose has the potential to inform nutrient pollution control strategies by: (1) explaining patterns of residential rooftop impervious connectivity using socioeconomic, biophysical, policy, and other predictors; (2) exploring how different methods and locations (within a watershed) of residential rooftop disconnection effect nitrogen export in urbanized watersheds; and (3) considering tradeoffs
between nutrient pollution reductions gained through residential rooftop disconnection and ecosystem function – terrestrial net ecosystem production, and water availability.

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Model for Predicting Rainwater Harvesting in Rainfed Regions

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The Human Development Report by the United Nations has emphasized on global water crisis; for instance, at present the number of people suffering from moderate to severe water stress is approximately 1.7 billion. By 2050, close to 60% of the world population would be facing mild to severe water shortage. Considering increasing demand of water for non-agricultural purposes (i.e. domestic and industrial uses), the availability of water for agriculture purposes is likely to reduce. Nevertheless, millions of people’s livelihood mainly depends on agriculture. For example, approximately 80% of global cropland is rainfed, which produces 60-70% of the world’s food supply. In rainfed regions, crop yields primarily depends on rainfall; enhancing water availability in rainfed regions can improve the crop yields. Rainwater harvesting in Distributed Reservoir Systems (DRS) can be a solution for improving crop yields in rainfed regions. In order to understand potential of rainwater harvesting in rainfed regions, and its impact on crop yields, we developed a model using water balance approach, which predicts crop water demands and the water availability in the DRS. Results show that harvested rainwater in the DRS can meet the supplemental irrigation (SI) requirement of the crop, and providing the SI increases agriculture productions. The work proposed here could have significant impacts on improving water availability in rainfed regions.
Coevolution of Geomorphology and Hydrology

Analyzing Spatial Patterns of Groundwater-surface Water Interactions at the Meander-bend Scale in a Gravel-bed Lowland River During a Large-scale Flow Experiment

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We measured the effects of a large-scale flow experiment on near-bed and subsurface temperature throughout three meander bends using fiber optic distributed temperature sensing (DTS) as a means to investigate groundwater-surface water exchange in a gravel-bed lowland river. We deployed 2 km of fiber-optic cable directly on top of the riverbed over three pool-riffle sequences each with a different degree of bed mobility. DTS data were collected every 2 m for 32 days (1.5 days at 10 cms, 10 days at 20 cms, 16 days at 10 cms, and 4.5 days at 2-4 cms). Three installations of six hyporheic zone sensors, located near the upstream and downstream ends of the DTS cable, recorded interstitial pore water temperature at depths of 46 cm. Measured channel bed elevation, flow depth, velocity, and bed-material grain size were used to develop a two-dimensional numerical model of the flow field as boundary conditions for a model of the hyporheic flow field.

The initial flow of 10 cms showed relatively uniform temperature over the 2-km reach. Near-bed temperatures averaged 15.6°C (12.8-18.4°C) while pore water temperatures at 46 cm averaged 15.4°C (14.8-16.3°C). The 20 cms flow decreased near-bed temperatures to 14.9°C (12.4-18.5°C) and pore water temperatures averaged 14.7°C (13.8-16.7°C). However, during the 20 cms flow, the bed became mobile causing local scour and deposition at three locations and buried the DTS cable with gravel/sand up to 26 cm deep. Our DTS results allowed us to record the transition from near-bed temperatures to shallow subsurface temperatures during a sediment-mobilizing flow. For the remainder of the experiment, we measured hyporheic flow at a shallow depth (where the cable had been buried) as well as 46-cm pore water temperatures at the lower boundary and near-bed temperatures at the upper boundary. Shallow pore water temperatures were buffered by >1.0°C and lagged compared to near-bed temperatures. The degree of buffering and lagging increased with 1) distance downstream over the length of a point bar and 2) duration of the flood event.

Our DTS results show spatially-discrete cold anomalies that were less than 0.5°C yet temporally persistent. The mean and amplitude of discrete anomalies changed as flow releases changed but spatial patterns remained constant suggesting localized groundwater exchange. Observed variability >1.0°C occurs in the shallow subsurface and near-bed only following a high flow event (20 cms) and continues during a low flow event (2-4 cms). During low flows, shallow pore water temperatures remained lagged but warmer than near-bed temperatures, while deeper pore water temperatures became cooler and were more closely in phase with near bed temperatures.

Currently we use these measurements to validate a 2D model of subsurface flow through meander bends. Subsurface modeling aims to generalize spatial patterns of upwelling and downwelling at the meander-bend scale over a range of experimental discharges. This study also allows us to quantify how those patterns change during morphogenetically significant flows.
21  
**A Numerical Model for Hydrologic, Hydrodynamic, and Erosion Processes**  
Jongho Kim*, Valeriy Ivanov, Nikolaos Katopodes

Soil erosion and excessive sedimentation are among the most important threats to sustainable agriculture and watershed management worldwide. Erosion leads to tremendous soil loss and imposes substantial social costs. Furthermore, in some regions, it is likely to increase in magnitude and accelerate due to climate change. In order to enhance the understanding of erosion mechanisms and investigate ways of reducing impact costs, a number of efforts to model erosion have been taking place over the last few decades. The performance of models may vary depending on whether the formulation can credibly take into account dominant factors controlling soil erosion. The process is strongly affected by many factors such as meteorological forcing, subsurface water pore pressure, flow conditions, vegetation cover and land use, topography, and human activities. It is also influenced by the soil’s inherent properties such as erodibility, cohesiveness, and particle size distribution. Overall, among external and internal factors, hydrological and hydraulic characteristics and particle distribution are arguably the three most crucial elements in modeling erosion.

This study links these three key elements within a single simulation framework. Previously developed hydrologic and hydrodynamic models are coupled with the Hairsine-Rose (H-R) model to describe soil erosion and sediment transport using physical principles. The H-R model can account for size-selective sediment transport based on particle size distribution; it differentiates soil of the bed as original and deposited soil layers to recognize whether the soil has an “intact” or a “loose” condition. Model verification is carried out to compare simulation results with analytical solutions and empirical data. Two benchmark cases dealing with rainfall-induced erosion and overland flow-induced erosion are used for model confirmation. The numerical model is consequently applied at a catchment scale using observational data for Lucky Hills watershed located in southeastern Arizona, USA. Model confirmation is carried for ten rainfall events with parameter values obtained through a minimal calibration for a single rainfall event. The model demonstrates robust performance and can be used for watershed-scale studies of erosion sensitivity to landuse practices and climate impacts.

22  
**Effect of Varying Stream Discharge on Bed Topography and Tracer Migration in Gravel Bedded Channels**  
Arvind Singh*, Peter Wilcock and Efi Foufoula-Georgiou, SAFL, University of Minnesota

Understanding the transport of tracers (e.g., sediment particles on which pollutants or nutrients are attached) is a problem of significant theoretical and practical interest for which, however, little understanding exists in non-plane bed rivers, i.e., in the presence of bedforms. A series of controlled experiments were conducted at a large flume the St. Anthony Falls Laboratory to study the effect of varying discharge on bed topography and tracer dispersal. Instantaneous, high-resolution bed elevations and sediment transport rates along with travel distances of tracer particles of size representative of the grain size distribution of bed material were measured, for a range of discharges. It is shown that bedform geometry directly depends on discharge with increasing height, decreasing length, and decreasing variability in bedform aspect ratio as the discharge increases. For the case of higher discharges where the bed topography is more pronounced, it is demonstrated that the length of the bed forms acts as a first order control on tracer travel distances. Based on a multi-scale analysis of bed elevation increment series, we demonstrate that the spectral slope and the degree of non-linear dependence of higher order structure functions on moment order control the distribution of travel distances, with larger particles traveling further at low discharge and smaller particles not significantly...
affected by the discharge rate. Results also show that the mean travel distance of smaller particles does not get much affected by the bed topography as the dynamics of smaller particles are mainly dominated by the particle hiding effect. Our results also confirm, for the first time, the heavy-tailed distribution (truncated power-law tail) in the statistics of tracer travel distances for a mixture of grain sizes and discharges as recently hypothesized in theoretical studies and as expected in natural rivers characterized by a wide grain size distribution and extreme flood events. The implications of these results for predictive modeling of sediment transport are discussed.

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Effect of Spatial Resolution of DEM and Vegetation Parameters on Ecohydrologic Predictions and their Sensitivity to Climate Variability in Sierra Mountain Watersheds
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Many hydrological models have been used to assess the impact of climate change on ecohydrologic response at the watershed scale or larger scales (Null et al., 2010; Knowles and Cayan, 2002). These model applications have typically been done at relatively coarse spatial resolutions (250m and 4 km) and thus ignore the fine-scale variation of topography and vegetation structure can be important controls on snow accumulation and melt (Josh et al, 2009, Musselman et al., 2008) and other ecologic and hydrologic processes (Zhang and Montgomery, 1994, Laussuer et al., 2006). Mountain watersheds have high heterogeneity in topography and vegetation over relatively short spatial scales which may be important for estimating watershed scale eco-hydrologic fluxes and their sensitivity to climate change.

In this study, we applied RHESSys (Regional Hydro-Ecologic Simulation System) to Southern Sierra Critical Zone Observatory watersheds. We assess the impact of spatial resolution of the RHESSys input (topography and vegetation) on the model performance (streamflow) and the estimates of the ecohydrologic responses (snow, ET, streamflow, and NPP) to climate variability. We examined the sensitivity of RHESSys estimates of both watershed scale fluxes and spatial patterns of snow, ET and carbon fluxes to the resolution of LIDAR DEM. For some watersheds, the use of a coarser resolution DEM (from 5m to 150m) resulted in a significant degradation of model performance, even after calibration. In addition, DEM resolution significantly impacted ecohydrologic estimations and their sensitivity to inter-annual climate variability.

We also test the impact of vegetation parameters (LAI, canopy fraction, rooting depth and litter biomass) on the estimates of eco-hydrologic responses to climate variability. We compare model estimates based on LIDAR-LAI and canopy fraction products with various resolutions (5m, 10m, 30m, 90m and 150m) and Landsat TM- LAI and canopy fraction product at a 30-m resolution. Results from this sensitivity analysis highlight the role that fine-scale vegetation structure and species-related parameters play in influencing climate related eco-hydrologic fluxes at patch to watershed scales.

24
Getting The Ecohydrology Right in Modeling Catchment Development
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Geomorphic processes are tightly coupled to vegetation dynamics. Yet, little is known how ecohydrologic dynamics of vegetation variability in space and time influence the tempo and timescales of catchment development, which feedback to ecohydrology. The first objective of this study was to get the ecohydrology "right", with sufficient representations of soil moisture, biomass, leaf area index (LAI),
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and flood frequency in a model of landscape evolution. For this purpose, we aimed at semi-arid ecosystems, and improved the CHILD model with a spatially distributed solar radiation component, leading to spatial patterns of soil moisture; a vegetation dynamics component that explicitly tracks above- and below-ground biomass; and a runoff component that more accurately represents the movement of surface runoff and subsurface soil moisture on hillslopes. The ecohydrological component of the model has been verified using the detailed data gathered from the Sevilleta National Wildlife Refuge (SNWR) in central New Mexico, and Walnut Gulch Experimental Watershed (WGEW) in southeastern Arizona. The second objective of this study was to use the model and examine the ecohydrologic role of solar radiation on modeled catchment forms and hydrologic response. This is performed using both a stationary and variable (with wet and dry cycles) climate with different periodicities. Our preliminary findings show that distinct signatures of aspect-driven insolation on soil moisture, plant cover, runoff response, and local erosion rates, lead to a steeper north-facing slopes and valley asymmetry. As a result of denser vegetation during the wet cycles, landscape topography climbs (reduced erosion), reduced vegetation cover during dry cycles lead to enhanced sedimentation, and reduced topography. This climate-drive uplift-decay behaviour of the landscape is found to tightly related to the amplitude and length of cycles, with influence of catchment hydrology.
**Data, Model and Information Sharing Solutions**

**25**

**Experience with Implementing an Off-the-Shelf System for Hydrologic Data Management**

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As part of the Baltimore Ecosystem LTER and related urban hydrology projects, we have been developing an end-to-end system of data collection, telemetry, storage, QA/QC, archiving, web services, and assimilation into mathematical models. Urban data sets are often highly resolved in space and time, features required to capture the complex variability of the systems. In an ongoing collaborative effort with the USGS MD-DE-DC Water Science Center, we co-maintain a set of USGS stream gages in suburban Baltimore. We aim to follow USGS standards for QA/QC of the synoptic data, which includes adjustment of stage data based on field observations, rating curve development, and other USGS protocols. In an effort to duplicate USGS in-house stream gaging QA/QC software, which is not available to nongovernment entities, several commercial options were tested and the Kisters software suite was chosen. This software permits implementation of the USGS protocols, while at the same time is well-suited to managing a wide array of our other hydrologic data (tipping bucket rain gages, well water levels, and water quality sensors). Kisters software organizes data in a tree hierarchy of station, parameter, and time series. This allows users access solely to their datasets through a user administration module. Metadata (text, XML, images, or spatial data) can be tied to the data values in the hierarchy. The software allows tracking of actions taken by each user from raw data ingestion through corrections, QA/QC adjustments, and any other required calculations. This system has proven to be a robust way to store and process raw data before exposing the data to CUAHSI HIS Central. Through an illustration using Dead Run stage data, we demonstrate the data workflow, how QA/QC protocols are applied, and the sharing of data to HIS central.

**26**

**A Novel Information Sharing Tool: IFIS Knowledge Engine**

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The Iowa Flood Information System (IFIS) is a web-based platform developed by the Iowa Flood Center (IFC) to provide access to and visualization of flood inundation maps, real-time flood conditions, flood forecasts both short-term and seasonal, and other flood-related data for communities in Iowa. The system is designed for use by general public, often people with no domain knowledge and poor general science background. To improve effective communication with such audience, we have introduced a new way in IFIS to get information on flood related issues – instead of by navigating within hundreds of features and interfaces of the information system and web-based sources-- by providing dynamic computations based on a collection of built-in data, analysis, and methods. The IFIS Knowledge Engine connects to distributed sources of real-time stream gauges, and in-house data sources, analysis and visualization tools to answer system-guided questions grouped into several categories. Users will be able to provide input based on the query within the categories of rainfall, flood conditions, forecast, inundation maps, flood risk and data sensors. Our goal is the systematization of knowledge on flood
related issues, and to provide a single source for definitive answers to factual queries. Long-term goal of this knowledge engine is to make all flood related knowledge easily accessible to everyone, and provide educational geo-informatics tool. The future implementation of the system will be able to accept free-form input and voice recognition capabilities within browser and mobile applications. We intend to deliver increasing capabilities for the system over the coming releases of IFIS. This presentation provides an overview of our Knowledge Engine, its unique user interface and functionality as an educational tool, and discusses the future plans for providing knowledge on flood related issues and resources.

27
ESSDB: A Relational Database Model for Environmental Ex-situ Sample Data
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In this paper we present a relational database model for environmental ex-situ sample data-ESSDB. The purpose for such database is to assist environmental field researchers and investigators to archive, share, search, analyze, and retrieve data efficiently. It is intend to be informed by the US Environmental Protection Agency (EPA) WQX framework to host laboratory based sample data collections and also be connected to the System for Earth Sample Registration, SESAR using the 9 character International Geo Sample Number identification code. As an important portal for searching and retrieving, controlled vocabularies, lookup tables, and ontologies, widely used and recognized in domains of environmental science, are assembled, merged, and then applied to the ESSDB. The model is designed to be light, compact, extensible, and straightforward to understand. The ESSDB will be implemented with SQL Server 2008, and installed as one node of multi-data-type Environmental Data Store (EDS) at the CrossRoads initiative at the City College of New York.

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Robust Impacts of Land Use Land Cover Change in a Changing Climate: Results from CMIP5 Climate Models
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Land use land cover change has significant impacts on hydrologic fluxes such as evapotranspiration and runoff, which in turn affect regional climate and water resource availability. Previous studies have demonstrated latitudinal variations and uncertainties in climate impacts of land cover change. While surface albedo feedback dominates in the mid-latitude region, the hydrologic feedback dominates in the tropical region. Through a comprehensive analysis of 15 CMIP5 climate models (a total 69 ensemble members), we show that land cover change impacts appear more robust compared to previous findings. Globally, regions of intensive land cover change have experienced greater decrease in precipitation and evapotranspiration between late 19th century and late 20th century compared to other regions. This finding is further confirmed by focusing on four major land cover change regions including central North America, Central Europe, India, and the Sahel. Three out of these four regions show greater decreases or weaker increases in precipitation and evapotranspiration in the intensive land cover change areas.
compared to the surrounding areas having no or less intensive land cover change. Even in mid-latitude regions, e.g., central North America, the peak summer monthly temperature is higher in the intensive land cover change region compared to the surrounding area, possibly due to a dominance of hydrologic feedback (lower evapotranspiration leading to higher temperature) over surface albedo feedback. Among the four regions studied, the land cover change has the strongest impacts on Sahel climate, a tropical region.

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HydroPad: Free iPad (iOS) and Android (Java) App for Hydrologic Data Discovery, Visualization, and Data Acquisition
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The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) uses a service oriented architecture (SOA) to provide users with access to distributed hydrologic data services that are published by a number of academic and government data sources. The main objectives of the research presented here is time series data discovery from the HydroServers and data acquisition and upload to a HydroServer via iPad or Android based mobile devices using a new software called “HydroPad”. HydroPad aims to be a freely available app for Apple or Android phones and tablet computers, with the intent of serving as a simplified entry point into data resources published using the CUAHSI HIS WaterOneFlow web services, much like the existing software, HydroDesktop. HydroPad is used to collect data at different remote locations and upload it to the “HydroServer Lite” light-weight HydroServers. Because, iPad and Android devices typically do not have enough memory for advanced data processing, data processing and chart creation for HydroPad is done using web services in a third party server. There are two main use cases in the data uploading option: If the tablet device has an internet connection the user can directly store data into the server. If the tablet device does not have an internet connection, data are stored on an SQLITE database on the tablet device and as soon as an internet connection becomes available, data are transferred to the HydroServer.

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HydroServer Lite Interactive Web Client: Development of Web Portal for HIS HydroServer Management and Data Visualization
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In an effort to enhance the field science programs at the McCall Outdoor Science School (MOSS), Idaho State University researchers are developing an interactive web client for use with the CUAHSI Hydrologic Information System (HIS). This web client will be made available as a free software package that operates in tandem with a HydroServer Lite database, which is hosted on a free or low cost data hosting site such as BlueHost or GoDaddy. This package gives users all of the comprehensive data storage capabilities of HIS as well as the data visualization and analysis capabilities without the software and hardware requirements of a traditional HydroServer. This is especially useful for organizations that may
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not have access to these requirements. The interactive web client provides a user management system (for data entry permissions), multiple data entry options and map-based visualization for the data contained within the specific HydroServer. Data entry options includes forms for entering a single data point at one time, entering multiple data points, or uploading a text file of data into the database. Data visualization is made available through a map that shows site annotations where data has been collected. From here, a user can select a site they are interested in to view a site details page, which contains several types of graphs and a table for variables available at that site. Data graphs and tables can then be exported for use outside of the system. Additionally, the lightweight HydroServer can be registered with HIS Central, so users can publish their data with the larger HIS network. This web client fulfills the use case for MOSS data collection and is also being developed further to appeal to a broader group of users in the Idaho EPSCoR project and elsewhere.
General

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On the Relationship between Storage and Streamflow in Urban Watersheds
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Kirchner (2009) conceptualized catchments as simple dynamical systems and set forth a methodology to derive storage-discharge relationships from streamflow data records. The method assumes that streamflow is directly related to storage and that precipitation and evapotranspiration are small relative to streamflow. Our aim was to test this methodology on watersheds characterized by a varying percent impervious surface area to evaluate the effects urbanization on the storage-discharge relationship. The study watersheds are part of the Baltimore Ecosystem Study Long-Term Ecological Research (BES LTER) project.

We conducted the analysis using USGS streamflow records from 2002-2008 for Dead Run (14 sq. km. with 45% impervious surface area) and Delight (11 sq. km. watershed with 22% impervious surface area). This period spans extremes in dry (820 mm rain in 2002) and wet (1630 mm rain in 2003) years. Rainless nights were isolated using bias-corrected Hydro-NEXRAD and Stage IV radar-rainfall fields and solar radiation from the BES LTER meteorological station. We compared the derived relationships for these watersheds with those for the Severn and Wye Rivers, which are undeveloped watersheds of similar size in Plynlimon, Wales as well as for the undeveloped Rietholzbach watershed in the Swiss prealpine.

We found that Dead Run, the most urbanized of these watersheds, had the most ‘flashy’ relationship between storage and discharge, and was followed by Delight, the second most urbanized watershed. Flashiness in this case is indicated by greater sensitivity of streamflow to changes in storage. Since the rising limbs of hydrographs are excluded in the method of analysis, the flashiness indicated by this analysis is related only to hydrograph recession. Flashy hydrograph recession may be due to the large but very quick streamflow contributions from impervious surfaces during storms, after which there is a fast decline in streamflow. This analysis is part of our overall effort to better understand urban groundwater-surface water interactions.

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Satellite-derived Potential Evapotranspiration Estimates for Operational Hydrologic Forecast Models
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The National Weather Service’s (NWS) strategic plan identifies the improvement of forecasting in support of national water supply management, economic productivity and healthy communities as a major priority. Both short- and long-range planners require dynamic operational forecast information, highlighting the need for hydrologic prediction systems that account for rapid changes at the watershed scale and smaller on daily to sub-daily time steps. This is particularly important given predicted
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Intensification of the hydrologic cycle due to climate change. Current NWS hydrologic forecasting methods use watershed-scale, conceptual models driven by ground-based observations of precipitation and temperature. Potential evapotranspiration (PET) inputs are also required. Climatologies from historical pan evaporation observations have traditionally been used, and PET inputs remain static from year-to-year. Furthermore, pan evaporation data records begin in the 1950s and may be unrepresentative of current climate, potentially leading to unrealistic modeled evapotranspiration fluxes. Accurate PET inputs are vital for simulating soil moisture conditions and subsequent watershed runoff during forecasting. In the past decade, remote sensing data, specifically from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua satellites, have become readily available. MODIS products are playing an increasingly critical role in various Earth system models. At the same time, adoption of a more robust forecast system by the NWS is in early operational stages. This new forecast system will ultimately be able to accommodate the addition of new data streams, such as data derived from MODIS products, that have the potential for advancing the science of hydrologic forecasting.

In this study, a MODIS-based PET algorithm that applies a Priestley-Taylor formulation to derive daily PET is tested in six basins under the jurisdiction of the NWS North Central River Forecast Center (NCRFC). Thirteen MODIS products are used to estimate daily PET values from May through September 2004-2010 at 500m resolution. In the first step of the study, a basin-averaged (lumped) mean daily PET value is generated and a new PET climatology curve is computed for input into the operational version of NWS forecast models. Initial results show a strong correlation between MODIS-based PET values and those based on ground observations. Additionally, MODIS-based PET curves peak earlier and remain higher throughout the summer compared to NWS PET curves. Further modeling analysis will include input of annually varying PET curves and the PET time series to assess how accounting for seasonal and daily variations may impact simulations. The gridded PET is also being tested in the distributed NWS models.

33 Improving Watershed Nitrogen Budgets with Spatial and Temporal Scaling of Denitrification
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Closing the nitrogen budget is a major scientific challenge at multiple scales. One of the largest sources of uncertainty is the importance of denitrification. Determining in situ rates of denitrification in elements of landscape that remove a disproportionately high amount of N from certain areas of catchment (hot spots) in response to seasonal and event driven conditions (hot moments) is critical to closing watershed nitrogen budgets. We develop an approach to scale denitrification flux from seasonal soil cores collected in different landscape positions to the entire watershed using a combination of laboratory core experiments, terrain analysis and in situ soil oxygen and soil moisture content sensors. In the Pond Branch watershed in the Piedmont region of Maryland, nitrogen deposition values are relatively high (10kg/ha/yr) with very little export in streams (0.5 kg/ha/yr). Our data suggest that
approximately half of this retention can be accounted for by denitrification. We highlight the importance of riparian microtopography and the need to better link observations and models.

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Assessment of Satellite-based Precipitation Products in Hydrologic Modeling: A Case Study from the Oum Er Rbia Watershed, Morocco
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Precipitation is the most important forcing parameter in hydrological modeling, yet it is largely unknown in the arid Middle East. We assessed the magnitude, probability of detection, and false alarm rates of various rainfall satellite products (e.g., TRMM, RFE2.0) compared to in situ gauge data (~30 stations) across the Oum Er Rbia Watershed in Morocco. The basin is one of the largest watersheds in the country with an area of 35,000 km2. Precipitation over the basin is relatively high with an average of 268 mm/year according to TRMM (1998-2008). The existing gauges indicate that the average annual precipitation across the Tadla and Coastal Plains region is 260 mm/year and 390 mm/year across the Atlas Mountains.

Following the assessment of satellite products against in situ gauge data, we evaluated the effects (e.g., runoff and recharge amounts) the various rainfall products due to difference in spatial and temporal resolution had on rainfall-runoff models (SWAT). Specifically, we performed a four-fold exercise: (1) The first stage focused on the analysis of the rainfall products; (2) the second stage involved the construction of a rainfall-runoff model using gauge data; (3) the third stage entailed the calibration of the model against flow gauges and/or dams storage variability, and (4) model simulation using satellite based rainfall products using the calibrated parameters from the initial simulation.

The preliminary results evaluate the potential for using publicly available remote sensing datasets in lieu of field gauges for data sparse and inaccessible regions. This will address one of the major difficulties facing hydrologists while constructing representative rainfall runoff models in the absence of field data as it is the case of most of North African watersheds.

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NevCAN; Monitoring Climate Variability and Change along Two Elevation Gradients
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The Nevada Climate-ecohydrological Assessment Network (NevCAN) is comprised of two transects of monitoring stations that cross elevation gradients in both the Mojave and Great Basin Deserts. One transect, the Snake Range Transect, is located within the heart of the Great Basin Desert in east central Nevada. The other, the Sheep Range Transect, is located north of Las Vegas near the transition between the Mojave and Great Basin Deserts. Monitoring stations are located in the center of key vegetation zones associated with specific ranges in elevation. The stations are equipped with sensors that enable assessment of present-day climate variability. The standard suite of sensors include: Geonor and tipping
bucket precipitation; ultra-sonic snow depth, solar radiation, net radiation, photosynthetically active radiation, multi-height air temperature, relative humidity, barometric pressure, wind speed/direction, soil moisture at the surface (DPHP) and at depth (TDR), soil water matric potential, surface runoff, soil heat flux, soil temperature at multiple depths, sap flow and point dendrometers for key species, and PTZ web cameras. Other sensors, such as NDVI and drainage sensors, are being installed at specific monitoring stations. Results to date document anticipated increased precipitation with increasing elevation as well as latitude, a larger diurnal range in air and soil temperature for the lowest elevation sites and higher wind speeds at both lower latitude and lower elevation sites in comparison to higher latitude and elevation sites. NevCAN data are publically available via the Nevada Climate Change Portal, http://sensor.nevada.edu/NCCP/.

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Variability in the Response of Plant Water Use to the Seasonal Timing of Climate Forcings
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A disconnect exists between the timing of when precipitation is received and when water is used by plants in the mountainous watersheds of the western United States. In these snow-dominated environments, the seasonal synchronicity or asynchronicity between the timing of water input and the timing of energy demands can be an important control on forest water use. Additionally, complex topography and inter-annual variation in climate can lead to variation in the balance between moisture and energy controls. In this analysis, we go beyond the lumped watershed analysis of energy versus water limitation typically done using mean annual time-scale and coarse spatial scale metrics to evaluate the importance of these controls on the seasonal synchronicity of forest water use.

Forests in the western U.S. are generally water limited at the end of their growing season and with climate change drought-like conditions are expected to increase in frequency and intensity which makes understanding controls on plant water availability even more critical. Vegetation responses to warming reflect the balance between the increased demand for water and either increases or decreases in water availability. This study uses a coupled hydro-ecologic modeling system applied to a snow-dominated mountain watershed to demonstrate how this balance changes across inter-annual climate and watershed forcing conditions. We show that responses are likely to vary substantially with year-to-year variation in precipitation and temperature and with spatial heterogeneity in energy and moisture inputs. Our results emphasize the role of seasonal timing. In snow-dominated environments shifts in timing, as well as the magnitude of water inputs relative to demand are important controls on effective water availability. We show that inter-annual variation in timing of water inputs is a second order control on vegetation water use and total water input is the dominant effect. We also show that under historic climate variability within-year variation in the timing of water input can be an important driver of ET, although only in a small percentage of years. These are years where annual scale metrics are likely to misrepresent ET behavior.

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Climate and Land Use Effects on River Discharge and Base Flow in Tile Drained Watersheds
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Land use changes such as tile drainage, cultivation, and cropping practices have been blamed for recent increases in river flows in the Midwestern United States. This study analyzed river flow data from 42 HUC 8 watersheds in Minnesota and Iowa to decipher climate and land use effects on river discharge
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and base flow. Base flow was quantified from daily river discharge values using the USGS PART program. Climate vs. land use effects were quantified by comparing regression relationships between annual river discharge or annual base flow vs. annual precipitation for two periods; prior to 1975 and after 1976. Mid 1970s was used as the break point because plastic tile line started to have widespread adoption for agricultural drainage during this period. Underlying premise of the regression comparisons was that land use changes, especially tile drainage, will significantly shift the relationship of flow vs. precipitation in the upward direction. Results show that the relationship between annual discharge or annual base flow vs. precipitation for several heavily tile drained watersheds were statistically similar for the periods prior to 1975 and after 1976, thus suggesting precipitation is the major driver of annual flows, and land use effects on river flows were minor. For some watersheds, the relationships between flows and precipitation were statistically different for the two periods; however, the upward shift was relatively small compared to the upward shift from recent wet climate. Analysis of the Raccoon River and other watersheds in Iowa showed that evapotranspiration has remained the same since 1916 and recent higher flows are due to higher precipitation and not due to the shift in area from small grains to row crops, as suggested in the literature. In this presentation, we show that past studies have wrongly characterized climate effects as land use impacts by overemphasizing statistics and by ignoring the physics of infiltration and runoff.

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Water Quality Modeling for Benefit-Cost Analysis in the Delaware River Basin
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A watershed model is developed to conduct benefit-cost analysis of improved water quality in the 13,500 square mile Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania. The USGS SPARROW model is adapted to estimate nutrient reductions needed to increase dissolved oxygen levels and to meet year-round fishable water quality standards for passage and spawning of diadromous fish such as American shad in the tidal Delaware River. Costs are estimated to reduce nitrogen Total Daily Maximum Loads (TMDL) by a median of 32% within confidence intervals of 20% (25th percentile) to 45% (75th percentile). Market and nonmarket benefits are estimated to meet future DO fishable water quality criteria of 5 mg/l. The water quality model links estimates of pollutant load reduction with economic valuation of benefits and costs of watershed restoration actions and implementation of point and nonpoint source best management practices.

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Fluvial Geomorphology of Rivers in the Greater Blue Earth River Basin
Andrew C. Kessler*, Satish Gupta, and Melinda Brown, University of Minnesota

Natural background levels are a crucial component for establishing Total Maximum Daily Loads for impaired rivers in the United States. One of the major components of background levels for suspended sediments is the contribution from river bank erosion. In Minnesota, there is a heightened interest in quantifying natural versus anthropogenic contributions of sediments in rivers of the Greater Blue Earth River Basin (GBERB). This is primarily because these rivers are highly impaired and they contribute large amounts of sediments to the Minnesota River and then on to Lake Pepin, a large floodplain lake on the upper Mississippi River about 80 km south of St. Paul, MN. This research characterized historical and modern rates of planform changes and bank erosion from GBERB rivers using a combination of 1855 Public Land Survey System PLATs, aerial photographs from 1938-2009, and light detection and ranging data from 2005 and 2009. The results showed that for most rivers sinuosity and river length have decreased and river width has increased since 1938. This suggests an increased capacity of these rivers
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to transport water and sediment. Annual volume loss decreased as the time interval between aerial photographs acquisitions increased, indicating that bank erosion in the GBERB is episodic and volume loss comparisons between two dissimilar time intervals may lead to the wrong interpretation of the effects of anthropogenic changes in the area. For similar time intervals, average bank retreat rates between 1855-1938 (0.51 m yr\(^{-1}\)) and 1938-2009 (0.37 m yr\(^{-1}\)) were statistically similar (\(p = 0.14\)), thus suggesting that bank erosion has remained largely unchanged since European immigrants settled the area. Precipitation explained 66% of the variation in retreat rates signifying its role as the primary factor controlling bank erosion in GBERB.

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Senator Beck Basin Mountain System Observatory
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Senator Beck Basin Study Area at Red Mountain Pass, established in 2003 by the Center for Snow and Avalanche Studies, is capturing year-round mountain system data in a 290 ha (719 acre) catchment in the western San Juan Mountains of the Upper Colorado River Basin. From a 4118 m (13,510') high point in alpine tundra to its pour point at 3353 m (11,000') in sub-alpine forest, Senator Beck Basin is a headwater of the Uncompahgre River, a tributary of the Gunnison River. Two intensively instrumented study plots are operating within the Basin, one in the alpine at 3712 m (12,180'), and the other in a forest clearing at 3371 m (11,060'). Both sites measure snow depth, wind, air temperature, humidity, snow temperature, soil temperature, soil volumetric water content, soil heat flux, and incoming, reflected, and emitted radiation. Precipitation Center for Snow and Avalanche Studies, Silverton, CO and barometric pressure are also measured at the subalpine plot, and SWE is manually measured at both sites. Interannual variations in weather are large, as exemplified by winters 2010/2011 and 2011/2012, but snowpack depth can reach 3m and annual precipitation can reach 1400 mm. A third instrument array on a nearby summit collects wind, air temperature, and humidity data. A notched, broad-crested weir at the Basin pour point measures discharge, temperature, and electrical conductivity. Long-term monitoring of the Basin plant community is also underway. Senator Beck Basin is a snow dominated system discharging up to 1,100 af of snowmelt each spring but monsoon rains also contribute to flows. CSAS has proposed complementing Senator Beck Basin with new and existing infrastructure downstream to create an Alpine to Arid Hydrologic Observatory dropping over 2,000 meters in 30 km and capturing a 385 km\(^2\) drainage area.

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Distributed Hydrological Modeling with Radar Precipitation Input – Case study for Flood Prediction in the Mountainous Three Gorges Region
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Yangtze River’s Three Gorges Region (TGR) is one of the typical mountainous storm zones in China as extreme rainfall events and consequent floods often occur in this area. At the same time, the TGR is poorly gauged due to its complex terrain and a large number of small tributaries. Urgently, we need much more distributed information on precipitation and river flow regime within TGR to estimate the
lateral inflow to Three Gorges Reservoir for both flood prediction and water management purposes. In this study, a distributed hydrological model combined with weather radar measured rainfall has been carried out to predict spatiotemporal hydrologic response in TGR during the flood season in 2010. First, we developed a radar-based precipitation estimation algorithm for the mountainous TGR that includes error correction methods associated with beam blockage, Z-R transformation, gauge-based bias adjustments. Compared with the traditional gauge-monitoring network, the results indicate that radar-based Quantitative Precipitation Estimates (QPE) provide useful spatial information of regional precipitation pattern. In addition, this new QPE information clearly demonstrates the inadequacy of current ground gauge network. Then with the radar QPE as input, a distributed Geomorphology-based Hydrological Model (GBHM) was applied to simulate the regional flood risks as response to the storm events. Comparing the flood prediction derived only from ground gauge measured rainfall with that from radar QPE products, we found that radar measurements combined with ground gauge observation could not only offer much more reliable rainfall estimates over complex terrain but also, consequently, improve the distributed flood risk prediction in the TGR region. Finally, we investigated the hydrological prediction uncertainties associated with the different sources (i.e. gauge, radar, and model etc.) and discussed a research framework for developing a best possible flood risk prediction system in TGR region.

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Understanding Groundwater-surface Water Interactions in the Heihe River Basin
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The Heihe River Basin (HRB) is the second largest inland river basin in the arid area of northwestern China, with an area of approximately 130,000 km². The main channel of the Heihe River has a length of approximately 800 km, originating from the Qilian Mountains in the south, flowing northward through the Hexi corridor of Gansu Province and entering into the Gobi desert. Water originating from the alpine terrains from snow and glacier melting turns the middle HRB into productive farmland with natural and irrigated oases. The struggle for water between deserts and oases has been going on for decades, and recently has accelerated due to climate changes and increasing demands for water resources from the rapid population growth and the development of the irrigated agriculture in the middle HRB. A marked degradation of the environment, salinization and desertification of the land has raised great concerns about the water management and ecological issues in the region. Since 2009 the “Heihe River Ecohydrology Research Programme” has been supported by the Chinese NSF to conduct an integrative study of ecology and hydrology in the HRB toward sustainable water resource management in arid ecosystems. Groundwater-surface water interactions and their effects on ecosystem functioning and services are one of the key scientific questions and are essential for the sustainable development of the HRB.

Integrated observation, experimentation, and modeling are applied to study groundwater and surface water interactions in the HRB. A groundwater monitoring network has been established to monitor regional groundwater dynamics and trends. Flow rates in the key locations along the Heihe River are measured to keep track of the changes in river flows. Based on the temperature differences, groundwater and surface water interactions in the middle HRB have been investigated by measuring the streambed temperature through fiber optic distributed temperature sensing. Moreover, airborne
thermal-infrared remote sensing has been conducted to obtain temperature distribution on the river surface. The distribution and pattern of temperature anomalies can thus be identified, providing an effective means of locating groundwater discharge areas. This information will be compared to the groundwater discharge zones as simulated by the integrated surface water-groundwater model, and serves to constrain the model calibration. Compared to the usually limited amount of monitoring data such as hydraulic heads and fluxes, the spatial distribution of temperature data provides a much broader and complete areal coverage, and more importantly, provides independent calibration data.

To develop a comprehensive groundwater-surface water model to quantify groundwater-surface water interaction in the HRB, a geological model was first constructed based on borehole information, previous hydrogeological maps and remote sensing data. It includes the Quaternary aquifer, the Tertiary aquifer and the bedrock in the region. A basin-scale groundwater-surface water model is being constructed for the middle and lower HRB, which will be integrated with ecological and economic models of the HRB to explore the strategies for the sustainable water management in the HRB. This presentation will summarize the progress to date in field data collection and model development for understanding groundwater-surface water interactions in the HRB.

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Mapping Drought in the Krishna Basin, India, with Remote Sensing
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The Surface Energy Balance Algorithm for Land (SEBAL) was automated using a rule-based pixel selection, and was used to calculate seasonal ET in a normal and drought year in the Krishna Basin. Validation with a water balance, evaporation pans, and ET modeled from lysimeters showed good agreement in irrigated areas but an underestimation of ET from rainfed areas in the normal year. Overall, ET decreased in a few upstream and downstream irrigation projects and increased at some projects in the upper and middle reaches, showing that drought impacts on ET were heterogeneous but correlated with changes in precipitation. The automated SEBAL algorithm proved to be useful for rapidly generating the lengthy time series of ET and was insensitive to changing spatial domain, suggesting that this method is useful for measuring ET distribution in data-scarce basins.

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Using Time-lapse Electrical Resistivity Tomography to Visualize Conduit-matrix Exchange in a Semi-confined Karst Aquifer
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The Santa Fe River Basin is a complex watershed containing hydrologic regions of confined, semi-confined and unconfined karst aquifer. Each region has unique characteristics that lead to difficulty in describing how groundwater and surface water interact. In the semi-confined region, the Santa Fe River is entirely captured by a sinkhole then flows through various karst windows and emerges as a spring 6 kilometers to the south. Recent work has developed a working hypothesis to describe how groundwater and surface water interact in the karst aquifer during high and low flow. In this study, we are interested in the semi-confined region and visualizing how groundwater and surface interactions control overall...
flow. Using electrical resistivity tomography, a time-lapse study was conducted at two locations to study changes in conductivity during groundwater and rain flow driven events over a six-week time period. Our results reflect the locations of known karst conduits. Changes in resistivity during rainfall infiltration and in karst and matrix flow over time provide insight into exchange dynamics. These observations provide details about the surface water-groundwater exchange in a complicated, semi-confined, sink-rise system.

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Preliminary Evaluation of Water Isotopes in Baltimore Precipitation and Streamflow
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In order to demonstrate the capability of a new Picarro liquid water isotope analyzer (model L2010-i), we analyzed one year of precipitation samples and stream synoptics collected under high (March) and low (July) streamflow conditions in 2011. Precipitation samples included snow events as well as tropical storms. The resulting Baltimore meteoric water line was parallel to and shifted upward from the global meteoric water line, with a best fit of $d_{2H} = 8.20 \times d_{18O} + 20.5$ for the Baltimore line. Precipitation values ranged from $(d_{18O}, d_{2H}) = (-24, -180)$ for snow to $(d_{18O}, d_{2H}) = (0, 10)$ for spring rain. The stream synoptics were carried out in Dead Run, a highly urbanized 14 sq km watershed (45% impervious area) that is part of the Baltimore Ecosystem Study LTER project. The purpose was to roughly characterize the stream isotopic composition as a function of space and time to ascertain whether later study of end members and deconvolution of the stream signal would be warranted or interesting. For each synoptic, approximately 40 stream samples were collected in one day (after one week of no rain), by driving around the watershed and sampling tributaries at road crossings. The resulting spatial variability in isotopic content of stream samples was striking. For the 3-15-11 synoptic, the values ranged from $(d_{18O}, d_{2H}) = (-6.6, -32)$ to $(-8.4, -49)$; for the 7-7-11 synoptic, the range was $(d_{18O}, d_{2H}) = (-9, -56)$ to $(-4, -25)$. A greater spread of values for the summer synoptic is apparent. The stream isotopic signatures had the following trends: for the March synoptic, $d_{2H} = 6.32 \times d_{18O} + 4.6$; for the July synoptic, $d_{2H} = 6.01 \times d_{18O} + 3.4$. The slopes (~6) are similar for the two synoptics and lower than the Baltimore meteoric water line slope of 8.2. This reduced-slope effect has been documented by others and is attributed to evaporation. We sampled tap water (during both synoptics) from a spigot in the watershed. The isotopic composition of tap water fell in the middle of the stream values and changed little from spring to summer. Further work will investigate the slope of isotopic values for each subwatershed within Dead Run. These sub-catchments are the same order of magnitude in size, but span a gradient of the percentage of area that has stormwater control measures, a variable that could potentially enhance evaporation.

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Hydrologic Response of Sierra Nevada Headwater Catchments to Rain versus Snow Inputs Using Spatially Distributed, Data-driven Hydrologic Modeling
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The separation of precipitation into rain and snow is very important for water-balance accounting in snow-dominated watersheds. Using distributed data from two headwater catchments in the southern Sierra Nevada, the sensitivity of evapotranspiration (ET) and discharge simulations by the Regional
Hydro-Ecological Simulation System (RHESSys) to improved separation of precipitation between snow and rain was tested. The catchment's actual annual ET and observed annual average streamflow are approximately 80 cm and 30 cm, respectively, with little to no water contribution to the groundwater table because of saprolite bed materials. This relatively high ET is primarily sustained by presence of snow that helps to increase soil moisture later into the year than does rain. Therefore, lower snow impacts ET, soil moisture, stream baseflow and water balance as a whole. Whether precipitation falls as rain or snow is mainly determined by the thickness and temperature of atmospheric layers, cloud properties (CP), wind speed (WS) and relative humidity (RH). A simple index in the hydrologic model could not accurately separate precipitation into rain or snow based on limited climatic input parameters such as maximum and minimum temperatures. Hydrologic simulations with snow and rain inputs separated based on distributed ground data did calculate more-accurate water balances in mixed rain-snow catchments. This study first analyzed the daily observed precipitation based on observed daily temperature, daily change in snow depth and snow water equivalent (SWE) to partition precipitation into daily rain and snow. The analysis shows a good agreement between the observed SWE and the estimated snow. Then, RHESSys was used to simulate water balances at using two different model inputs i) total precipitation, and ii) rain and snow. The results show a better agreement between the observed streamflow and simulated streamflow using separate snow and rain inputs versus total precipitation input. Therefore, it is necessary to improve model formulation not only based on a temperature threshold, but also using other climatic parameters (CP, WS, RH) for better partitioning of precipitation into rain and snow. Investigating the impact of snow /rain versus precipitation in hydrologic model is essential for hydrological cycle in western mountains where snow and rain transition play an important role in water balance. This research area is a part of the Southern Sierra Critical Zone Observatory (CZO).

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Distributed Hydrologic Modeling of the Monocacy River Basin using ParFlow.CLM: Effects of Initial Conditions on Spin-Up Behavior
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We present results from the construction of a ParFlow.CLM model of the 5600 sq km Monocacy River Basin located in Maryland and Pennsylvania. This subdomain model was constructed during the development of a larger Chesapeake Bay Watershed model as verification case against an existing MODFLOW model, which was previously developed to investigate seasonal trends of groundwater levels for current versus pre-development conditions of the Monocacy River Basin. In particular, the ParFlow Monocacy model was used to determine suitable initialization methods over a range of land surface topography. Representation of initial conditions plays an important role in modeling surface and subsurface flow. Here we present the spin up behavior of the model as a function of initial conditions. The model was developed at a horizontal resolution of 500 m. Meteorological forcing for the year 1980 was applied using the National Land Data Assimilation System dataset. Available hydrogeologic data was incorporated as 10 subsurface model layers. Results of the uncalibrated model after spin-up showed good agreement between observed and predicted stream flow. Model spin-up behavior was evaluated for two different initial conditions: (1) a simple elevation-dependent initial condition with a water table depth of 10 meters below land surface; and (2) an elevation-dependent initial condition
with a water table depth of 10 meters below land surface, followed by an artificial drainage of the basin using a very high hydraulic conductivity. Equilibrium spin up was carried out by repeating each model run successively for a number of years. Results showed that groundwater discharge was the main driver of spin-up time. Effects of initial conditions were still noticeable after more than 10 years. Effects of initial conditions on streamflow were more pronounced during base flow than peak flow. The two initial conditions types resulted in different spin up behavior. The artificially drained model reached equilibrium faster with a 5% difference in yearly average discharge between consecutive runs reached after 4 years vs 6 years with the simple elevation-dependent type initial condition.

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Breaking Down the dQ/dt-Q Data Cloud: Examining Causes for Shifts in Event dQ/dt-Q Curves

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Plots relating the rate of change in stream discharge (dQ/dt) versus the concurrent mean discharge (Q) have long been used to make inferences into the aquifer properties of watersheds. New work has investigated the possibility of considering dQ/dt-Q plots more broadly as a means to infer the storage-discharge relationship or the channel network morphology of a watershed. However, no matter how interpreted, a key limitation to using dQ/dt-Q plots has been the large amount of scatter among the data points. To date, different investigators have considered different approaches to dealing with the scatter: 1) looking at the envelope of the data cloud, 2) fitting a best-fit line though the middle of the data cloud, or binning data with similar Q and finding a mean dQ/dt value within each bin. As an alternative to these approaches, we propose distinguishing individual recession events within the data cloud. When viewed in this way, it becomes apparent that the data cloud consists largely of multiple individual events that shift seasonally. Using four medium-sized watersheds in central New York, this work seeks to explain the reason behind shifts in the individual recession events. In particular, we assess whether shifts are related to variations in the intensity of evapotranspiration or variations in catchment moisture storage prior to the recession event. Variations in evapotranspiration are assessed using two measures: the Priestly-Taylor equation applied to meteorological station data and spatially-average latent heat flux as provided by NCEP North American Reanalysis (NARR) data. Variations in moisture storage are also assessed using two measures: baseflow prior to the recession event and soil moisture as estimated within the NARR dataset. Understanding the cause for shifts in individual recession curves within the dQ/dt-Q plot can provide fundamental insights into hydrologic behavior at the watershed scale.

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Patterns of Forest Cover, Hydrological Regime, and Aquatic Biota in Alabama

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The changes in natural forest landscape and aquatic systems are a major consequence of increasing population and urbanization. The processes of converting, harvesting, and fracturing forest landscapes can result in profound changes in aquatic flow regime. We hypothesize that (i) loss of forest cover or increased frequency of disturbances may increase stream peak flow, and reduced low flow; (ii) stream flow regime shapes the dimensions of a channel, including depth and speed; and (iii) changes to the
natural flow regime may impact aquatic biological processes and result in novel selective pressures to biota. In the state of Alabama, timber industry is the second largest business. Forest cover loss has potentially profound effects on the flow regimes of stream networks and biota in the state. Through literature and historic data, patterns of forestation, hydrologic flow regime, and aquatic biological distribution are quantified and their co-relationships are estimated. The spatial relationships are identified and the above hypotheses are tested.

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Wind Energy Forecast Ensembles Using a Fully-coupled Groundwater to Atmosphere Model
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As wind energy becomes an increasingly important component in the renewable energy portfolio, accurate wind forecasts become critical. We apply the PF.WRF model, a fully-coupled groundwater-to-atmosphere model incorporating the parallel three-dimensional variably-saturated hydrologic model ParFlow and the Weather Research and Forecasting (WRF) atmospheric model to simulate the components of the hydrologic cycle from bedrock to the top of the atmosphere. Model components are coupled via moisture and energy fluxes in the Noah land surface model. The fully-coupled model dynamically simulates important meteorological effects of interactions between the land surface and the atmosphere. In this study, we complete an ensemble of simulations for a wind energy production site on the west coast of North America using varying stochastic random fields of subsurface hydraulic conductivity and forced with meteorological data from the North American Regional Reanalysis dataset for a series of wind ramp events, and compare the simulated results with observational data. We attribute error between the modeled and observed data to uncertainty in the statistical representation of subsurface heterogeneity and errors in boundary condition forcing data. We can reduce subsurface uncertainty by conditioning the stochastic random field representation of subsurface hydraulic conductivity to values drawn from a “truth” simulation. This reduction of uncertainty propagates through subsurface and surface variables, and into atmospheric variables like wind speed.

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Effect of Hyporheic Exchange Induced by Riverbed Dunes on Mixing of Contaminants Daylighting from Aquifers to Rivers
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Interaction of surface water and groundwater in hyporheic sediments of river systems is known to create unique biogeochemical conditions that can attenuate contaminants flowing downstream. In such cases, oxygen, carbon, and the contaminants themselves often advect together from sources in surface water. However, the ability of the hyporheic zone to attenuate contaminants in upwelling groundwater plumes as they exit to rivers is less known. Such reactions may be more dependent on mixing of carbon and oxygen sources from surface water with contaminants from deeper groundwater. A few studies have shown that attenuation in shallow sediments can be much greater than in upgradient aquifers, yet did not determine what site characteristics most control such “hyporheic natural attenuation.” Here we focus on mixing between hyporheic flow paths induced beneath riverbed dunes (by form drag from river current) and upwelling deeper groundwater. We simulated such mixing using numerical simulations of groundwater flow, particle tracking, and solute transport using MODFLOW, MODPATH, and MT3DMS, respectively. We conducted a sensitivity analysis where we modified parameters that control degree of mixing (groundwater discharge rate, average hydraulic conductivity of sediments (K), heterogeneity of K, anisotropy of K, and dispersivity) to determine their effect on mixing (depth of hyporheic flow paths into
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the bed, residence time distribution of hyporheic flow paths and upwelling groundwater, and area of mixing between hyporheic flow paths and upwelling groundwater). We found that mixing area and hyporheic flow path depth increased with decreasing upwelling flowrates, increasing average K, increasing heterogeneity of K, decreasing anisotropy of K, and increasing dispersivity. Nevertheless, mixing area overall was relatively small compared to the bed area, and varied comparatively little with sensitivity parameters except for dispersivity. This relatively small mixing area indicates that reactions which depend on mixing of reactants from sources in surface water and groundwater may have fewer opportunities to occur within riverbeds than reactions which rely on interaction of reactants that all come from surface water. We are currently continuing to develop the model including adding chemical reactions of common groundwater contaminants (e.g., chlorinated solvents) in order to determine the degree of which upwelling pollutants can be transformed within the riverbed. Such investigations will help understand the potential for hyporheic natural attenuation of groundwater contamination within riverbeds.
Learning from Disasters

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Changes to Snow Accumulation and Ablation Following the Las Conchas Forest Fire, New Mexico, USA
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Water resources derived from montane forests are critical to the water sustainability of the Western U.S. and subject to major changes in water partitioning as a result of natural and anthropogenic forest disturbances, including fire, harvest, disease, and insect mortality. Previous plot-scale studies have demonstrated that a burned forest canopy will have less interception by vegetation and greater energy fluxes to the snowpack during melt, but little is known about how these changes would control snowpack mass balances over the complex topography characteristic of montane catchments. In this study, we investigated changes to the processes controlling snow accumulation and ablation during the winter-season in a small catchment heavily impacted by the Las Conchas fire and a nearby ‘control’ catchment lightly impacted by fire damage. We were interested in the testing how two competing hypotheses would interact to determine the snowpack at maximum accumulation in a burned catchment: 1. reduced interception leading to increased new snow accumulation and reduced spatial variability and 2. increased winter-season ablation leading to reduced maximum accumulation and increased spatial variability. A 20-cm snowfall surveyed at 475 locations in the two catchments showed significantly greater snow depths in the burned versus the unburned catchment (p<0.001), with an average of 15.0 cm new snow in the burn versus only 8.5 cm in the unburned forest. The influence of forest canopy density on new snow accumulation was more significant in the unburned forest, with reduced length scales of spatial variability in the burned forest. Conversely, the approximately 1500 snow depth measurements made near maximum accumulation showed significantly greater depths in the unburned forest compared to the burned forest (mean of 54.3 and 46.8 cm, respectively). The same locations had nearly identical mean snow depths in the burned and unburned forests (71.3 and 71.9 cm, respectively) when estimated with pre-burn 2010 LiDAR-derived snow depths. Maximum snow depths in the unburned forest had strong canopy density controls, while the burned forest had a strong negative relationship with elevation. Surprisingly, the variability of snow depths were similar between the burned and unburned catchments, despite a shift to more topographically-controlled snow distribution (aspect and elevation) in the burned forest. These overall changes highlight the importance of our two competing hypotheses by showing that changes in canopy structure can both increase new snowfall by reducing interception and decrease maximum accumulation by increasing winter-season ablation. Although this work does not quantify changes to the snowpack energy and mass balance, previous work in this area suggests that sublimation losses can be substantial and wind distribution minimal in a typical healthy forest. Future modeling work and additional field data will be necessary to quantify these competing processes across variable topography and climate, however these changes to snow water partitioning are potentially a significant detriment to the terrestrial water balance in areas heavily impacted by fire.

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Leveraging Federal and State Funding to Advance Flood Research and Benefit Local Public: Iowa Flood Information System
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The 2008 Midwest flood, the fifth largest disaster in United States (US) history, highlighted a need for enhanced flood information, awareness, and preparedness in the region. Recognizing this need, the State of Iowa established the Iowa Flood Center (IFC), a state-funded academic flood research and education center, at the University of Iowa’s IIHR – Hydrosience & Engineering in the spring of 2009. The IFC is a unique resource, being the first and only state- or federally-funded academic center in the country focused on flood science. The IFC complements the roles of relevant state and federal agencies by providing added flexibility in creating and testing new methods of measurement, forecasting, and data dissemination. The Center is developing flood frequency estimation methods, real-time and seasonal flood forecasting models, flood inundation maps libraries, and new instrumentation for monitoring of flood-related environmental variables. The Center builds on research and technologies developed with the support of the National Science Foundation, NASA, and NOAA. In addition to more traditional academic and technical avenues, the Center communicates the products of its work directly to the public in easily understood formats via the web-based Iowa Flood Information System (IFIS). The IFIS is a web-based tool to provide to communities access to flood inundation maps, real-time flood conditions, flood forecasts both short-term and seasonal, flood-related data, information and interactive visualizations. IFIS will help community leaders make better land-use decisions and become more flood resilient and will alert communities in advance to help minimize damage of future floods. The Center also engages communities to assist in improving flood preparedness, promoting the theme of living with floods.

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Uncertainty for Time–Spatial Hydrological Structures in the Upper Missouri River Basin: the Use of Statistical Learning

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The concept of uncertainty must be considered in order to study, describe, assess and communicate the risk associated with hydrologic events such as flooding or drought. The need for a general theory of uncertainty was introduced by Lofty Zadeh in 2005. Zadeh considered uncertainty as a property of information, and used the human language’s property and functions to explain his improvement of mathematical modeling (fuzzy logic) for complex systems. To move from uncertainty as a property for informational exchange in engineering systems and mathematical theories (possibility theory: Zadeh, 1978; Dubois and Prade, 1988) to the uncertainty for hydrological events, the uncertainty must be considered as a part of human (scientific) knowledge and communication.

Knowledge about natural systems such as watersheds may be obtained only by the analysis of empirical data (instrumental observations). The source for uncertainty in the interaction in systems must be traced in the chain: researcher – modeler (model maker) – stakeholder; those systems must be defined with processes taking place in relation to the watershed.

The goal of the poster presentation is to illustrate the uncertainty knowledge relationship and modification during hydrological study of Upper Missouri River Basin (UMRB) with the application of statistical learning. Statistical learning (Vapnik, 1998) is based on statistical techniques (empirical principal components, linear multi-regressions, simplified Fourier, shifts), and allows quantification of:

(1) the multidimensional time-spatial variability of hydrological events in the UMRB as hydrological structures;
(2) the “recovery” of regionalization and seasonality of river discharge in UMRB;
(3) the variability of time series in the form of hydrological structures with oscillations and seasonality.
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The definition and properties of coordinate systems aid visualization of the uncertainty concept of hydrological events in a given river watershed. The models affiliated with different coordinate systems in the UMRB reflect 30% - 78% of variability of existed empirical data. Those characteristics of mathematical models (reflected variability, number of factors and others) may be used to establish hydrology and then bring the concept of the knowledge and uncertainty to stakeholders (scholars). Definition of the uncertainty for hydrological events based on the use of statistical learning opens the way for a variety of disciplines for the development of an artificial intelligence approach to analyze the interaction of hydrological events, engineering installations, and social systems in the UMRB, including the concepts of risk assessment.
Large-scale Experiments

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The Hills are Alive: Earth Surface Dynamics in the Biosphere 2 Landscape Evolution Observatory
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To meet the challenge of predicting landscape-scale changes in Earth system behavior, the University of Arizona has designed and constructed a new large-scale and community-oriented scientific facility – the Biosphere 2 Landscape Evolution Observatory (LEO). The primary scientific objectives are to quantify interactions among hydrologic partitioning, geochemical weathering, ecology, microbiology, atmospheric processes, and geomorphic change associated with incipient hillslope development. The infrastructure is designed to facilitate investigation of emergent structural heterogeneity that results from the coupling among Earth surface processes by rapidly iterating dense experimental measurement with development and validation of coupled computational models.

LEO consists of three identical, sloping, 333 m² convergent landscapes inside a 5,000 m² environmentally controlled facility. These engineered landscapes contain 1 meter depth of basaltic tephra ground to homogenous loamy sand and contains a spatially dense sensor and sampler network capable of resolving meter-scale lateral heterogeneity and sub-meter scale vertical heterogeneity in moisture, energy and carbon states and fluxes. Embedded solution and gas samplers allow for quantification of biogeochemical processes, and facilitate the use of chemical tracers at very dense spatial scales to study water movement. Each ~1000 metric ton landscape has load cells embedded into the structure to measure changes in total system mass with 0.05% full-scale repeatability (equivalent to less than 1 cm of precipitation). Each landscape has an engineered rain system that allows application of precipitation at rates between 3 and 45 mm/hr.

These landscapes are being studied in replicate as “bare soil” for an initial period of several years. During this time investigations will focus on hydrological processes, surface modification by rainsplash and overland flow, hillslope-scale fluid transit times, evolution of moisture state distribution, rates and patterns of geochemical processes, emergent non-vascular and microbial ecology, and the development of carbon and energy cycles within the shallow subsurface. After this initial phase, heat- and drought-tolerant vascular plant communities will be introduced. Introduction of vascular plants is expected to change how water, carbon, and energy cycle through the landscapes, with potentially dramatic effects on co-evolution of the physical and biological systems.

LEO also provides a physical comparison to computer models that are designed to predict interactions among hydrological, geochemical, atmospheric, ecological and geomorphic processes in changing climates. These computer models will be improved by comparing their predictions to physical measurements made in LEO. The main focus of our iterative modeling and measurement discovery cycle is to use rapid data assimilation to facilitate validation of newly coupled open-source Earth systems models. Some of these models include NOAH-MP land surface model, CATHY hydrological model, and
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PHREEQC geochemical model.

LEO will be a community resource for Earth system science research, education, and outreach. The LEO project operational philosophy includes 1) open and real-time availability of sensor network data, 2) a framework for community collaboration and facility access that includes integration of new or comparative measurement capabilities into existing facility cyberinfrastructure, 3) community-guided science planning and 4) development of novel education and outreach programs.

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Using the COsmic-ray Soil Moisture Observing System (COSMOS) to Test a New Upscaling Strategy
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Soil moisture plays an important role in drought, flood events, climate variability, and other water cycle processes. Currently, there are two widely used methods for determining soil moisture: in-situ measurements and remote sensing. There are benefits and downsides to both. In-situ measurements can be collected at the desired depth at specific points compared to remote sensing techniques which are only sensitive to near-surface soil moisture. However, upscaling of this information in order to see the relationship of soil moisture over an area leads to large uncertainties unless the spatial density of in-situ measurements is high. Satellites provide a larger spatial view of soil moisture which is beneficial for regional relationships, but downscaling these measurements to higher spatial resolutions is difficult.

Satellite measurements need to be verified, which requires upscaling of in-situ measurements. There are different methods in use to upscale in-situ measurements such as kriging, co-kriging, using topography data only, using soil types and textures, and using inverse distance weighting.

A new method being developed is vector space interpolation (VSI) which uses topographic and EMI (electromagnetic inductance) data for points to be sampled at and then interpolated. This method eliminates the need for expensive, dense networks of sensors as well as provides values of soil moisture at the spatial resolution desired while ignoring spatial dependency between points. By analyzing the topographic and EMI data, best matching units (BMUs) can be found using k-clustering. A k-cluster of 2 would result in the two optimal locations within a field to sample based upon topography and EMI data that would be used to upscale to the desired spatial area’s average soil moisture.

A way to verify results from the VSI method is needed. The COSMOS – COsmic-ray Soil Moisture Observing System is perfect for this as a COSMOS sensor has a footprint of approximately 350 m radius. A COSMOS sensor has characteristics similar to satellites but it has a constant footprint and provides hourly data. COSMOS sensors measure the change of fast neutrons being absorbed and scattered by the changing presence of hydrogen molecules within its footprint. This is an inverse relationship, an increase in fast neutrons being read means a decrease in hydrogen, or water content, and is used to calculate the soil moisture.

Using the VSI method, a variety of k-clusters was found. The k-cluster locations were sampled for gravimetric soil moisture samples throughout the growing season within the Iowa Validation Site and used the VSI method to upscale to the soil moisture within the COSMOS footprint. These values were
then compared to the values of soil moisture that the COSMOS sensor was calculating in its footprint. Initial methods and results from this validation of the VSI method will be presented.

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**Mapping Evapotranspiration from Regional to Continental Scale**

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Motivation: Evapotranspiration (ET) is a combined process of evaporation of liquid water from various land surfaces (including small water bodies, e.g. lakes and rivers), transpiration from the leaves of plants and sublimation of ice and snow. A large amount of water lost from the earth's surface is due to ET) Hence, ET is essential in the water balance assessments and water management plans. The process of ET serves as one of the main phases of the hydrological or water cycle. For water and food security. ET data are critical for settling water-resource conflicts and are especially important for agricultural water issues, since irrigated agriculture accounts for more than 80% of the consumptive water-use in USA. There is need to estimate the continental to regional scale ET estimation. Continental scale estimates of ET will advance our understanding of the mean state and spatial and temporal variability of this significant component of the water cycle. MODIS and Landsat offers a promising opportunity for estimating daily, weekly and monthly Evapotranspiration with a low and high spatial resolution respectively.

Objective: The objective of the study is to develop evapotranspiration estimation model using remote sensing data from regional to continental scale. Evaluate the performance of the developed model using in-situ data.

Results: New MOD-ET model was developed and validated by the data from the growing season in 2007, and showed a good consistency between the simulated and the measured seasonal evapotranspiration dynamics. We also used METRIC model for Landsat data on high spatial resolution. Inter-comparison of the model estimates of evapotranspiration with 3 AmeriFlux eddy-covariance towers across the Nebraska yielded root mean square errors of 0.63 and correlation coefficient is 0.82 respectively. Our results indicate that MOD-ET can be applied to monitor the ET with reasonable accuracy. The seasonal cycle over the continents is well represented in the plots and the suppression of ET during summer period in High Plain, and the Great Plain are well picked up.

Impact: This study provides one of the first moderate resolution estimates of ET on a global scale using only remote sensing based inputs and forcing; and furthermore the first ever multi-model comparison of process-based remote sensing estimates using the same input. Seasonal maps of ET using landsat shows the water use on high resolution. These monthly and seasonal maps able to locate each center pivot individually and measure ET accurately.
Water Resource Sustainability

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Regional-Scale Integrated Modeling Applications for Sustainable Land and Water Resource Management
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For better management and decision making in the face of climate change, Earth system models must explicitly account for natural resource and agricultural management activities. Including cropping systems, water management, and economic models into an Earth system modeling framework can help in answering questions related to the impacts of climate change on water resource availability, water demand, crop productivity, and environmental impacts. Herein we describe two projects to develop regional-scale integrated models to address these questions. The first project is a Columbia River basin (CRB) water supply and demand forecast for the year 2030 in which we couple process-based hydrologic, cropping system, and water management models into an integrated biophysical modeling framework. The socio-economic aspects of this system are captured through economic analysis of the impacts of climate change and irrigation water availability on crop patterns. The second project involves development of the Biosphere-relevant Earth system model (“BioEarth”). This framework includes atmospheric models (for meteorology and atmospheric chemistry), land surface models (for hydrology, cropping systems, and biogeochemical cycling), aquatic models (for reservoir operations and nutrient export in rivers), and economic models. The end product will be a state-of-science regional Earth system modeling framework that explicitly addresses Nitrogen and Carbon flows in the context of inter-annual and decadal climate variability. Communications research is used to assess and improve the relevance of the new model for land management decision making. For both projects, relevance and utility to decision-makers is enhanced through stakeholder input throughout model development.

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Ultra High-Resolution Distributed Watershed Modeling of Urban Landscapes Using ParFlow
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As part of an NSF Water Sustainability and Climate project, we are using ParFlow, a distributed groundwater-surface water model, to simulate the interaction of urban development patterns and the hydrologic cycle. For this application, we are incorporating spatial data at the highest resolution available, namely topography and land use/land cover data derived from meter-scale LIDAR and orthoimagery. Use of data at fine scales permits the explicit modeling of urban landscape heterogeneity and enables us to capture the effects of urban land use dynamics on surface and subsurface flow paths. However, fine-scale LIDAR reveals discontinuities in the land surface of urban watersheds that pose difficulties for the methods used in overland flow calculations. To address this computational challenge, we have developed and applied a global slope enforcement approach that can incorporate highly irregular topography while using the kinematic wave approximation implemented in ParFlow. Previously published analyses enforce slopes for grid cells that are part of the drainage network; our procedure extends slope enforcement to the entire land-surface domain, eliminating ambiguities and
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conflicts affecting overland flow direction. The method utilizes information derived from GRASS GIS routines to create flow-conditioned input topographic slopes for ParFlow while retaining the detail afforded by the LIDAR DEM. We have used this successfully to enforce drainage in domains gridded as finely as 1 m in the horizontal. A preliminary application of the methods described will be presented for the Dead Run subwatershed of the Gwynns Falls in Baltimore. The domain is approximately 3 square kilometers, and horizontal model resolution is 10 m by 10 m with a vertical resolution of 1 m. This resolution adequately describes urban features such as building footprints and highways, while balancing performance considerations. The results demonstrate the usefulness of the slope enforcement methodology on a challenging domain, and provide a test case for ParFlow application at a fine scale using high-resolution data.

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Understanding Changes to Contaminant Transport in Mountain Pine Beetle Infested Watersheds
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Changing climate in the Rocky Mountain West, including higher winter temperatures and recurrent drought conditions, have led to insect infestations that are at epidemic levels. Since the onset of infestation, the Mountain Pine Beetle (MPB) has disturbed over four million acres of pine forests in Colorado and Wyoming. The change in land cover is known to impact snow accumulation and melt, interception, and evapotranspiration in these forested watersheds. While the potential for water quantity changes is under investigation by researchers from Colorado to British Columbia to Germany, the impacts on water quality are not fully understood. Using a collection of field, modeling, and laboratory techniques, this project works to distinguish how the loss of forest cover over large areas and relatively long time scales will change the interrelated hydrologic, nutrient, and contaminant cycles in the Rocky Mountain West.

One potential water quality concern resulting from severe pine beetle infestation is the potential increase in metal fluxes through the release of organic matter and alterations in pH. To understand this potential impact, metal mobility of eight metals of interest (Al, Ba, Cd, Cu, Fe, Mn, Ni and Zn) were compared from soils beneath impacted (red phase) and living (green phase) trees. Preliminary results from this study found significant decreases in solid – liquid partitioning coefficients among the majority of metals analyzed in organic horizon samples. These results suggest an increasing tendency to the liquid phase in deposited litter and underlying soil horizons after beetle attack. The relative importance of the mechanisms responsible for the observed increase in mobility is currently under investigation and may include reduced pH due to increased litter decomposition and nitrification or increased dissolved organic carbon. Understanding changes in flow paths and water sources will also help distinguish the impact of the pine beetle on contaminant transport in these important mountain headwater systems. Ultimately, this work moves toward a better understanding of how climate change induced phenomena, such as amplified insect-infestation, will impact the water supply and quality of the Rocky Mountain West.
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**Rarotonga: Groundwater-surface Water Interactions in Sustainable Water Management**  
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Rarotonga is a picturesque volcanic island with a broad fringing reef. Over the past 20 years, its appearance remains the same, but now only dead coral frames and sea cucumbers populate large portions of the reef lagoons. This same time span coincides with a boom in the tourist industry on the island and construction of many beachside hotels. Without a centralized sewer system, both old and new residences rely on septic systems to manage effluent, where almost all septic systems are installed in sandy sediment no more than 1 km from the coast and generally within 200 m. Together with pig farming, septic systems contribute large quantities of nutrients into the lagoon that have supported algal blooms that overgrow corals, eventually destroying fish habitat and killing the corals. Both surface water and groundwater inputs into the lagoon contribute to this nutrient flux. We investigate the groundwater flowpaths into the Muri fringing reef on Rarotonga, Cook Islands. Electrical resistivity surveys in the lagoon indicate freshwater seeping well beyond a classically defined seepage face at the shore. Discrete plumes of fresher groundwater also occur in the alongshore direction, suggesting preferential flowpaths. On land, the shape of the local freshwater lens reflects the presence of variable geology controlling the freshwater-saltwater mixing zone. Despite spatial variability in the distribution of fresher groundwater, high frequency monitoring of groundwater levels suggest mainly upward and seawards discharge. We hypothesize that the presence of high elevation alluvial fans and terraces allows for groundwater recharge that is substantial enough to support discharge far into the reef, even in the absence of recharge in the high mountains or fracture flow directly to the reef. These long flowpaths from high elevation could flow under nutrient-rich local groundwater flows and may not contribute to the eutrophication of the lagoon. However, fresher groundwater plumes in the nearshore extend into the lagoon and may be local vectors for nutrient transport. Sustainable management and rehabilitation of the reef lagoon requires a sufficiently detailed understanding of multi-scale subsurface structure and groundwater flowpaths to prevent continued nutrient loading.

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**Green Infrastructure as a Model System for Implementing Sustainable Urban Water Systems**  

Aging and outdated water infrastructure is failing to meet contemporary regulatory standards in urban centers across the US. Moreover, the sustainability of traditional hydrotechnical engineering solutions is challenged by changing climate and shifting societal expectations regarding environmental quality and infrastructure performance. Proponents of a new generation of decentralized stormwater management practices for densely populated urban watersheds claim that the many negative environmental impacts of urbanization can be reduced by “mimicking” natural hydrologic processes on individual development sites. This is accomplished by various water harvesting, infiltration, evapotranspiration, and re-use practices integrated into “green” lot, landscape, and drainage designs. The growing interest in green infrastructure (GI) is also seen as an opportunity to revitalize communities, restore urban ecosystem function, adapt to changing climate conditions, enhance green profiles, and create green jobs, among other ancillary goals. For meaningful hydrologic and environmental change to accrue, green infrastructure would need to be distributed widely over public and private land throughout urban...
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watersheds. While many different kinds of GI studies are underway, our ability to predict the effectiveness of these practices in urban watersheds is not well developed. Nevertheless, several urban centers are investing hundreds of millions of dollars in large scale implementation of GI. The NRDC (2011) ranked the 14 greenest cities in North America based on long term GI plans, and of these the three highest ranked cities that have developed long term plans for GI are Philadelphia, PA, New York, NY, and Syracuse, NY. We present a catalog of new green infrastructure monitoring sites, samples of ongoing experimental data and modeling work in these three cities to promote contemporary opportunities to develop urban hydrologic observatories.

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Incorporating Water Management into a Physically-based Hydrologic Model
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Water management decisions are commonly made using surface water models with simplified and/or abstracted physical processes and limited groundwater-surface water interactions. Optimizations with such models might not capture the potential importance of and feedbacks from physical processes such as evaporation and infiltration. This study details how management algorithms from the Water Evaluation and Planning (WEAP) model are coupled with an integrated hydrology model, ParFlow. ParFlow is a fully coupled physical hydrology model capable of simulating groundwater surface water interactions in heterogeneous porous media. Richards equation is used for variably saturated subsurface flow and the diffusive wave equation is applied for overland flow. The common land model (CLM), which is coupled to ParFlow, simulates land surface processes. WEAP is an integrated model that utilizes linear optimization management algorithms with a network based hydrology model. The WEAP allocation algorithms are robust, however, they rely on lumped physical hydrology that is relatively simple and incapable of simulating complex groundwater surface water interactions. In the coupled framework presented here ParFlow simulations provide water supply and physical demand values. While, the management algorithm allocates water and determines which demands should be met by groundwater pumping or surface water diversions. Proof of concept for the resulting coupled model is demonstrated on a simple test domain.

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How Does Forest Thinning Affect Short- and Long-term Water Partitioning in the Semi-arid Santa Fe Municipal Watershed, and How Do These Changes Compare to Unmediated Forest Responses to Climate Change?  
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In water-limited environments, water and vegetation systems are intrinsically linked. Vegetation exerts direct controls on water partitioning through transpiration and indirect controls on partitioning through radiation and precipitation interception, rooting effects on soil permeability, and litter effects on water
capture and storage, among others. In semi-arid forest systems of the Southwest U.S. in particular, vegetation controls on water partitioning are often the most dominant after climate, so changes in vegetation structure, species type, and biomass can lead to large shifts in downstream water availability. We use a coupled ecologic-hydrologic, process-based model (RHESSys) to investigate how human- and nature-induced changes in vegetation biomass, structure, and spatial distribution affect the partitioning of water into evaporation (E), transpiration (T), groundwater recharge (GW), and streamflow (Q) in the Santa Fe Municipal Watershed in Northern New Mexico. Previous work at this site has shown that RHESSys can successfully capture observed seasonal streamflow patterns and inter-annual biomass dynamics (growth/mortality) in response to climate. In this study, we estimate the relative magnitude of responses in E, T, GW, and Q due to a range of different vegetation manipulation scenarios, including uniform changes in biomass, varying spatial patterns of vegetation thinning, increasing canopy cover gaps through thinning, and changes in litter and coarse woody debris. The dynamic vegetation model allows us to not only evaluate instantaneous changes in partitioning associated with these manipulations, but also how partitioning evolves over time. Finally, we compare model estimates of effects on water partitioning from forest treatment to effects from unmediated “natural” vegetation responses to climate warming.

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Water Conservation Measures Impacts on Water Resource and Ecosystem in the Jinghe River Basin of the Loess Plateau, China
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The Loess Plateau of China is ecologically vulnerable region due to serious soil erosion and strong impacts of human activities. Water conservation measures are widely applied in this region to reduce water and soil loss. In order to analysis impacts of these measures on water resources and ecosystem, we developed a distributed eco-hydrological model to simulate and predict hydrological and vegetation growth processes by coupling a vegetation ecosystem model, BIOME-BioGeoChemical Cycles (BIOME-BGC) and a distributed hydrological model, Water and Energy transfer Processes in Large river basins (WEP-L). BIOME-BGC updates the vegetation parameters of WEP-L in a daily time step, and WEP-L provides hydro-meteorological data to BIOME-BGC. To obtain vegetation growth data, we carried out on-site ecological observation using photosynthesis apparatus. We applied the eco-hydrological model to the Jinghe River basin (45421km²) of the Loess Plateau. The model validation shows that the simulated results have good agreement with the field observation data or literature values of Leaf Area Index (LAI), Net Primary Production (NPP) of vegetation and river discharge. Five scenarios based on water and soil conservation measures were used for the eco-hydrological model to evaluate impacts on water resources and ecosystem in Jinghe River Basin. Results show that under the water and conservation measures impact, the average annual and flood season discharge would decrease, the average annual Net Primary Production (NPP) would increase, and Net Ecosystem Production (NEP) would decrease. This means a big challenge to the water resources management in the basin and mitigation/adaption measures are desired to be worked out.
**Poster Abstracts**

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Sensitivity of Groundwater Stress to Aquifer Storage Estimates  
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Groundwater provides freshwater for much of the world, particularly in arid and semi-arid regions. This study analyzes groundwater stress as a comparison between how much groundwater is being used to how much groundwater is available in aquifer storage. Despite being such an important water resource, sustainable management of groundwater is a huge challenge globally. While some regulations exist to monitor the use of groundwater in specific locations, large-scale monitoring and control is lacking. This is largely due to technical challenges in consistently monitoring groundwater over small regional to large scales, which is both a hydrologic and management issue. Satellite remote sensing improves our ability to monitor groundwater use with improved spatial and temporal resolution as compared to traditional monitoring wells. This study uses NASA’s Gravity Recovery and Climate Experiment (GRACE) to quantify groundwater use for known aquifer systems. The groundwater use is then compared to estimates of aquifer storage. Estimates of global aquifer storage are distributed into known aquifer systems and compared to best estimates of storage from the literature. Groundwater stress is computed with the available storage estimates to determine the sensitivity and range in the magnitude of groundwater stress to the available storage estimates. The results give a range in the years to depletion of large global aquifer systems based on available storage estimates.

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Estimating Multi-scalar Ecosystem Impacts and Water Scarcity Caused by Freshwater Withdrawals: A Case Study of the Kalamazoo Watershed  
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1Arizona State University  
2Michigan Technological University

Like most coupled human-natural systems, watersheds are utilized by people to achieve valued benefits. This utilization results in impacts on the freshwater resources in a watershed. The impacts are not uniform in space and time, but are rather concentrated on specific portions of the annual flow regime, and in specific portions and spatial scales of the watershed. Consequently, the relationship between the human values and benefits associated with freshwater withdrawals and the ecosystem impacts of those withdrawals can be shown to change significantly depending on the spatio-temporal reference scale of the analysis. This scalar heterogeneity has consequences for the management of freshwater ecosystems and watersheds, and for the adaptive management of watersheds to achieve maximum benefits under conditions of water scarcity. We use the Kalamazoo River as a case study to examine the spatial distribution of water scarcity and its relationship to space and time scales. We find that water scarcity does occur at specific locations in space and time, generally at smaller scales. Implications of the findings for the management of water resources are discussed.
Poster Abstracts

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Are sustainable water resources possible in the Indian Punjab?
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Sustainable water resources can have many definitions with the simplest as a supply-demand problem, with climate dictating the supply of water and human water use the demand. One sign of a system that is not sustainable would be falling groundwater tables, as is the case in northwest India. This region serves as the country’s breadbasket, and irrigated agriculture is ubiquitous. The state of Punjab alone produces 22% of the country’s wheat and 13% of all the country’s grains while only accounting for 1.5% of the country’s area. Although the region receives an average precipitation of 600mm per year, it is dominated by monsoonal rainfall with streamflow augmented by upstream snowmelt and glacial melt in spring and summer that is released from a large dam into canals. Large agricultural water demands occur both during the rainy season as well as during the drier winter season. Water and food security are inextricably linked here, and when considering how to manage water sustainably, the consequences on agriculture must also be considered. In this study, we evaluate what a sustainable water resources system would look like in this region, accounting for current climate, crop water demands, and available reservoir storage. The effects of multiple water-saving scenarios are considered, such as crop choice, cropped area, and the use of forecasts in irrigation scheduling. We find that the current system is untenable and hard decisions will have to be made by policymakers in order to halt the depletion of groundwater and manage the region’s water resources in a sustainable, effective manner.

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Envisioning a Sustainable Future for the Lower Mississippi River: Linking Engineering, Science and Design
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2Coastal Sustainability Studio, Louisiana State University
3School of Architecture, Louisiana State University

Once a natural system and the primary source of much of the sediment and nutrients that formed the southeastern and central Louisiana coast, the Mississippi River is now highly engineered and controlled to meet the needs of the state and national economy. Because of the control structures and management regime, the river is no longer able to respond to natural geologic and coastal processes and, as a result, the coastal wetlands have deteriorated across much of the deltaic plain and the viability of the lowermost river for navigation is becoming more challenging. Significant investments continue in maintaining the channel but these efforts are increasingly inadequate. In short, the mouth of the Mississippi River, a channel with greater shipping volume than anywhere on earth is silting up. The communities that line the river, the economies that operate there, and the capacity of the River to ship goods are all at stake.

The recently approved State Coastal Master Plan lays out an ambitious vision of restoration and protection strategies. Restoration projects range from marsh creation using dredge sediment to large-scale river & sediment diversions to the possibility of major river realignment. There is clear evidence that some of the very large scale projects may eventually be necessary however, the dramatic changes as a result of these projects would be hugely disruptive to communities and industries that operate in place like Port Sulphur, Empire, Boothville, and Venice. Any future changes to the river will need to be
considered not simply from the needs of navigation but equally from the ecological, cultural, and the communities affected.

In our presentation, we will first identify the controlling hydraulic and geomorphologic factors affecting the sustainability of the lower river and highlight some of the critical infrastructure and communities that are being impacted. Next, we will utilize a suite of physical and numerical modeling results to discuss future trends in the lowermost river, taking into account relative sea level rise and put this in context with what the ports in the lower river are planning in order to stay competitive. The final part of the talk will present some vision for the lower river in terms of diversions, navigation and critical infrastructure and settlement.

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Tidal Subsurface Mixing and Nitrate Attenuation at the Land Ocean Interface
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3Marine Science Institute, University of the Philippines, Diliman, Quezon City, Philippines

The interface between groundwater and seawater is a biogeochemical interaction zone for both land- and ocean-derived materials. This subsurface mixing zone controls the nutrient composition of groundwater discharged into coastal waters. Because seawater is nitrogen limited and groundwater nutrient concentrations are orders of magnitude higher relative to seawater, the dynamics of freshwater-saltwater mixing at this interface is critical for determining the fate of nutrients that affect coastal water quality. We studied a subsurface mixing zone on a fractured carbonate platform using porewater salinity as a tracer near Bolinao, Philippines. Electrical resistivity (ER) tomograms suggest a mixing zone that thickens seaward and may extend beyond the ER transect. This broad mixing zone deviates from the classical model of a freshwater lens discharging across narrow seepage faces, and this is likely due to the local carbonate geology. The mixing zone is deepest during spring tide when large variations in pore pressure occur because of the bigger fluctuation in sea elevation. Hydraulic heads from piezometers yielded vertical and horizontal head gradients which vary spatially and temporally with tides. Upward subsurface gradients reach up to 0.25 m/m at low tide whereas downward gradients reach 0.3 m/m during high tide. Horizontal gradients are consistently an order of magnitude lower than the vertical gradients indicating a vertical advection dominated system. Nitrate porewater concentration varies linearly with salinity during high tide but deviates from the conservative mixing line at other times. This indicates that nitrate attenuation in subsurface mixing zones can be tidally modulated. Direct groundwater discharge accounts for 6% of the global freshwater input to the ocean but this discharge delivers 50% of the dissolved salts by rivers. This relative range of fluxes can be extended to nutrients because nutrient concentrations in groundwater are usually higher relative to surface waters. However, our findings suggest that estimating global nutrient contribution from direct groundwater discharge into the ocean may present some challenges because of site-to-site variation in coastal processes especially tides which may dominantly control nutrient transformation near the land-ocean interface.
Boulder – Maps and Dining
Inns, Motels & Lodges
1 Best Western Boulder Inn • 303.449.3800 • 800.233.8469
2 Best Western Golden Buff Lodge • 303.442.7450 • 800.999.2833
3 Boulder Creek Quality Inn & Suites • 303.449.7550 • 888.449.7550
4 Boulder Mountain Lodge • 303.444.0882 • 800.458.0882
5 Boulder University Inn • 303.442.3830 • 800.258.7917
6 Colorado Chautauqua Association • 303.442.3282, ext. 11

Bed & Breakfast
7 Alps Boulder Canyon Inn • 303.444.5445 • 800.414.2577
8 The Bradley • 303.545.5200 • 800.858.5811

Hotels
9 Boulder Broker Inn • 303.444.3330 • 800.338.5407
10 Boulder Marriott • 303.440.8877 • 800.228.9290
11 Boulder Outlook • 303.443.3222
12 Courtyard by Marriott • 303.440.4700 • 800.321.2211
13 Homewood Suites by Hilton • 303.449.9922 • 800.CALLHOME
14 Hotel Boulderado • 303.442.4344 • 800.433.4344
15 Millennium Harvest House • 303.443.3850 • 800.545.6285
16 Residence Inn by Marriott-Boulder • 303.449.5545 • 800.331.3131
17 St Julien Hotel & Spa • 720.406.9696
BOULDER RESTAURANT GUIDE

Looking for a recommendation on a restaurant? Boulder has an amazing food scene.

“Boulder has won just about every shiny happy lifestyle award a city can: Healthiest, Most Educated, Most Bicycle-Friendly—the list goes on. And this year, it can add one more: Bon Appétit’s Foodiest Town in America. It turns out that, along with having fit, smart, and eco-conscious citizens, Boulder is home to a number of innovative food companies (Celestial Seasonings, Izze Beverage Company, and Bhakti Chai), several top-tier restaurants, and one of the best farmers’ markets in the country.”

October 2010 Bon Appetit

“A culinary tour of the world’s tastiest cities led us to Boulder, CO.” January 2009 Travelocity

“A good culinary school, artisanal breweries, an active slow food chapter, and eco-conscious community with notable eateries—Boulder is once again on our radar as a great foodie town.” October 2009 Bon Appetit

“Downtown Boulder is the scene of a high-end food fight among dozens of ambitious eateries.” November 2009 Wall Street Journal

Within walking distance of the St. Julien:

Black Cat

1964 13th St., Boulder, 303-444-9110

Diners can be assured that the produce, dairy, and meats are sourced from nearby farms—sometimes even from executive chef Eric Skokan’s backyard.

Brasserie 1010

1011 Walnut St., Boulder, 303-998-1010
BOULDER RESTAURANT GUIDE
The bustling environment and unpretentious food pay homage to a traditional French brasserie.

Centro Latin Kitchen
950 Pearl St., Boulder, 303-442-7771
The Latin American menu is straightforward—corn, chiles, meat, shrimp, veggies, chicken—and spectacular. Enjoy soulful dishes such as the cheesy smoked pork belly masa cakes.

Dushanbe Tea House
1770 13th St., Boulder, 303-442-4993
Sit below a hand-painted ceiling, amid traditional Persian artwork at this teahouse transported from Tajikistan. The menu offers more than 80 teas as well as traditional Asian meals, such as curry chicken wraps.

Frasca Food and Wine
1738 Pearl St., Boulder, 303-442-6966
A respect for honest ingredients coupled with innovation and technique helped skyrocket Frasca chef Lachlan Mackinnon-Patterson to one of I Magazine’s Best New Chefs. Reservations required.

Jax Fish House
928 Pearl St., Boulder, 303-444-1811
Fun, upbeat atmosphere and fresh grilled seafood. Specialties include the raw oyster bar and tuna.
BOULDER RESTAURANT GUIDE
The Kitchen and The Kitchen Next Door

1039 Pearl St., Boulder, 303-544-5973

The Kitchen is Boulder’s Community Bistro – a restaurant built by a community of craftsman, serving food & drink from a community of like-minded farmers, ranchers and purveyors for the sustainable enjoyment of the whole community – including staff. Being a Community Bistro also includes their commitment to environmentally-friendly practices, including composting, wind power, eco-friendly packaging and recycling used cooking oil to power Steve’s car (Steve is a Server at The Kitchen Boulder). The Kitchen Next Door is a community pub offering reasonably priced-entrees and a great place for lunch.

Pizzeria Locale

1730 Pearl St, Boulder, CO 80302

Pizzeria Locale is a contemporary pizzeria inspired by the traditional pizzerias of Napoli, Italy, from the creators of Frasca Food and Wine. The pizzeria is located downtown and features the first Stefano Ferrara oven in the state of Colorado, Italian wine on tap, and the first V.D.F. (read: incredibly fancy) prosciutto slicer in North America.

Oak at 14th

1400 Pearl St, Boulder, CO 80302, (303) 444-3622

Oak at Fourteenth is a neighborhood restaurant that features local and seasonal new American Cuisine in a friendly and professional atmosphere. Open daily for lunch, dinner and late night. Chef/Owner Steven Redzikowski’s simple yet inspired menus are focused around wood fire cookery. Oak offers a creative hand-crafted cocktail menu, artisan wine and beer list that help create a fun and energetic experience.

Riff's
BOULDER RESTAURANT GUIDE  
1115 Pearl Street, Boulder, CO 80302

Riffs Urban Fare is a Boulder foodbar featuring moderately priced, liberal appetizer portions of chef John Platt’s artfully prepared diverse cuisine. Carefully chosen beverages. Genuine hospitality, Comfortable social setting. A thoughtful Boulder urban dining experience.

Salt Bistro

1047 Pearl St., Boulder, 303-444-7258

Drink and dine in this hyper-local restaurant that captures the historic spirit of Pearl Street for a taste of all that’s fresh in Boulder County. Try the wood-grilled pork chop with Colorado peaches, green beans, and polenta paired with one of their pre-Prohibition cocktails like the Pico Punch with grapes, pisco, fresh pineapple juice, and Leopold Bros. alpine herbal liquor.

Snooze

1617 Pearl St., Boulder, 720-304-8839

Snooze re-energizes the way you think, feel, and ultimately eat breakfast. Picture breakfast and lunch crafted from scratch recipes focusing on the highest level ingredients; a setting filled with energy and pouring over in creativity; service radiating fun and knowledge throughout.

The Bitter Bar

835 Walnut St., Boulder, 303-442-3050

In the Bitter Bar, Happy's late night alter ego, World Champion Mixologist Mark Stoddard (Gold Medal winner at the 42 Below Cocktail World Cup in New Zealand) honors the classic American tradition of the handcrafted cocktail. The Bitter Bar staff shares a passion for blending the old school with the new and taking a chef’s approach to using the freshest, local and organic ingredients in each creation. The end result is a
BOULDER RESTAURANT GUIDE
cocktail that is well balanced, driven both by its flavor profiles and textural components.

The Pinyon

1710 Pearl St, Boulder, 720-306-8248

The Pinyon offers a unique rendition of American cuisine with an innovative take on traditional cooking methods using fine local produce and respecting the legacy of our shared culinary heritage. We seek inspiration from Colorado and other states and regions to ensure reliable sources of top-quality producers and artisans, utilizing both common and more modest ingredients such as wild herbs, and foraged produce and mushrooms, in new and distinctive contexts. Any craft relies on the process as much as the end result, so making our own cheeses, breads, pickles, charcuterie, smoking our own meats, and making our preserves seasonally is an important aspect of who we are.

The West End Tavern

926 Pearl St., Boulder, 303-444-3535

This classic American tavern has been a Boulder tradition for over 20 years. Chef/Owner Chris Blackwood has created delicious home-style cuisine that features Boulder’s best burgers, steaks, chops, fish n’ chips, fantastic salads, and creative daily specials

And just a cab ride away:

Flagstaff House

1138 Flagstaff Rd., Boulder, 303-442-4640

Grab a drink or dessert at this house on the side of the Flatirons and enjoy the best view of Boulder! Reservations recommended.