AGU Hydrology Section Newsletter

December 2010

From the Section President

Dennis P. Lettenmaier (University of Washington)

The fall meeting is now very close – just two weeks away as I write this. Many of us are into the last minute scramble of preparing talks and posters. The meeting continues to grow – there will be over 2100 talks and posters in hydrology alone this year! Managing this number of submissions is a job of staggering proportions (I was the hydrology representative to the program committee in the early 1980s; in my final year, we had 190 hydrology submissions, which we thought was amazing!). Roseanna Neupauer, this year's Section Fall Meeting Committee Chair, and committee members Matt Rodell and Mike Cosh have done an excellent job of managing the flood of submissions. Although the total number is large, they have managed to hold the line on oral sessions, the number of which is essentially the same as last year. If you see them in San Francisco, please thank them for a job well done.

On another front, the Union is well along in what is now being called its Mission Alignment Project (MAP). This is described in more detail in an article that will appear in the December 7 issue of *EOS*. In brief, MAP is intended to address the question: *How does our [AGU] science need to be organized, recognized and rewarded, disseminated and promoted?* Perhaps some background is in order. Most of you are probably aware that AGU

In This Issue

Student Representative Needed

The Hydrology Section Bylaws (http://hydrology.agu.org/bylaws.html) state the Section's Executive Committee should include one student representative. We are seeking nominations for this position (they can be self nominations), which provides a unique opportunity for a student AGU member to gain practical experience and insights into the Hydrology Section. Attendance at the Fall Meeting (2011 and on) and attendance at the Executive Committee meeting held there is required. Participation in one or more conference calls per year will be required as well. Nominees should expect to be student members (i.e., not complete their graduate studies) until at least June 30, 2011. Please make nominations to the Section Secretary, Martha Conklin (mconklin@ucmerced.edu).

has undergone major administrative changes over the last two years. Two years ago, the Union lacked a strategic plan and was mostly reactive in its response to new challenges (electronic publication is a good example). Bob Van Hook, AGU's Interim Executive Director from January 2008 through August of this year, did an excellent job of setting AGU on a new course, with a more functional administrative model. That includes, among other things, the new bylaws which were overwhelmingly approved by the membership. They provide for formation of a Board of Directors, which will deal primarily with financial matters, along with the existing Council, which will deal with scientific matters.

MAP is mostly about the functioning of the Council, which essentially has (two) representatives from each section and focus group, along with various other designated representatives (committee chairs and at-large early career representatives). At present, that comes to almost 60 members, a number that is unwieldy to say the least. There is a general feeling that this structure is awkward, and furthermore, that the functioning of focus groups has not worked as well as it might (there are now more focus groups than sections). The initial motivation behind the focus groups was to help span the boundaries of the traditional disciplines. In the minds of many (myself included), this is to be encouraged, and some focus groups (Global Environmental Change is a good example) serve this purpose. On the other hand, many of the focus groups represent subdisciplines and basically have the effect of balkanizing the Union. In my view, the challenge of large sections, like hydrology, is how best to interact across subdisciplines. One aspect of the Hydrology Section, which is unique in AGU, is our technical committee structure, which allows activity at a subdiscipline level. Some of our Technical Committees (Precipitation is an obvious example) are joint with other sections (Atmospheric Sciences in the case of the Precipitation Committee).

In addition to the issue of the structuring of AGU Council (and hence the roles of sections and focus groups) other issues have arisen in the context of the MAP process. One is a general sense that AGU does not do as good a job as it might in its outreach activities – basically dissemination of science to the general public, as well as to governmental and nongovernmental organizations that could benefit from a better understanding of earth science. Another general theme is involvement of young scientists – both students and early career professionals. There is a sense that the organization is a bit impenetrable. My own sense is that our section does a better job in this area than the Union as a whole, in part due to our technical committee structure, which provides an entry point into the organization for young scientists (many TC members are early career scientists, as are some of the chairs and deputy chairs). In this vein, I hasten to note that the TC meetings in San Francisco are open, and I especially encourage students and early career scientists to attend (for dates, times, and locations see the Fall Meeting Highlights herein).

Member input into the MAP process (in which I am integrally involved as a member of the Council Leadership Team, which essentially is the Council's executive committee) is actively being sought. In the first phase of the process, about two dozen "hand-picked" individuals were interviewed.

These were people who were viewed as science leaders whose positions require them to be focused on the future, or who were viewed as having a unique and forward-looking perspective. Their input to the process was via responses to a set of questions dealing with specific aspects of how earth and space science will evolve in coming decades. In a second phase of the process, MAP is soliciting input from members in two ways. The first is via a set of "guided group discussions" that will be held at the Fall Meeting on Monday December 13 and Tuesday December14 at the times and locations listed below:

Participants	Date	Time
Session 1 for Section/Focus Group members	Monday 13 December 2010	4pm – 5:45pm
Session 2 for Section/Focus Group members	Tuesday 14 December 2010	10:30am – 12:20pm
Session 3 for international members	Tuesday 14 December 2010	1:30pm – 3:30pm
Session 4 for students/young careerists	Tuesday 14 December 2010	4pm – 6pm

I strongly encourage you to attend these sessions if at all possible. In addition, AGU staff is preparing an on-line survey, details of which will follow "soon" (probably via an *EOS* announcement). My understanding is that this survey will be made available to all members. I strongly encourage you to participate, as results of the MAP process may well result in significant changes to the functioning of the Union. I do want to emphasize that I fully endorse the intent of the MAP process, which is a careful examination of future directions of the Union. Our challenge will be to assure that we adapt to change, while at the same time not fixing what is not broken. The best way to assure a positive outcome is broad participation in the process by the Section. Please feel free to contact me with any thoughts you have, and be sure to read the article in the December 7 issue of *EOS*.

In closing, I note with sadness the passing over the last year of two greats in the field, James (Jim) Dooge and M. Gordon ("Reds") Wolman. A tribute for Jim Dooge will appear in the December 7 issue of *EOS*; a tribute to Reds Wolman appeared in EOS August 10. Truly, we stand on the shoulders of giants.

From the Section President-Elect: Giving in support of Hydrology Section initiatives

Eric F. Wood (Princeton University)

In less than two weeks many of us will be attending the Fall Meeting, including the Section's luncheon on Tuesday. Besides reconnecting with friends and colleagues, we'll have the opportunity to meet the two students who are the 2010 recipients of the Robert E. Horton Research Grants – Ciaran Harman of the University of Illinois and Maya Bhatia of the Woods Hole Oceanographic Institution.

Student participation at the luncheon is encouraged by the Section, which subsidizes the first 125 luncheon tickets purchased by students (if you're a student, and didn't get the subsidy, the advice is to register earlier next year!). These subsidies come from annual donations that many members add to their annual dues, with a designation that the donation go to the Section. In addition to subsidized luncheon tickets for students, these donations help to support the travel of Horton Research Grant recipients to the Fall Meeting, as well as travel support (when requested) for the Hydrologic Sciences and Early Career Award winners. In total the Section has

been receiving approximately $8,000 annually from these donations in recent years.

The two Horton grant recipients, Ciaran Harman and Maya Bhatia, were selected by the section's Horton Research Grant Committee from over 100 applications. Each will receive a $10,000 one-year grant from the earnings on the endowment funds left to the Section by the eminent hydrologist Robert E. Horton. The Horton Research Grants promote excellence in research and encourage the next generation of professionals in the hydrological sciences. The applicant's proposals are reviewed for originality, creativity, timeliness of the ideas, and the likely impact of the proposed research. Jud Harvey, the outgoing Chair of the Horton Research Grant Committee, commented to me that in his view, 15% or more of the proposals are judged to be excellent and 5% or more are truly outstanding. He went on to say that the "difficulty selecting awardees from a growing pool of outstanding finalists suggests the need to consider funding additional awards each year".

I agree with Jud that we should expand our student grant program by soliciting additional gifts that would go to support new grants. These could either supplement the Horton funds, or they could support a parallel grant program that might be named in one of several ways. Not all new grants would necessarily need to be at the level of the current Horton grants, but any new program would need to be sustainable over the long term – essentially implying the use of endowment funds. I see this as the Section's most important need for new funds. Enhancing the Horton Grant program would be an effective way for the Section to foster its interaction with our most promising student members, who literally are the future of the Section.

Besides expanding the grants program, there may be other areas where section donations could be targeted. If you have ideas, please feel free to contact me (efwood@princeton.edu). Over the next six months or so, the section executive expects to move forward with the Union in structuring a development plan which would help to enhance the Section's endowment. Your thoughts on how we can best go about this will be greatly appreciated.

From the Section Secretary

Martha Conklin (University of California, Merced)

As I prepare for my first AGU meeting as Section Secretary, I want to share some changes that affect the Section and solicit your feedback. One of my goals as Section Secretary is to ensure that AGU continues to provide the services our Hydrology section needs in this time of change for the organization. One of the key aspects of the new AGU leadership structure is that it is more inclusive, so Hydrology needs to work with other sections to implement changes. To illustrate this, I want to review changes that are occurring on Outstanding Student Paper Award (OSPA) judging and to test the waters about a section survey on publications. Please send me feedback on these and other areas you would like to see changes (mconklin@ucmerced.edu).

The process of OSPA judging has been somewhat less than transparent in the past. There are no links to the judging criteria on the AGU website. In the past, each section has had the option to judge student papers, but supporting Union resources have been sporadic. The Hydrology Section initiated these awards in 1994, and became the third AGU Section to recognize our student members in this way. Last year, we had over 600 student papers in the Fall Meeting Hydrology sessions – almost one-third of the total hydrology papers. The Section's OSPA committee (for membership see the Section website, hydrology.agu.org) has coordinated judging through session conveners, but we have not explicitly asked the session conveners to confirm that they will take this responsibility when they propose a session. It is now apparent, based on the low return of judging sheets for the last two years, that a majority of Section student papers have had fewer than three judges (often only one).

When I started to populate the OSPA committee this fall, the feedback was that I should target younger scientists – this is because in recent years committee members have spent most of their time at AGU meetings tracking down judges. The success to date of OSPA judging has been due to a few individuals who were willing to make a very large time commitment. Recognizing that change was needed, AGU staff has requested that each section identify judges before the meeting. This year the OSPA Committee was provided with lists containing student papers and session conveners at the end of the second week of November, and was asked to identify three judges for each student paper by December 3. The committee has done our best to work within these constraints. We have asked session conveners to act as judges themselves, and to help with identification of additional judges for sessions with a large number of student papers. I will be working with the Technical Committee chairs to identify possible changes that can help to streamline the process in years to come. One possibility is to ask conveners to identify a panel of judges for their sessions when the session is submitted for approval. Another would be to restructure the program and greatly reduce the number of awards (this year we intend for about 5 percent of the student papers to receive awards).

On another front, I am interested in feedback from our section members as to whether AGU publications provide the correct platform for a national voice for hydrologic sciences. When I was part of a discussion of where to publish the lessons learned from the WATERS Network planning exercise (www.watersnet.org), we had difficulty in identifying a publication that is relevant to a broad spectrum of hydrologic science. The citation numbers clearly indicate that the AGU journals in which Section members tend to publish (mostly *WRR*, *JGR*, and *GRL*) are premiere scientific publications. Is that sufficient, or do we need another publication that publishes short communications, that has broad interdisciplinary appeal and is relevant to multiple users of hydrologic science (including policy makers, resource managers, and educators)? Does *GRL* or *EOS* fill that niche? The section leadership is working with AGU staff to formulate a poll of Section members on a number of topics, and I will be working with the President and President-Elect to include questions as to the needs of Section members with respect to publications.

As we grapple with changes as the Union and our section grow, we need to stay focused on what makes this an organization valuable to us, and that raises the national profile of the profession. I look forward to seeing you at AGU (and I hope many of you have volunteered to be student paper judges!).

Fall Meeting Hydrology Highlights

Tuesday 12/14 10:00 AM	Langbein Lecture (Bill Gray)	103 Moscone South
Tuesday 12/14 12:30 PM	Section Luncheon	InterContinental Grand Ballroom A-C
Tuesday 12/14 6:45 AM	Ecohydrology TC	Marriott Salon 2
Tuesday 12/14 6:45 AM	Ground Water TC	Marriott Salon 3
Tuesday 12/14 6:45 AM	Hydrogeophysics TC	Marriott Salon 4
Tuesday 12/14 6:45 AM	Large-Scale Field Exp. TC	Marriott Salon 5
Tuesday 12/14 6:45 AM	Precipitation TC	Marriott Salon 6
Wednesday 12/15 12:30 PM	Remote Sensing TC	Marriott Salon 4
Wednesday 12/15 12:30 PM	Surface Water TC	Marriott Salon 5
Wednesday 12/15 12:30 PM	Unsaturated Zone TC	Marriott Salon 6
Wednesday 12/15 12:30 PM	Water Quality TC	Marriott Salon 1
Thursday 12/16 6:45 AM	TC Chairs	Marriott Salon 3
Thursday 12/16 12:30 PM	Executive Committee	Marriott Salon 3

From the Water Resources Research Editor-in-Chief

Praveen Kumar (University of Illinois)

I want to take this opportunity to highlight a few recent changes at WRR. To facilitate rapid integration of research with education, AGU has now implemented an option for authors to submit educational supplements with their articles. These educational supplements will receive light review along with the articles and will be available as open access material on the AGU website. They will be linked to the published paper. The authors are encouraged to take advantage of this resource for faster adoption of their work by uploading presentation material with attractive graphics, data files, and programs related to the research presented, etc.

To streamline the review process, we are now encouraging authors to prepare manuscripts for review such that figure captions appear along with the figures. Also, figures may be integrated into the text instead of at the end, if the authors so choose, as it prevents flipping back and forth during the review. A separate set of high resolution figures should be uploaded in addition to the ones that are integrated in the text to support the production needs.

The manuscript submission process now requires that authors submit a "Research Significance" statement, in 150 words or less, targeted to a broad scientific audience. This is not meant to be a restatement of the abstract but an opportunity to carefully state the importance and novelty of the research in language that is understandable by those who may not be working directly in the area. This will enhance broader accessibility and appeal of the work.

In our attempt to ensure that *Water Resources Research* maintains the highest standard for publication, AGU has started screening all WRR submissions using CrossCheck [http://www.crossref.org/crosscheck.html] for verbatim use of previously published material. Some discussion on these issues can be found elsewhere, see for example, *Nature* (Vol 466, 8 July 2010, page 167). Use of previously published material without appropriate attribution, such as using quotations and/or citing the original source, is an unacceptable practice. Similarly, verbatim use of introductory or methodological material from one's own prior work is also not in the best interest of scientific advancement. Such submissions add a significant burden on the editorial process and are subject to editorial rejection without exception. While we accept that there are only so many ways to describe a study site, or an experimental technique, or a mathematical procedure, such factual descriptions are best designated to an independent section written with suitable attribution and and brevity by pointing the reader to previously published detailed description. Similarly, use of previously published figures must be suitably attributed. These practices allow for an assessment and propagation of the original content of the submitted manuscript and also prevent copyright violations. Authors are also urged to check the AGU dual publication policy [http://www.agu.org/pubs/authors/policies/dualpub_policy.shtml]. Manuscripts prepared in a manner that is cognizant of these issues will significantly reduce the burden on the editorial process and help us to better serve the community.

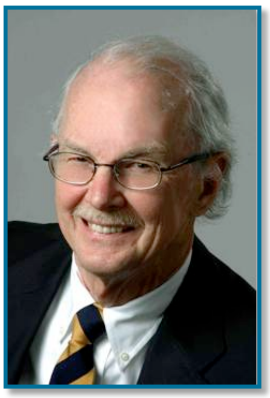
The Fellows speak: Achieving clean water in the developing world -- The role of the scientific hydrologist

John Dracup (University of California, Berkeley).

The best time to plant a tree is 20 years ago. The second best time is now. African proverb

Introduction

Many scientists and engineers have spent their lives contributing to science and the education of the next generation, as well as improving the infrastructure of our world. Despite the altruism inherent in these activities, we recognize the need to contribute to those who have less. In a small way it is a payback for the good fortune that we have received over the years.



Therefore, the question that I pose in this AGU Hydrology Section Newsletter article is "How can scientific hydrologists and engineers who are currently active in research and teaching in their professions help to solve the global problems of clean water, particularly in developing countries?"

The Problem

The data from UNESCO, WHO and a myriad of Non-Government Agencies (NGOs) are well known and compelling. Almost a billion inhabitants of our planet do not have access to clean water. Throughout the world, over 5,000 children under the age of 5 die each day from diarrhea caused by lack of access to clean water. These children are especially susceptible to the pathogens in polluted water because their immune systems are still immature, making them more vulnerable to infection and sepsis.

Target 7C of the Millennium Development Goals (MDG) requires that by 2015 the number of people without sustainable access to safe drinking water and basic sanitation in the world be reduced by one-half. Actually the world is ahead of schedule in meeting this target in drinking water. However, in 2008 some 13% of the worlds' population (884 million people) still relies on unimproved water sources (surface water from lakes, rivers, dams, or unprotected dug wells or springs) for their drinking, cooking, bathing and other domestic activities.

Because two billion people in the world earn less than US $2.00 per day, clean water must be made available at a price that they can afford. UNESCO has documented that the minimum daily requirement for clean water for drinking, washing and cooking is at least 20 liters per day per person. Therefore, clean water needs to be delivered at a cost of about US $0.001 per liter (US $1.00 per cubic meter). Due to a lack of available funding for the treatment of water, the installed systems must be cheap and sustainable.

Further complexities in the developing world include: the lack of a safe working environment in war torn regions; villages that are widely dispersed and remote; the tradition of using the same water source for generations; long distances to viable water sources; badly polluted local water sources; wells containing arsenic and other pollutants; a lack of community organizations to collect fees for the water and to sustain the water purification system; and a lack of energy for pumping water.

The nature of water itself brings an additional layer of complexity to this problem:

1. No one solution solves all of the water supply and treatment problems of the world; that is, no one size fits all. Water supplies come from many different sources with different types of physical, biological and chemical pollutants; therefore, each demand site requires its own unique collection, treatment, storage and distribution characteristics.
2. The long-term sustainability of water systems in developing countries is a continual challenge. UNESCO reports that one-half of all water systems in developing countries fail within five years of installation.
3. Providing sustainable clean water in the developing world requires more than digging a well or installing a pump. A community structure needs to be formed, including a water committee, to collect fees for long-term maintenance and to ensure that the water supply system is sustained.

4. In addition, providing a clean water supply requires the following sequence of steps:
   - maintaining a safe source
   - establishing a sedimentation procedure
   - creating a method for filtration
   - developing some type of disinfection such as chlorination or ultra violet light
   - ensuring safe storage.

All of the required steps can be difficult to establish and even more difficult to maintain in a developing country.

Potential Solutions

To begin this effort, I have studied a variety of clean water systems. They range from small and simple to large and complex and include micro filament filters for individuals; biosand filters and UV treatment for households; and village-sized pre-packaged treatment systems that include sedimentation, filtrations and chlorination capabilities. In my opinion, complex water treatment systems such as reverse osmosis are not viable for developing countries as they are too expensive, require a large amount of energy, and produce excessive green house gases and toxic brine.

Dambisa Moyo, NY Times bestselling book entitled: *Dead aid: Why aid is not working and how there is a better way for Africa,* divides aid to developing countries into three categories: 1. Disaster aid that is provided to victims of floods, tsunamis, earthquakes, etc.; 2. Grass root aid that is provided by the NGOs (Non-Government Organizations) who work on and solve numerous problems at a local level; and 3. Large-scale aid that moves billions of dollars from the governments of developed countries to the governments of developing countries. It is this last category of aid that leads to corruption, graft and even wars over its distribution. Over the past three decades, a trillion dollars has been spent in sub-Sahara Africa with minimal results. Therefore, it is my opinion that it will be the NGO's who, working at the local level, will eventually provide clean water to the developing world, one village at a time. In order to solve this complex problem of providing clean water to developing countries, an optimal blend of political will, sustainable financial instruments and business management methods is required.

Input from the Scientific Hydrologist

Given these obstacles, how can we as scientific hydrologists use our expertise to assist in alleviating this problem? Here are some suggestions:

1. We can join an existing NGO that specializes in providing clean water programs for developing countries. There are approximately 2,000 existing NGOs, large and small, some secular and some religious, who work on providing clean water to villages, regions and countries all over the world. All of these NGOs have hard working and dedicated volunteers; however, scientific hydrologists bring a special knowledge base and expertise to these NGOs that are often missing.
2. We have the unique skill to identify optimal sources of surface or ground water and their long term sustainable yield. An example for surface water supplies is: what is the frequency of floods and droughts that will impact the sustainability of a source? For ground water sources, the sustainable yield of aquifers is an important question. If the aquifer goes dry the sustainable source is lost.
3. Those who are expert in climate change can determine how future trends in temperature and precipitation will influence the surface and ground water supplies.
4. As members of the AGU Hydrology Section, we have a wide range of skills and expertise. Those with engineering skills can become involved in project planning, design and construction of clean water systems.
5. We also can join service clubs, such as Rotary International, which, along with their member clubs located thoughout the world, have a unique role in providing clean water.

At the end of the day, many developing countries lack effective water programs and they have neither the skills nor the manpower to solve their water problems without help. Scientific hydrologists can play an important role in solving the water needs of developing countries.

The Fellows speak: Water in the Murray-Darling Basin -- the finite-planet challenge in microcosm

Michael R. Raupach (CSIRO Marine and Atmospheric Research)

One of the greatest rewards in science is the respect of one's highly respected peers. That is why an AGU Fellowship is such a high honour, and such a humbling one.

We are entering what can be called the "century of the finite planet" - an era in which the consumption of material and ecological resources by humanity is approaching the capacity of the Earth for resource supply and metabolism. This will call for a redefinition of growth itself, as humanity faces the challenge of prospering without the exponential growth in consumption that has occurred over the last several centuries. Here I would like to consider some of the signs and implications of these great trends, through the small lens of a recent event in my home catchment.

For most of the first decade of this century, the lower Murray River nearly stopped flowing. The Murray is the major river in the Murray-Darling Basin (MDB) in southeast Australia, rising in the high country of the Great Dividing Range, flowing west into semiarid terrain, and finally turning south to meet the sea at Goolwa in South Australia. About 40% of Australia's food production occurs in the MDB, much of it supported by irrigation.

The near-cessation of flow in the lower Murray coincided with a major drought known as the "Big Dry" (Ummenhofer et al., 2010) - the hottest and longest drought on record for the region. The Big Dry was both a severe blow to rural industries and also to ecosystems such as the lower Murray lakes. The Murray mouth was closed by sandbars for much of the low-flow period. Rainfall in 2010 has been above average in the MDB, particularly in the north. This signals an end to the Big Dry but does not diminish its significance.

The factors contributing to variations in river flow can be diagnosed by using a simple identity: river flow (F) equals precipitation (P) times fraction of precipitation appearing as runoff (R) times flow in river as a fraction of runoff, or

$F = P \times (R/P) \times (F/R)$.

This is an algebraic truism with no explicit mechanistic content (implicit mechanisms involve the soil water balance, which determines R as the residual of P after evapotranspiration and soil water storage changes, and the river water balance, which determines F as the residual of R after human offtakes, natural losses and river storage changes). Even so, the identity is useful for diagnosing the flow chain from rain to river gauge. It has parallels with the "Kaya identity" for CO_2 emissions (Raupach et al., 2007).

Table 1 shows the factors in the identity for 1951-2001 and 2002-2006, and the ratios of the factors in these two periods. In the Big Dry, flow in the lower Murray fell to just 24% of its average for the previous 50 years. The contributors to this reduction were a decline in precipitation to 76% of the 1951-2001 average, to 41% of the 1951-2001 average for the runoff to precipitation ratio, and to

	***F* (TL/y)**	=	***P* (TL/y)**	×	***R/P***	×	***F/R***
Average 1951-2001	9.01	=	518	×	0.109	×	0.16
Average 2002-2006	2.21	=	395	×	0.045	×	0.13
Ratio = (2002-06 value)/ (1951-2001 value)	**0.24**	**=**	**0.76**	**×**	**0.41**	**×**	**0.79**

Table 1: Factors in the identity $F = P \times (R/P) \times (F/R)$, for flow in the lower Murray River. P and R were determined from 0.05° monthly estimates (Raupach et al., 2009; www.csiro.au/awap), spatially aggregated over the whole MDB. Data on F are from Lock 9 near Wentworth, which captures effectively all flow in the MDB.

79% of the 1951-2001 average for the flow to runoff ratio. Let us consider each factor in turn.

Changes in precipitation

Decreased precipitation in the Big Dry was certainly attributable, at least partly, to climate variability, associated with oscillations in both the Pacific and Indian Oceans (Ummenhofer et al., 2010). A big question is: to what extent was anthropogenic climate change also a factor? Evidence is now accumulating that the intensity of the subtropical ridge of high pressure in southern Australia has increased over the last century, and that this is attributable to climate change (Timbal et al., 2010). Other studies are also suggesting that climate-change effects—via the subtropical ridge—modulate the intensity of mid-latitude U.S. rainfall (Li et al., 2010).

Changes in runoff/precipitation ratio

Of the three factors in the identity, this makes the largest contribution to the decline in river flow. A well-known hydrological feature of medium to low rainfall environments (*P* less than potential evaporation) is that fractional changes in rainfall are amplified by a factor of typically around three in the resulting fractional changes in runoff (see Figure 1). This occurs because vegetation has evolved to be very good at exploiting water resources and gets the first option on water supply. The consequence is that a decrease in rainfall of 24% is amplified to a decrease in runoff of nearly 70% (see table). This "rainfall-runoff amplifier" is one reason why the effects of climate change on rainfall patterns are a significant concern.

Changes in flow/runoff ratio

In the MDB at present, only around 10% of runoff from the uplands reaches the lower Murray. The rest goes to human use (dominated by irrigated agriculture) and natural losses (evaporation, groundwater recharge). Human water use in the MDB declined greatly in absolute terms in the Big Dry but represented an increased share of much-reduced flows. The augmented ecological stress on the system has created added pressure for government protection of environmental commons in the MDB through mandated "sustainable diversion limits" with scientific support (CSIRO, 2008). Proposed reforms to increase *F* severalfold are presently the source of much political controversy.

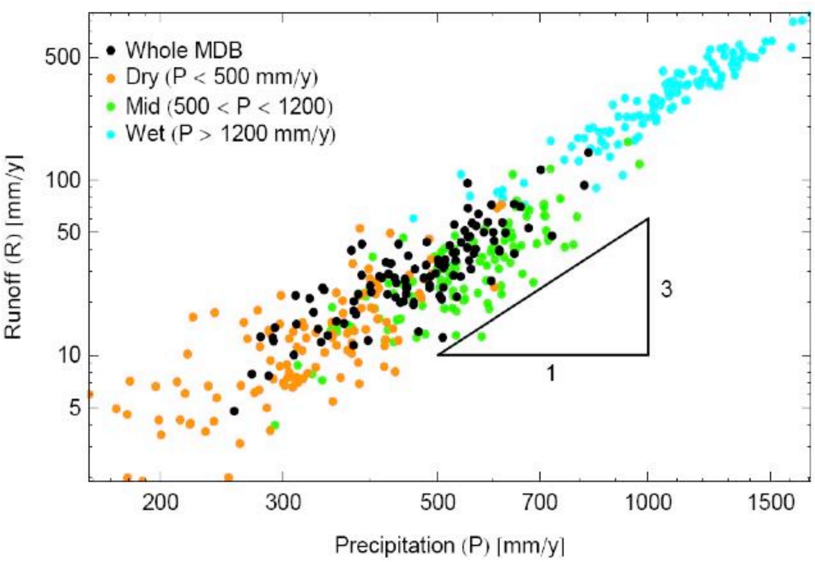


Figure 1: Annual runoff (*R*) plotted against annual precipitation (*P*), spatially aggregated over the entire MDB and over wet, medium and dry subregions. Each point represents one year from 1900 to 2008. The slope shows that fractional runoff changes amplify fractional rainfall changes about threefold ($d(\ln R)/d(\ln P) \approx 3$). Data from Raupach et al. (2009); www.csiro.au/awap.

The factors briefly analysed here can be summarised as a pseudo-equation: water = climate × hydrology × people. Emergent water stresses are manifest in many parts of the world, often more severely than in southeast Australia. Contributing factors include population pressures, poverty and climate change, among a wide set of earth system processes. Rockstrom et al. (2009) identified nine processes which define a "safe operating space for humanity": biodiversity loss, climate change, disturbance to nitrogen and phosphorus cycles, global freshwater use, land use change, stratospheric ozone depletion, atmospheric aerosol loading, and chemical pollution. Our planet is maintained by a connected network of earth system components, among which human-induced pressures are significant and interactive at many points.

This brings me back to the challenges of the "century of the finite planet". Water resources pose one obvious challenge on the supply side. On the output side of human activities, limiting climate change is an equally pressing challenge which can also be framed in resource-utilisation terms: if risks from human-induced climate change are to be kept acceptably low, then future cumulative global CO_2 emissions must be capped at a quota about equal to past cumulative emissions since 1750 (Raupach, 2009; and references therein). These challenges are closely connected.

A small postscript: the lower Murray lakes rank among my sacred sites, as they do for many. They are places of great beauty, particularly the Coorong, a 100-km narrow lagoon separated from the Southern ocean by a thin barrier of sand dunes. My Ph.D. work (Raupach, 1978) involved measurement of water-air sensible and latent heat exchanges over those lakes. This was done with eddy covariance techniques using analog computation, propeller anemometers (sonic anemometers being unavailable) and a home-built infrared-absorption water vapour sensor; the principle is still used now.

Acknowledgments: I am indebted to many colleagues - specifically Peter Briggs, Edward King and Matt Paget for the Australian water availability work, and Pep Canadell for inspiration in work on the global carbon cycle. Most of all, I am indebted to my family.

References:

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The Fellows speak: Scaling issues – A challenge to understanding hydrologic, erosion, and contaminant transport processes

Roy C. Sidle (Appalachian State University)

During the past few decades, hydrologists have made substantial progress in articulating various types of flow in heterogeneous porous media, often linked to non-Darcian behavior. These advances have been associated with theoretical breakthroughs, field experiments, statistical treatment of data, and modeling related to complex hydrological response. These developments have provided insights into processes such as preferential flow in soils and aquifers. However, our ability to capture the dynamic behavior of such systems in time and space remains a challenge for the type of upscaling that needs to be incorporated into models of catchment processes. Few experimental studies even consider the possibility of how such pathways would interact with changing landform conditions or substrate as water travels downslope in the continuum from ridgelines to riparian zones and eventually to rivers and groundwaters (Figure 1). The problem is much more complicated than that of fate and transport of water and chemicals through non-uniform porous media, and requires a thorough understanding of the complexity and interactions of pathways from sources to sinks (or, in the case of contaminants, from stressors to receptors). These issues constitute a major challenge to the field, and are not only of a fundamental nature, but also have very important practical implications for land management, hazard assessment, and environmental regulation.

Nutrient and contaminant transport are highly scale dependent (Steefel et al., 2005). To understand the transport of nutrients or contaminants from source to sink or from stressor to receptor, knowledge of specific pathways is fundamental (Figure 1). The biogeochemical reactions that affect fate and transport of chemicals, nutrients, and biological contaminants differ greatly in various pedological and geological environments. They are influenced by residence times as well, which may vary depending on the spatial distribution and temporal behavior of preferential flow paths (Simic and Destouni, 1999). As such, the dynamics of hydrological pathways play an important role in the fate and transport of contaminants and nutrients and need to be represented in models.

Understanding how hydrological processes evolve in time and space also has strong implications for sediment processes in particular systems – from source to sink. For example, knowledge of pore water pressure development in steep hillslopes is critical for predicting the timing and location of different types of landslide occurrence (Sidle and Ochiai, 2006). A more difficult challenge is how this landslide erosion (and/or surface erosion from disturbed or bare soils) is routed through catchments. Where is it stored? How and under what conditions is it remobilized? When is there sufficient bulking of sediment to trigger debris flows and what hillslope-channel conditions facilitate this process? Alternatively, what conditions promote the direct mobilization of landslides into debris flows (Figure 1)? All of these questions require detailed dynamic and spatially distributed knowledge of hillslope hydrology and how this contributes to flow in streams. Furthermore, such data need to be better articulated in models of catchment sediment processes.

With recent advances in hydrological modeling, we are able to couple hydrology with atmospheric energy and large-scale and long-term water balances. Technological improvements in remote sensing have allowed researchers to assess large-scale changes in land cover, surface temperatures, and energy and water budgets. Other modeling advances have derived from increasing computational power. Nevertheless, in spite of such technological progress, much of the modeling in hydrology appears to be increasingly disconnected from process understanding. While it could be argued that many of the detailed processes that hydrologists have investigated for decades at small scales are difficult to measure or quantify at large

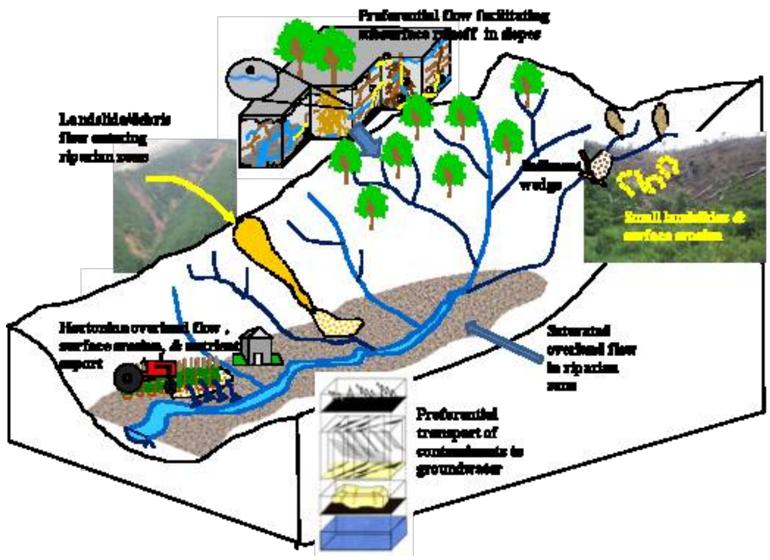

Figure 1: Examples of how small and moderate scale hydrogeomorphic processes contribute to catchment scale transport of materials

scales and do not affect ‘downstream’ (larger scale) outcomes, it is clear that such detailed knowledge of pathways is needed to better address many of the important challenges facing our discipline and society (Figure 1; Sidle, 2006). Certainly we cannot use a completely reductionist approach when modeling large-scale catchment behavior or surface–groundwater systems. However, I believe that the challenge facing us is to articulate what level of detail and which details are necessary to better predict responses within larger hydrologically-driven systems where sources-sinks and stressors-receptors may not be constant in time and space.

One of the solutions to these challenges is to develop interdisciplinary team approaches to address complex environmental problems. While many such groups have evolved in recent years, hydrology does not always appear to have its proper place at the table. Oftentimes the hydrologic component of such teams is relegated to developing distributed models. Many such approaches circumvent important field investigations related to the scaling of hydrologic processes in favor of more easily gathered surrogates that can be used to upscale existing models (Sidle, 2006). As such there appears to have only been minor advances in temporal and spatial scaling of hydrological pathways in many complex multidisciplinary modeling efforts. Furthermore, many models are limited to estimation of fluxes for average conditions rather than during episodic events when the bulk of the materials are typically transported. Furthermore, such approaches are difficult if not impossible to test internally, which brings into question the application of these models for land use decisions and regulations that require robust spatially and temporally based predictions. I argue that we cannot and should not attempt or purport to predict a specific concentration or flux of material at a given point in a real-world system, rather we should approach this problem from a stochastic perspective where we assess the probability of a given flux or concentration (or suite of fluxes and concentrations) for various time frames. Such assessments are more realistic and more useful for management and regulatory agencies.

As a hydrology community, we now recognize that catchments and surface-groundwater systems are spatially variable and are not static in terms of temporal response. However, we need to move away from a purely statistical approach in addressing these temporal and spatial scaling issues in hydrological models. It is important that we focus on understanding and predicting the internal function of hydrological systems in addition to just the outputs. Such spatially and temporally robust predictions are needed to support land management decisions, regulatory actions, and hazard mitigation measures. As such, our community needs to refocus efforts on carefully designed, field-based hydrological process studies that address these issues of scale. Based on the trends that I have observed in the past few decades, I feel that we are rapidly losing this fundamental element of our discipline, not only in research, but also in educational and management programs. Many graduate programs in hydrology now seem to be based primarily on modeling and technologic advances with little focus on the underlying field processes. Additionally, land management agencies are now collecting far less hydrological data than was the practice in the 1950’s through the 1980’s, partly due to budget cuts and redirected priorities. As such, our discipline has not done a good job in justifying the necessity of these valuable, long-term hydrology investigations and, as a result, many of these field programs have been terminated or significantly refocused by agencies that have not given due attention to the wider utility of the resulting data sets and the associated data collection process. The result is that many resource managers who must deal with hydrology issues seldom go to the field and now rely on GIS and remotely sensed information and secondary data to support land management decisions. I contend that the insights gained by students and young resource managers from collecting and interpreting field hydrological data is an essential component in their education and training. If not corrected, this decline in field hydrology understanding will snowball as young academics, resource managers, and regulators emerge. We need to make certain that our land use guidelines and regulatory procedures are based on robust hydrological information, and that when modeling such processes, appropriate temporal and spatial scaling issues are considered.

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The Fellows Speak: The Anthropocene -- Are we there yet?

James P.M. Syvitski (University of Colorado, Boulder CO)

To be clear to my oceanography colleagues, yes I am still a coastal oceanographer. But I do have a substantive body of work in the field of hydrology, and I feel honored to be asked to write for the Hydrology Section newsletter of AGU. It is hard to conduct coastal oceanography without intimate knowledge of river fluxes. At the University of Colorado, I am fortunate to hold faculty appointments in Geological Sciences, Applied Math, Geophysics, Hydrological Sciences, and Atmosphere and Ocean Sciences, and to work closely with INSTAAR colleagues from Ecological and Environmental Biology, Environmental Studies, and Civil, Environmental, Mechanical, and Aerospace Engineering. At heart we are all Geophysicists trying to figure out planet Earth. The Community Surface Dynamics Modeling System, my present passion (csdms.colorado.edu), is dedicated to merging knowledge from this spectrum of specialties by developing, supporting, and disseminating integrated software modules that predict the movement of fluids, sediment and solutes in landscapes, seascapes and their sedimentary basins. CSDMS deals with the Earth's surface—the ever-changing, dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere. It is such an exciting time to be conducting research!

I was recently asked to write for the *Philosophical Transactions* (Royal Society) on whether Earth has entered a new geological period called the Anthropocene, from which I draw information for this article (Syvitski and Kettner, in press). The Anthropocene is being considered as a defined geological epoch wherein the human species has collectively impacted the Earth's surface so as to result in a global signal in the permanent geological record. I was to focus on water and sediment fluxes. Based on other signals, the Anthropocene began in 1950 (atmospheric temperature), or 1870 (accelerated sea level rise), or 1750 (increases in global atmospheric concentrations of CO_2, CH_4 and N_2O) (IPCC, 2007). The human population also increased by one order-of-magnitude, between 1600 and 1976, with a concomitant need for minerals, soil and aggregate, agriculture, energy, water, transportation, and other infrastructure.

Humans have intervened against the force of gravity, decelerated and accelerated natural processes, focused energy, altered or destroyed ecosystems, altered earth's atmospheric and ocean climatology and chemistry, the extent of snow cover, permafrost, sea ice, glaciers and ice sheets, and indeed the entire hydrological cycle. Known geomorphic activities involving humans include:

- Deforestation and its associated role in soil erosion, slope failure, and downstream sedimentation;
- Farm-animal grazing leading to gully development and soil erosion;

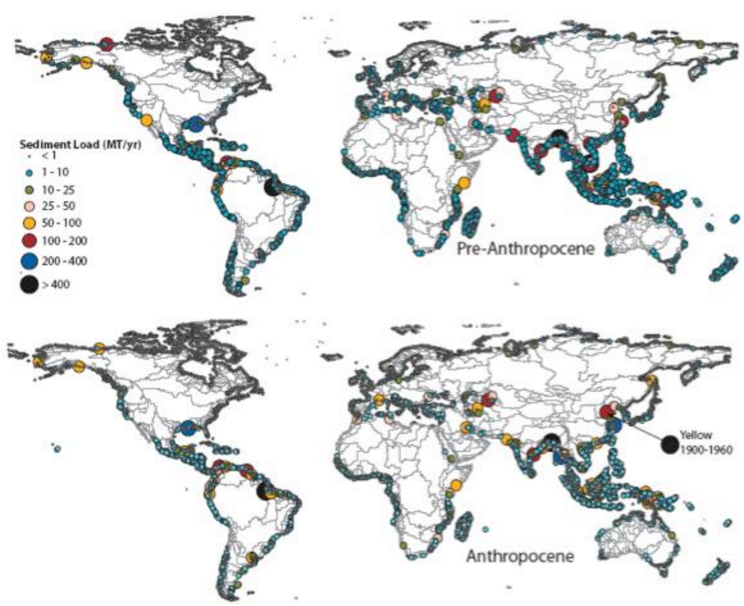

Figure 1: Simulated suspended sediment load before the major imprint of humans (Upper), and after the imprint of humans, circa 1990 (LOWER). Note that the magnitude of the sediment loads is a moving target for many of the populated river basins. For example during the period of 1900 to 1960, the sediment load of the Yellow River exceeded 1000 MT/y and has since 1995 has fallen to <200 MT/y. Model simulations are based on the BQART model (Syvitski and Kettner, 2008).

- Agriculture including tillage, terracing, irrigation systems, and subsurface water extraction leading respectively to increased soil erosion, creep, siltation and subsidence;
- Mining and its associated role in river channel and hill slope alteration, slope instabilities, and subsidence;
- Transportation systems impacting gully development, soil erosion, and riverbed scouring;
- Waterway re-plumbing including reservoirs and dams, diversions, channel levees, channel deepening, discharge focusing, and ultimately coastline erosion;
- Coastal management through groins, jetties, seawalls, breakwaters, harbors, leading to unnatural coastal erosion or sedimentation, wetland, mangrove and dune alterations;
- Warfare which magnifies many of the above activities for a duration that extends beyond the period of combat; and
- Global climate warming and its impact on coastal inundation, precipitation intensity including the intensity of cyclones, desertification, and an accelerated hydrological cycle.

Way to go humans! Humans have both increased the erosion of the landscape and intercepted the sediment along the hydrological pathways, sometimes simultaneously, sometimes in sequence. Approximately 75% of the elevated sediment yields of Mediterranean basins are attributed to human activity (Dedkov and Mozzherin, 1992). Terracing of hillslopes and mountainsides for agricultural use is certainly one of the largest geomorphic processes for Asia and Indonesia, particularly since modern terracing involves heavy machinery, unlike the Mayan or early Chinese terracing methods. Human activities have also compounded climate events with catastrophic consequences. A proliferation of small farms employing poor tilling practice on top of a prolonged drought in the central U.S. in the early 1930's, led the U.S. Department of Agriculture to estimate the loss of topsoil at 12.5 Gt. The sediment was dispersed widely into waterways, and even outside of the drainage basins to areas of New England.

The annual volume of sediment moved by direct human intervention is now at the scale of sediment discharge to the global coastal ocean (Syvitski et al., 2005). The Hull-Rust-Mahoning Mine in Hibbing, Minnesota, has moved 1.2 Gt of material since 1895. The Syncrude tar sand mine, in northern Canada, has already removed and processed 30 Gt of sediment. The Palm Islands construction that will add 520 kilometres of beaches to the city of Dubai has moved 3.1 Gt of sand and rock. Construction of the Hong Kong Airport saw more than 0.6 Gt of sediment displaced. [How large is 0.6 Gt? The Great Wall of China is ~6,250,000m x 7m x 5m or ~0.4 Gt of earth and stone]. There are thousands of mines worldwide.

The major means to reduce the flux of river sediment to the coast is through sediment retention in reservoirs (Vörösmarty et al., 2003). Globally there are > 48,000 large dams (heights >15 m, average reservoir area 23 km2), with > 2000 large dams under construction. Globally, the 20th Century sediment delivery to the coastal zone has been reduced by 15%, although at the continental scale, the change between Anthropocene and Pre-Anthropocene loads can vary by 30% (Syvitski et al. 2005), and by an order-of-magnitude for individual river basins (Syvitski et al. 2009) with some rivers transporting virtually no sediment: Nile, Colorado, Ebro, Sao Francisco and Indus (Figure 1).

Humans have succeeded in harnessing much of the world's freshwater resources for improved use (agriculture, industry, consumption, transportation), and for natural hazard reduction (reduced flooding). Rivers are free to meander between stop-banks, some 10 to 100 times narrower than their natural floodplain widths. Some rivers even have their meanders frozen in space with hardened channel banks.

The downstream consequences of these interventions are many and include accelerating the subsidence of modern deltas. In addition to sediment sequestration in upstream reservoirs, the sediment flux across a delta plain is engineered through stop-banks to bypass the floodplain and directly enter the coastal ocean (Syvitski et al., 2009). For many deltas, aggradation rates have substantively decreased or been eliminated. On average deltas are subsiding 4 times faster than sea level is rising often through regional mining for groundwater and petroleum (Syvitski et al., 2009).

Humans have also altered the mechanisms by which a river's discharge is dispersed into the coastal ocean in contrasting ways:

1) *By elevating suspended sediment concentrations to such an extent in some rivers (e.g. NZ, USA, Taiwan, Indonesia) that hyperpycnal currents are generated.*
2) *By reducing a river's sediment concentration so as to reduce or eliminate its ability to produce a hyperpycnal current (e.g. Italy, China).*

Human interventions on Earth's hydrological pathways are impressive. Major impacts by humans began more than 3000 years ago in some basins. By the 16th century, soil disturbance was rampant as modern societies began engineering their environments. By the early 20th century, mechanization related to earth removal, mining, terracing and deforestation led to global signals in increased sediment flux in most large rivers. By the 1950's, this sediment disturbance signal reversed due to the proliferation of dams and is now the dominant signal in most major rivers.

As long as modern civilization is around, it is hard for me to imagine that we are not fully in the Anthropocene. As scientists and engineers, we must recognize the varied manifestations of human engineering and combine this with our knowledge of natural processes to make much better estimation of the long-term consequences. As I study the details of the 2010 Indus flooding, I note that the location of the two major stop-bank breaches relate to specific engineering structures, weak points, being overwhelmed. We must do better. I thank my numerous colleagues at CSDMS and abroad (e.g. Milliman, Meade, Parker, Paola, Vörösmarty, Brakenridge) for their insights into this discussion. I thank the University of Colorado, NSF, ONR, NASA, IGBP, USGS, LOICZ, and the GSC for their strong support of my research career.

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The Fellows Speak: Geomorphology – a Look Forward

Kelin Whipple (Arizona State University)

It is an exciting time to be a geomorphologist – a time rife with opportunities, new capabilities, and compelling challenges. Our field has grown by leaps and bounds in the last two decades. In this time a great many bright, enthusiastic, and creative young scientists have joined our ranks and engaged in a wide array of integrative, quantitative studies of the processes operating on the Earth's surface and in the near-surface environment. I am at once pleased and a bit shocked to realize that I have been transformed so quickly into one of the old guys in the room at AGU meetings. Reflecting and nurturing this growth, the last decade has seen the launch of a new AGU Journal (*JGR – Earth Surface*), the formation of both a new NSF program (Geomorphology and Land Use Dynamics) and a related major cross-disciplinary research initiative in the Critical Zone Observatories, and most recently the creation of a new AGU Focus Group (Earth and Planetary Surface Processes). This growth has been coupled to, and facilitated by, technological advances (e.g., airborne lidar altimetry, ground-based scanning lidar, cosmogenic isotope dating, low-temperature thermochronology, physical and isotopic tracing techniques, and computing power; Figure 1) that are revolutionizing our ability to study how the surface environment that hosts our civilization works, how to read the record of past conditions and events, and to predict system response to perturbations such as climate or land use change. The recent NRC Report "Landscapes on the edge: New horizons for research in Earth surface processes" (NRC, 2009) puts a spotlight on these advances and opportunities ripe for significant scientific advance.

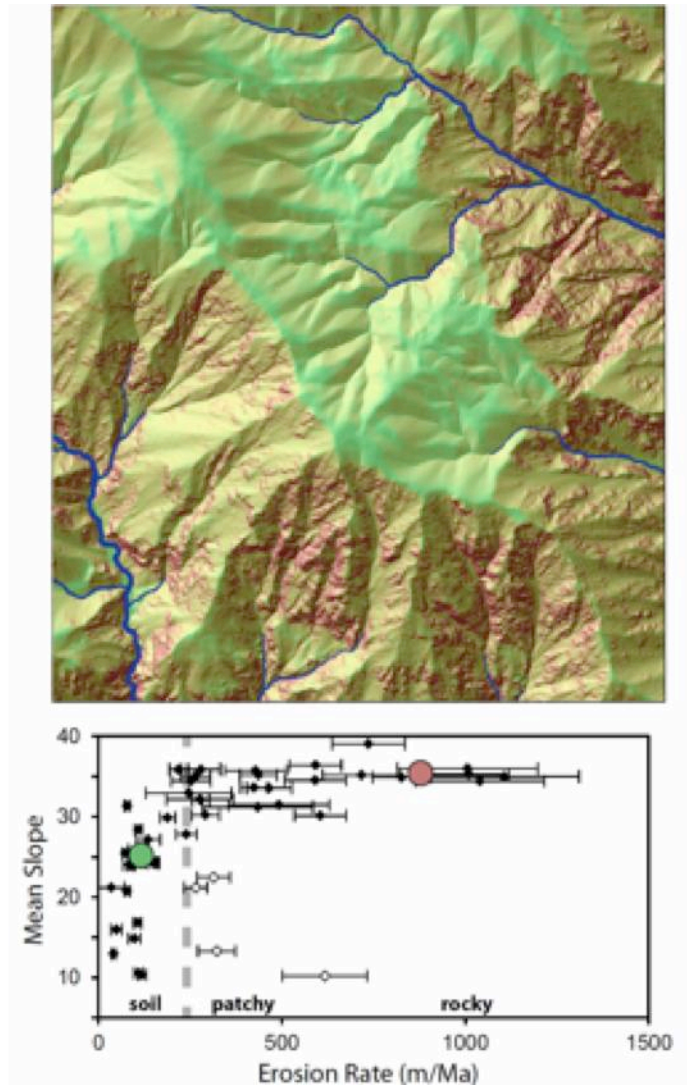

Figure 1: Illustration of the power of new technologies at work. Upper panel shows high-resolution (1 meter) lidar shaded relief map from high in the San Gabriel Mountains, CA, colored coded by local slope (green < 15, red > 40 degrees) (image is 2 km across). A soil-mantled area of rolling hills is surrounded by very steep, rugged and rocky terrain. Lower panel shows the relationship between mean slope and erosion rate determined using measurements of cosmogenic ^{10}Be in stream sands (DiBiase et al., 2010). Vertical dashed line demarcates the maximum soil production rate independently measured with cosmogenic ^{10}Be and, as expected, defines the process transition between soil-mantled and rocky landscapes. The green dot shows the slope and erosion rate of the soil mantled area (upper panel) and the red dot shows slope and erosion rate of the surrounding rugged, rocky area.

Geomorphology encompasses study of the evolution of the morphology, composition, and function of the Earth's surface and near-surface environment, including the controls on mass fluxes (water, solutes, and solids). The Earth surface system is termed the Critical Zone because it is critical to supporting life and civilization (NRC, 2001). Although the term "Critical Zone" is often used as interchangeable with "regolith" (the mantle of soil and weathered rock) and the ecosystems hosted therein, the dynamics of the Critical Zone is in fact the dynamics of the Earth surface system as a whole. Full understanding will require integration of the physical processes of landscape evolution with atmospheric science, hydrology, low-temperature geochemistry, and ecology to capture the interactions and feedbacks among climate, surface processes, landforms and substrate properties, and life. Pursuing the most promising opportunities will require crossing disciplinary boundaries and asking new questions, or addressing old questions with new tools and approaches. At the same time, it is essential to maintain the specialized training that makes this kind of cross-fertilization effective. In my opinion, whereas there is great value to immersing graduate students in an interactive interdisciplinary environment while pursuing their specialized training, there is an equally great risk of dilution in fundamentally interdisciplinary training. We need specialists that are adept at collaborating more than we need generalists.

Of the many opportunities for advancement of understanding the evolution of the Earth's surface system that will require interdisciplinary cross-fertilization probably the most promising is the co-evolution of life and landscapes, sometimes termed "ecomorphodynamics". All processes operating in the near-surface environment are modulated or catalyzed by life. Pioneering studies have illustrated the complex co-evolution of ecosystems, soils, hydrology, and landforms. The interplay among these components is essential to predictions of system response to perturbation (e.g., fires, climate change on decadal to millennial scales, land use change) and to understanding the linkages between environmental conditions and the geologic record, and between current landforms, the ecosystems they host, and the history of climate change. In addition, we must recognize the great impact that human activities are having on the form and function of the Earth's surface and the operation of the environment that sustains our civilization.

More specifically, below I share some thoughts about three opportunities or challenges that I believe merit collective, concerted effort. These challenges bridge the human timescales of applied problems to the million-year timescales of landscape evolution: (1) Developing environmental sensor networks to study the physics and chemistry of surface processes at spatial and temporal resolutions never before possible, (2) Quantifying linkages among climate, hydrology, and the processes of mass transfer (erosion, transport, and deposition), and (3) Exploring the influence of mantle convection on regional uplift and landscape evolution.

Environmental Sensor Networks

The study of surface processes is a data-limited field. We remain ignorant of many critical processes simply because of the difficulty of adequately measuring the operation of mass-transfer processes with sufficient spatial and temporal resolution to test and refine process models under field conditions. Recent advances have changed the playing field. For instance, a combination of airborne and tripod scanning lidar systems allows researchers to map topography and even collect time series of topographic change at unprecedented resolution – at the scales at which the formative processes operate. In addition, the development of small and inexpensive pressure, shear stress, soil moisture, turbidity and other sensors have revolutionized process monitoring at the event scale. However, such studies have typically harnessed sensor systems designed for other applications. There is a need and an opportunity for scientists and engineers to work together to develop technologies explicitly for real-time environmental observing (fluid flow, temperature, composition, sediment load, stresses) including sensor development, sensor deployment, and data retrieval systems. Simple, robust and inexpensive sensors and sensor networks are essential for sufficiently instrumenting systems to capture the spatial and temporal variability required to test and refine process models. Given the obvious and pressing societal concerns (e.g. agricultural soil loss, flooding, system response to climate and land use change, water availability and quality), a focused effort along these lines could reap considerable rewards.

Climate, Hydrology, and Mass Transfer Processes

Few questions are more fundamental to geomorphology than the question of how exactly climate influences landscapes – the extent of weathering and the thickness of soils and weathered rock, the morphology of landscapes (e.g., relief, channel slopes, hillslope gradient and curvature), the efficiency of erosion and sediment transport, the relative flux of mass in sediments and solutes. Despite the foundational nature of this question, much remains unquantified. Empirical model parameters often absorb all climatic influence, but remain uncalibrated to measureable climate attributes such as mean annual precipitation, seasonality, aridity, and storminess. At a more fundamental level, while we are beginning to learn how the probability distribution of daily stream discharge influences sediment transport and river incision, we do not know what controls the probability distribution of rainfall events (size, duration, intensity, frequency) in a given setting, nor how this is transformed by the hydrologic process into the variability of stream discharge. Landscape evolution models usually assume simple Hortonian runoff and thus do not capture the interactions between hydrological processes, topography, and biota that presumably importantly influence stream flow variability. Progress on a quantitative understanding of the controls on the probability distribution of stream discharges may lead to unraveling an essential element of the link between climate and landscape evolution by bringing together advances in mesoscale atmospheric science, hydrology, and geomorphology.

Mantle Convection and Landscape Evolution

Much effort in the past couple decades has focused on the interactions between climate-driven erosion and crustal deformation in tectonically active mountain ranges. Tectonic geomorphology has grown into a large and vibrant field with this focus on crustal geodynamics. A new horizon is looming, however, in understanding the role of mantle convection on landscape evolution, re-invigorating and redefining age-old questions. Geodynamicists are developing the capability to predict (or retrodict) the influence of motions in the mantle on uplift and subsidence histories that will be manifest in predictable temporal and spatial patterns of landscape evolution. The essential idea is that images of mantle tomography (heterogeneities in seismic wave speeds) can be combined with knowledge of mineral physics to generate maps of heterogeneities in mantle buoyancy that can be fed into a mantle convection model to estimate the history of long-wavelength patterns of uplift and subsidence over million to 10’s of million year timescales. Many details of current models are debated in the geophysics community regarding how best to map tomography into buoyancy and what model approximations can be made while still capturing the main patterns and rates of mantle convection. Current models disagree with one another and in the next decade we can expect to see significant advances as the merits of different approaches are evaluated. Essential to this process will be testing predicted uplift/subsidence histories against geologic and geomorphic observations. New light will be shone on long standing debates about continental landscape evolution and mantle geodynamics as a consequence of this interaction between geophysicist and geomorphologists.

These are just a few areas with exciting prospects. There are many more I have left unmentioned, some of which are discussed in the Landscapes on the Edge NRC report (NRC, 2009). It is a great time to be involved in the study of the evolution of Earth’s surface system and near-surface environment. The future has never been brighter nor the problems more societally compelling. To move forward effectively we need models and theory to generalize understanding and guide observational studies. We must not forget, however, that ours is a data-limited field – significant advances will follow from new observations. Cross-disciplinary collaboration is also likely required for significant advances, but within the context of collaborative studies we must ensure that we train the specialists of the next generation who will find great value in collaborating with one another.

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Satellite Remote Sensing of Hydrology – Challenges and Opportunities

Mekonnen Gebremichael[1] (University of Connecticut)

The world is in a water crisis today, with over a billion people lacking access to safe water and going to bed hungry every day, 2.5 billion without improved sanitation facilities, 4 million dying each year from water-borne diseases, and floods and droughts topping all natural disasters. The challenge of securing water resources will only increase in light of burgeoning human needs, competition for water among various sectors, and climate variability and change. However, our current ability to plan, develop and manage water resources is severely limited. I believe that part of this limitation is caused by insufficient use of data from satellite observing systems that are now available at regional and global scales. Satellite remote sensing has long been identified as a technology capable of monitoring precipitation and evapotranspiration at high space-time resolutions suitable for water resource applications. It is often the only source of information about these variables over large areas in developing countries or remote locations. Furthermore, the near-real-time data availability and consistent quality of satellite remote sensing data makes it suitable for water resources management. However, satellite precipitation and evapotranspiration data are not yet widely utilized by the water resource applications community. Below, I briefly discuss the opportunities and challenges associated with satellite remote sensing of hydrology, and provide some recommendations.

Satellite Remote Sensing of Precipitation

Opportunity – The successful deployment of the first precipitation radar in space as part of the Tropical Rainfall Measurement Mission (TRMM) in 1997 spurred the development of high-resolution satellite precipitation products (e.g., Huffman et al., 2007). Satellite measurement capabilities will further improve with the anticipated launch in 2013 of the Global Precipitation Measurement (GPM) mission, which envisions a global constellation of microwave sensors.

Challenge – Satellite precipitation estimates are subject to a variety of error sources (gaps in revisit times, poor direct relationship between remotely sensed signals and rainfall rate, atmospheric effects that modify the radiation field), and the errors are expected to increase with increasing space-time resolution. Nevertheless, the operational satellite precipitation estimates lack any estimate of their uncertainty. Hydrologists ask: *What is the uncertainty in each satellite precipitation estimate*? *There are so many satellite rainfall products currently available – which one does one use for a specific region to get the best results*?

Recommendation – Representative ground validation sites, equipped with high-quality dense rain gauge networks or weather radar, need to be established in various regions of the world to quantify estimation errors in satellite rainfall estimates. Further algorithm development, through incorporation of rain gauge data or other datasets, is needed to improve the accuracy of the current satellite precipitation estimates, particularly in complex terrains.

Satellite Remote Sensing of Evapotranspiration (ET)

Opportunity – The availability of multi-band visual and thermal infrared imagery from the Thematic Mapper (TM) and Enhanced TMPlus (ETM+) sensors on Landsat satellites, the Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) on Terra satellite, and the MODerate resolution Imaging Spectroradiometer (MODIS) sensor on Terra and Aqua satellites has made the estimation of ET feasible. Data from these polar-orbiting satellites can be combined with geostationary-orbiting satellite data from a number of satellites (MSG2 over Europe and Africa, GOES 11/12 over Americas, FY2 D/E and MTSAT over Asia) to generate time-aggregated ET maps. Recently, ground-based scintillometers have been developed to evaluate the accuracy of the satellite estimates at equivalent footprints (Zeweldi et al., 2010).

Challenge – Unlike satellite precipitation maps, operational ET maps are not currently available to the public. The main challenge lies in estimating ET in cloudy sky conditions during which the remotely sensed visual and thermal information of land surface are contaminated by clouds. Another challenge is the coarser resolution of ET data from the geostationary satellite data (3 km to 6 km) and MODIS data (250 m to 500 m for visible bands, and 1 km for thermal bands) compared to the finer resolution required in water management applications.

Recommendation **–** New techniques need to be developed to estimate ET during cloudy sky conditions. Following the recent results of Li et al. (2009), remotely sensed microwave information about the land surface may be an alternative way to estimate ET during cloudy sky conditions, since microwave remote sensing can observe land surfaces under all sky conditions. New techniques for spatially downscaling ET products need to be developed. Norman et al. (2003) developed the DisALEXI (Disaggregated Atmosphere Land EXchange Inverse) downscaling algorithm for ET based on inputs of vegetation index and surface temperature, but this method needs to be tested under a large range of land surface and temperature conditions.

Hydrologic Modeling Based on Satellite Remote Sensing Inputs

Opportunity – In addition to precipitation and evapotranspiration, satellites also provide spatial maps of land surface properties (e.g., elevation, vegetation index, fraction of photosynthetically active radiation, land cover, etc.) that may be useful inputs to hydrologic models. Recent advances on adaptive grid size and high performance computing make it possible to run physically-based hydrologic models over large river basins.

Challenge – It remains a challenge to the scientific community to integrate the various satellite data sets in the most optimal method in a hydrological modeling framework. Obtaining accurate hydrologic model parameter estimates from remotely sensed data and identifying the most appropriate hydrologic model(s) for remotely sensed data also remain a challenge.

Recommendation – Efforts must be made to remove the bias in satellite rainfall estimates before using them as inputs into hydrologic models, especially for calibration purposes. Figure 1 shows that bias correction of satellite rainfall estimates improves the model simulations, regardless of the complexity of the hydrologic model used. Several researchers (e.g., Sivapalan et al., 2003) suggest that an improvement in predictability of streamflow can be achieved by seeking "explanations and descriptions of patterns across scales". This new approach needs to be explored further as satellite remote sensing datasets provide such spatial and temporal patterns.

Bridging Research and Application

Challenge – Hydrologists have a myriad of questions about common operational issues of satellite remote sensing datasets. Some of these questions are: *Where can the satellite data be acquired for operational applications*? *Which satellite data sets are appropriate for a given*

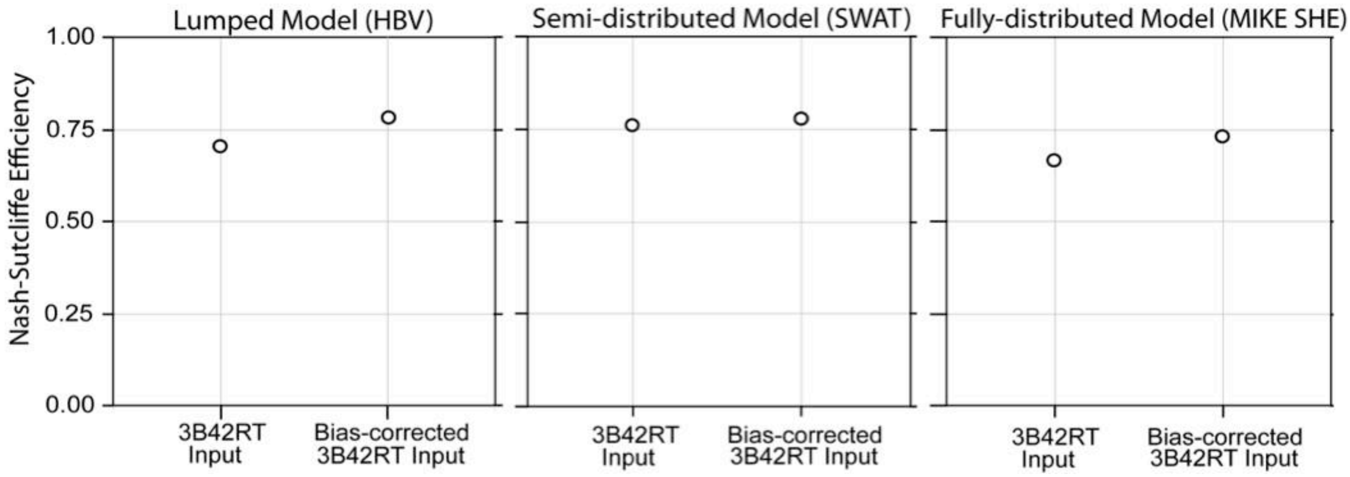

Figure 1: Comparison of hydrologic model daily streamflow simulation performance statistic (Nash-Sutcliffe Efficiency) for the Gilgel Abay watershed (a mountainous, 1,700 km^2 watershed located in the Ethiopian highlands) using raw satellite rainfall input (TMPA 3B42RT) and bias-corrected TMPA 3B42RT rainfall input, for three types of hydrologic models: (left panel) the lumped model HBV, (central panel) the semi-distributed SWAT, and (right panel) the fully-distributed MIKE SHE. The performance statistic was obtained by comparing the model simulations to streamflow measurements at the outlet of the watershed, for the period 2006 – 2007.

application? Satellite data sets often do not have a common data format, making it difficult for practicing hydrologists to utilize them.

Recommendation – Effective communication tools need to be established between research organizations and water management authorities. The next generation of water resource professionals and scientists needs to be trained in hydrologic remote sensing – this is the best way to assure adoption of these tools. A course in hydrologic remote sensing should be included in all water resources curricula, and completion of such a course should be considered among the minimum requirements for professional competence.

I would like to close by bringing to attention a new book, "Satellite Rainfall Applications for Surface Hydrology" (editors Mekonnen Gebremichael and Faisal Hossain), which provides more information on this topic.

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[1]Recipient of 2010 Hydrology Section Early Career Award

Sustainability in the face of uncertainty: Research trends in groundwater[1]

Barbara A. Bekins (U.S. Geological Survey) and Geoffrey C. Bohling (Kansas Geological Survey)

Groundwater is the source of drinking water for 51% of the U.S. population, 32% in the Asia-Pacific region, 75% in Europe, 29% in Latin America, and 15% in Australia (Sampat, 2000). Although historically the science of hydrogeology was driven by water supply questions, the role of groundwater in ecosystems is an emerging area of research. The dynamic nature of hydrogeology is apparent from the way research directions have changed over time as understanding has grown and new measurement technologies have been developed. Compared to 1979, recent work published in *Water Resources Research* covers a wider range of topics and is more interdisciplinary (Schwartz et al., 2005). The purpose of this article is to briefly summarize some current groundwater research topics and trends including sustainability, modeling of complexity and uncertainty, data integration, and representation of subsurface heterogeneity.

Sustainability of groundwater quantity and quality is a pressing concern worldwide. Estimated rates of groundwater depletion have more than doubled in the last 50 years (Wada et al., 2010). Well-constrained studies of groundwater depletion are becoming possible where databases extending over many decades can be assembled but methods are needed for areas with little data (Konikow and Kendy, 2005). Remote sensing technologies such as Synthetic Aperture Radar and GRACE (Gravity Recovery and Climate Experiment) compare well with measured water levels, showing promise for quantifying seasonal recharge and long term groundwater changes in areas with few data records. In many heavily populated areas groundwater quality has been degrading over the last 50 years due to migration of ubiquitous point and nonpoint source contaminants and seawater intrusion. Figure 1 shows how concentrations of nitrate in shallow groundwater have increased at sites across the U.S. Fogg and LaBolle (2006) argue that sustainability of groundwater quality should be considered a major challenge for an interdisciplinary synthesis of research. Challenges for sustainability research lie in coupling groundwater and surface water models to economic models with legal constraints.

Groundwater modeling continues to be central to understanding, managing, and forecasting groundwater resources. A notable recent trend in groundwater modeling has been the increased use of highly parameterized models, potentially allowing for more accurate representation of natural heterogeneity and a fuller exploration of predictive uncertainty (Hunt et al., 2007). A current challenge for the modeling community is to incorporate uncertainty assessment procedures into regular practice in order to provide stakeholders and policy makers with more realistic bases for decisions (Beven, 2009). Several recent studies have investigated the relative merits of various model selection and multi-model averaging techniques in providing such assessments (Poeter and Anderson, 2005; Singh et al., 2010; among others). A particular challenge in multi-model averaging is the elicitation and quantification of expert opinion

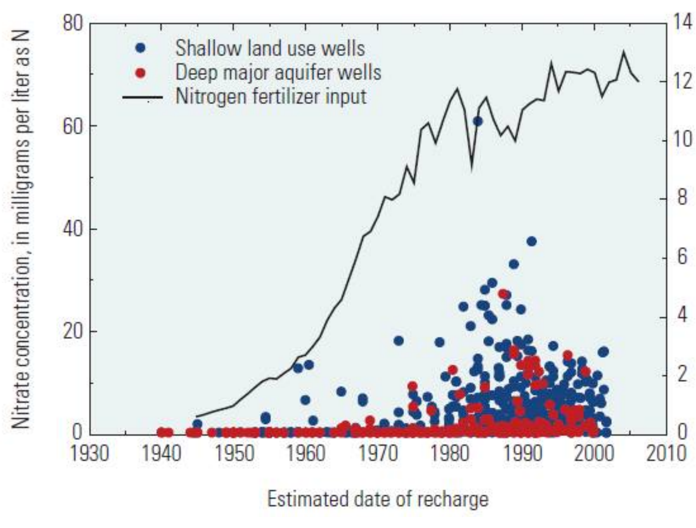

Figure 1: Nitrate concentrations in individual well samples plotted against estimated groundwater recharge date. Nitrate loading at the land surface over the same time interval is also plotted. Nitrate concentrations in shallow groundwater have generally increased in the last 50 years. Although the samples were collected during a narrow range in time between 1994 and 2005, the recharge dates represented by these data span many decades. Figure from Dubrovsky et al. (2010).

regarding the viability of the alternative models (Ye et al., 2008).

One area of current research is aimed at integrating hydraulic, geophysical, geological, chemical, and other sources of information for aquifer characterization (e.g., Rubin and Hubbard, 2005; Hyndman et al., 2007). A challenge in data integration studies, discussed in the context of geophysical data integration by Singha et al. (2007), is accounting for differences in resolution associated with different subsurface characterization techniques. Another challenge is to develop efficient methods for joint inversion of multiple processes in order to avoid imposing artifacts of an independent inversion process on the estimated hydrologic properties and to allow for fuller assessment of the consistency of different data types. Hinnel et al. (2010) discuss these issues in the context of hydrogeophysical joint inversion.

Characterization of heterogeneous flow and transport properties is the overarching topic of the vast majority of current research in hydrogeology. Realistic assessment of the impact of heterogeneity on flow and transport requires 3D modeling, since 2D models consistently underestimate the degree of connectivity present in 3D fields (Fogg, 2010).

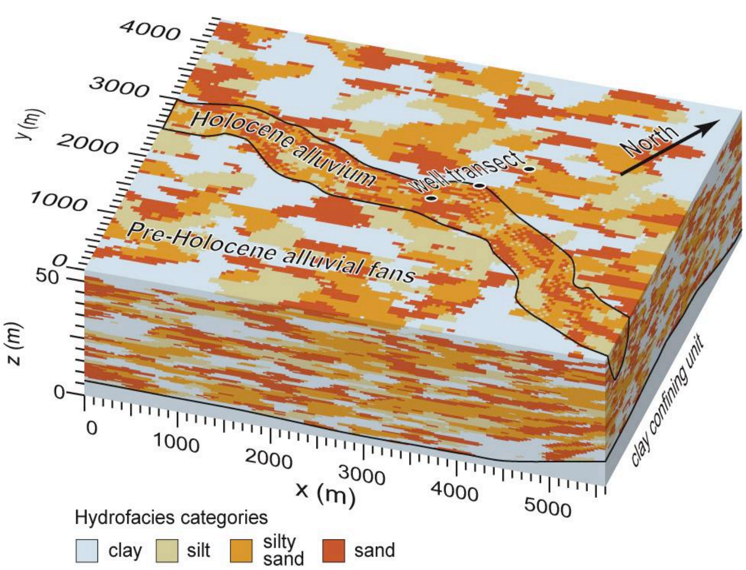

Figure 2: Markov chain realization of the shallow aquifer in the Merced area of the San Joaquin Valley, CA, USA reprinted from Green et al. (2010). Reprinted by permission of the American Geophysical Union.

Sedimentological and lithological variations produced by geologic processes exert primary control on the distributions of flow and transport properties (Bridge and Hyndman, 2004). Some approaches to infusing property fields with more geological realism include stochastic simulation of facies using sequential indicator (Deutsch and Journel, 1998) or Markov chain (Carle and Fogg, 1997) simulation, object-based (geometrical) simulation of facies bodies (Deutsch and Tran, 2002; Ramanathan et al., 2010), and multi-point geostatistics (Strebelle, 2002). An example of a 3D geological realization of geology based on Markov chain simulation is shown in Figure 2. Geological process models perhaps provide the most compelling representations of geological heterogeneity but are difficult to condition on real data (Koltermann and Gorelick, 1996). The multi-point geostatistical approach allows conditional simulation to incorporate information from training images that could be derived from process- or object-based simulation, as well as conceptual geological models developed from expert knowledge.

Research on the connection between groundwater and surface water is experiencing a recent expansion driven by ecological water requirements, climate change, and the need for better quantified water budgets. A number of robust computer models are now available for addressing questions about the hydrologic connection between the vadose zone, surface water and groundwater. In addition, new measurement techniques, such as distributed fiber optic temperature monitoring, are being developed and tested to obtain data to constrain these models. Ongoing research efforts focus on the temperature changes and biogeochemical processes that occur during exchange of water between aquifers and surface water bodies. Cross-disciplinary links for these studies cover quality of aquatic habitat, sources of eutrophication, and the effect of climate change on groundwater and surface water exchange. For example, the U.S. Environmental Protection Agency is developing numeric nutrient criteria for marine waters, which may include non-point source contributions by submarine groundwater discharge.

Only a few of the many topics within the purview of the AGU Groundwater Technical Committee can be covered in this short article. In future newsletter articles, we plan to expand on this highly summarized compendium. These topics may include more comprehensive treatment of groundwater-surface water issues, fracture flow, karst hydrology, coastal hydrogeology, artificial recharge, and groundwater management optimization.

[1]This article was prepared by the authors on behalf of the Groundwater Technical Committee

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Hydrogeophysics: Incorporating geophysical data in the identification and quantification of hydrologic properties and processes

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Quantifying processes that control water movement in the subsurface has been recognized as a "grand challenge" in environmental science (National Research Council, 2001) with far-reaching implications for human health, environmental sustainability, and economic development. Data sensitive to hydrological state variables and properties controlling flow and transport are needed to predict and simulate, among other things, water-resources management, aquifer remediation, well-head protection, ecosystem management, and geologic isolation of radioactive waste. Despite advances in field methods, numerical modeling, and inverse methods, aquifer characterization remains a difficult problem due to spatial heterogeneity, temporal variability, and feedbacks between physical, chemical, and biological processes. Predicting hydrogeologic processes, such as fluid flow or contaminant transport, at field-scales is consequently difficult. Hydrologists increasingly find themselves considering a diverse range of behaviors, data types, and analytical tools to help unravel processes controlling the dynamics of moving water.

Geophysical methods can play an important role in addressing this problem as they can provide minimally invasive, relatively inexpensive, and spatially exhaustive measurements in 3-D, through time, that can depend on parameters and state variables of interest. Geophysical data have been increasingly incorporated into quantitative hydrologic studies in recent years for (1) hydrogeological mapping of subsurface architecture; (2) estimation of subsurface properties and state variables that influence or characterize flow and transport; (3) monitoring of subsurface processes associated with natural or engineered *in situ* perturbations. These data allow us to better understand subsurface processes where limited amounts of classical hydrological data exist, and allow us to better categorize spatial and temporal changes over multiple scales (see, for example, Figure 1). The main limitation is that the geophysical data are only indirectly related to the hydrological properties and state variables of interest; this requires careful calibration of relations between variables and consideration of measurement support volume, among other things, to make these data useful in quantitative hydrological studies. That said, reliable predictions of hydrologic processes depend on our ability to develop numerical models that accurately represent field conditions based on collected data; integrating geophysical data, when done carefully, may reduce the viable set of models and improve estimates of field-scale parameters and processes.

Hydrogeophysics is a relatively new research field that attempts to use geophysical data, in a quantitative way, to understand hydrologic processes and parameters in the subsurface (Rubin and Hubbard, 2005). Hydrogeophysical studies have among other things allowed for better understanding of flow in fractured rock, the transport of contaminants and/or tracers in the subsurface, and changes in water content in soils. Recent successes in hydrogeophysics in the field include quantifying groundwater-surface water exchange (e.g., Slater et al., 2010; Ward et al., 2010), exploring water uptake by plants (e.g. Michot et al., 2003; Jayawickreme et al., 2010), hydrological characterization on the watershed-scale (e.g., Linde et al., 2007), estimating changes in water content (e.g., Kowalsky et al., 2005; Lunt et al., 2005), imaging solute transport in the saturated and vadose zone (e.g., Binley et al., 2002; Kemna et al., 2002), and the development of relations between geophysical and hydrologic parameters of interest (e.g., Moysey et al., 2005). Careful linking of data collection, analysis, rock physics models, and numerical modeling is a pre-requisite for successful studies. Despite recent developments, much work remains to be done with respect to data integration, quantification of model and prediction uncertainty, and understanding the worth of different geophysical data types under different hydrologic conditions and applications.

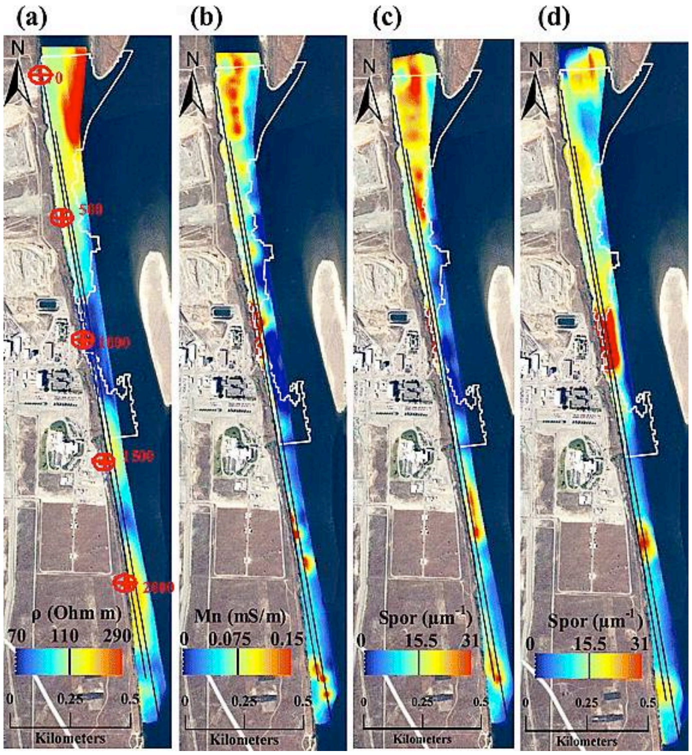

Figure 1: Structural constraints based on geophysical models thought to control uranium transport from the Hanford 300 Area, Washington, to Columbia River. Plan view distribution of electrical properties in the form of (a) electrical resistivity (ρ) and (b) normalized chargeability (M_n) used to estimate surface area normalized to pore volume (S_{por}) for the depths of (c) 7 m and (d) 5 m, respectively. The white line indicates the suggested uranium contributing area from previous studies. The thickness of the permeable Hanford Formation (characterized by low values of (S_{por}) in (c) and (d)) overlying the less permeable Ringold Formation (characterized by high values of (S_{por}) in (c) and (d)) is thought to play a key role in regulating uranium transport to the river. Fiber-optic distributed temperature sensor monitoring confirmed the hydrological relevance of these geophysical results by showing enhanced surface water-groundwater exchange where the estimated thickness of the Hanford Formation was the greatest. From *Slater et al.* (2010), reprinted by permission of the American Geophysical Union.

Joint inversion of geophysical and hydrologic data is an active area of research.

Hydrogeophysics has developed considerably since the nineties by exploring new data and integration types and application areas, but perhaps most significantly by considering the effects of data errors, model prediction errors, the resolution-loss during inversions, and the fact that field-scale rock physics relations are often poorly known. Much work remains to develop and test both deterministic and stochastic data integration or joint inversion frameworks that explicitly consider these effects and incorporate them in the model and prediction uncertainty. We also believe that significant improvements can be obtained by tailoring the data acquisition and modeling to the hydrological objective. This includes development of experimental design procedures that are flexible enough to obtain the most important information about the subsurface needed to resolve the question posed within a predefined uncertainty range and within economic constraints. We must also continue to redefine the parameterization and the objective function of geophysical inverse problems to make them more suitable for hydrological applications. Additionally, continued exploration of the relations between hydrologic and geophysical parameters at the field scale, under time-varying conditions, is needed.

There is still significant room for improvements in finding new and more robust ways to relate geophysical properties to hydrological, geochemical, or geological parameters and/or processes. There is also a largely untapped potential of using natural stimuli, such as changes in stream height, for larger-scale time-lapse experiments through long-term monitoring. Together with this comes the need to develop methods to remove unwanted contributions to the geophysical signal (e.g., temperature effects) prior to integrating the data with other data sources or inverting the geophysical data. Scale effects have largely been ignored in hydrogeophysics despite the fact that hydrological processes, properties, and petrophysical models all vary as a function of scale. Additionally, different methods are known to have different support scales.

There are many research directions that interest the AGU hydrogeophysics community, and we have just highlighted a few here. Significant challenges remain, and the inputs of both hydrologists and geophysicists, along with scientists from other fields, are needed so that hydrogeophysics continues to evolve dynamically. The AGU Hydrogeophysics Committee is committed to continue playing an active role in the development of this discipline, in integrating it with other fields, and in expanding the range of topics covered in future AGU sessions.

[1]This article was prepared by the authors on behalf of the Hydrogeophysics Technical Committee.

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Large-scale field experiments in hydrology: What have we learned and where do we go from here? [1]

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Since the Kansas experiments in micrometeorology in the late 1960s that shaped the fundamentals of micrometeorology (e.g. confirming Monin-Obukhov scaling among other findings (Businger et al., 1971)), there have been many large-scale field experiments that have included aspects of surface hydrology. These include for example, the Hydrological-Atmospheric Pilot Experiment- Modélisation du Bilan Hydrique (HAPEX-MOBILHY; Andre et al., 1986), FIFE (Sellers et al., 1992), HAPEX-Sahel (Goutourbe, et al., 1994), Boreal Ecosystem-Atmosphere Study (BOREAS; Sellers et al. 1995), Southern Great Plains 1997 Experiment (SGP97; Jackson et al., 1999), Semi-Arid Land Surface-Atmosphere Program (SALSA; Goodrich et al., 1998), Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA; Avissar and Nobre, 2002), Cold Land Processes Experiment (CLPX; Cline et al., 2003), Soil Moisture Experiment 2002 (SMEX02; Bindlish et al., 2006), among many others. The stated goals of many of these experiments are similar, and typically include some combination of: i) improve process understanding, representation, and modeling of surface/subsurface hydrologic processes and land-atmosphere interactions and their interactions with ecosystems; and ii) improve the understanding of the scaling of these processes in order to incorporate new data sources (i.e. remote sensing) via retrieval or data assimilation algorithms. These and other experiments have examined diverse scaling problems, and mass/energy exchange across various ecosystems and climates ranging from the Boreal zone to the Tropics and from humid to arid systems. The characterization of vegetation composition and classes of land-surface heterogeneities are also well represented in these studies. In addition to these focused field experiments, other on-going 'long-term' monitoring initiatives have proliferated under networks and programs such as FluxNet, NSF Critical Zone Observatory (CZO), Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUASHI) and other initiatives.

While these individual experiments have produced rich data sets and a myriad of publications that have advanced the field of hydrologic science, it is often the case that we have moved perhaps too quickly from one field campaign to the next. We believe that the time is ripe for a synthesis of what we have learned from these experiments, including which common problems have been solved, which ones remain open, and how to plan future experiments that will bridge the remaining gaps.

The AGU Large-Scale Field Experimentation Technical Committee has recently been rejuvenated with new membership. The overarching goal of the committee is to catalyze the design and execution of new large-scale experiments and to enhance the representation of hydrological processes in ongoing experiments in related fields (ecology, atmospheric sciences, etc). These experiments also necessarily have strong links to cross-cutting topics like remote sensing and ecohydrology, and we hope to bridge stronger links and co-sponsored activities with those and other relevant Technical Committees.

The first meeting of the newly formed membership will take place in just a few weeks at the Fall AGU meeting (see schedule of Technical Committee meetings elsewhere in this newsletter). This meeting is open to all interested participants. Our initial goals are to create an AGU-hosted Web portal with links to the myriad of previous large-scale field experiments, as well as ongoing and future experiments, that will facilitate the synthesis of these datasets and findings. It is our hope that such activities will spur new sessions at AGU meetings, and we will also undertake planning of a Chapman conference that will initiate the synthesis evaluation, which was argued for above. We also plan for the committee to undertake writing of one or more review/synthesis papers and/or organization of special issues in AGU journals.

Figure 1: A joint experiment featuring several sensing systems (SODAR, LIDAR, EC, radio and tethered sondes) near Boulder, Colorado (2001). The aim of the experiment was to intercompare atmospheric profiling systems and their application to the study of land-atmosphere fluxes and the surface energy budget over flat, homogeneous terrain.

[1]This article was prepared by the authors on behalf of the Large-Scale Field Experimentation Technical Commitee.

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Outlook for high-resolution precipitation measurements for hydrologic applications[1]

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Precipitation is the primary driver of the land surface branch of the hydrologic cycle and is a key variable in physical models that have purposes that range from real-time flash flood forecasting to prediction of land-atmosphere fluxes in regional and global weather and climate models. In theory, due to the intermittent and dynamic nature of precipitation, it should be observed at the highest possible space-time resolution to provide useful information for accurate modeling of highly variable hydrologic systems and processes. However, maintaining high accuracy in precipitation estimates, quantifying their uncertainty, and accurately capturing their temporal and spatial distribution are among many of the challenging research topics in our community. We outline in this short article some issues and trends in precipitation observations.

Precipitation measurement methods

There are two main techniques for precipitation measurement: (1) surface-based (rain gauge and weather radar) methods and (2) space-based methods. Measurement of rainfall by rain gauges is conceptually simple, direct, and has been the primary source of climatological rainfall records. Although rain gauges provide reliable point measurements, they suffer from poor spatial coverage and lack areal representation over land, which is particularly problematic for intense rainfall with high spatial variability. With the advent of surface weather radar networks, unprecedented capability to account for high temporal and spatial variability of rainfall systems at regional and national scale became available (e.g., the NEXRAD Stage IV rainfall product in the U.S. since 1994). Recently, the National Mosaic and Quantitative Precipitation Estimation (QPE) system (NMQ/Q2) (Zhang et al., 2009; http://nmq.ou.edu) has been developed at the NOAA/National Severe Storms Laboratory and the University of Oklahoma. The NMQ/Q2 system combines information from all ground-based radars comprising the NEXRAD network (in addition to FAA, Canadian, and gap-filling research radars), mosaics all reflectivity data onto a common 3D grid, estimates surface rainfall accumulations and types, and blends the estimates with collocated rain gauge networks to arrive at accurate, ground-based estimates of rainfall. The uniqueness of the Q2 system lies in its high spatial resolution at 1-km^2 and high frequency of QPE product generation at 2.5 minutes on the national scale. The polarimetric upgrade to the NEXRAD network, presently underway, and the expansion of gap-filling X-band radar networks will continuously improve the network's accuracy and spatial coverage.

The rising popularity of high-resolution spatially distributed hydrologic, global land-surface, and storm-scale atmospheric models have contributed to the increasing demands of the hydrologic community for accurate, frequent, consistent, and high-resolution precipitation data from local to global scales. The coverage limitations of rain gauges and ground-based weather radar systems (e.g., lack of information over the oceans, remote areas, and mountainous regions) highlight the importance of satellite-based global precipitation estimates for use in hydrology and water resources studies (e.g., Maddox et al., 2002). Space-borne precipitation retrieval techniques have shown improved effectiveness in recent years in providing worldwide access of near-real-time data without being hampered by the effects of political borders that are often associated with ground-based data. A number of operational, quasi-global satellite precipitation datasets have become available for hydrologic applications at 1 to 3-hr frequency and 4 to 25-km resolutions (e.g., TMPA, Huffman et al., 2007; CMORPH, Joyce et al., 2004; PERSIANN, Sorooshian et al., 2000 and Hong et al., 2004). Multi-spectral (Behrangi et al., 2009) and multi-satellite precipitation retrieval techniques still need to be investigated in order to improve the accuracy and resolution of global precipitation estimates, as anticipated from the Global Precipitation Measurement (GPM) constellation mission (Hou et al., 2008; http://gpm.gsfc.nasa.gov). During the GPM mission, global coverage of satellite-based precipitation products is expected to increase significantly with over 90% of the globe to be sampled every three hours or less. In the meantime, new techniques are being developed to improve the time/space resolution, quantitative accuracy and long-term homogeneity of the precipitation data sets through combining integrated satellite estimates (e.g. CMORPH) with gauge observations and ground-based radar estimates (Xie et al., 2010).

Uncertainty quantification for hydrologic applications

Hydrologic validation of remote-sensing precipitation products is another important line of research that in our view should be pursued more rigorously in parallel with ongoing development of advanced instruments and precipitation algorithms. The international precipitation working group (IPWG; see http://www.isac.cnr.it/~ipwg/) has established a program for continental-scale validation of daily rainfall estimates that is being applied to almost all global real-time operational satellite products. This program uses rain gauges and radars in data-rich parts of the world (e.g. USA, Australia, northwestern Europe). Although products from the Tropical Rainfall Monitoring Mission (TRMM) have made inroads into the operational hurricane tracking community, satellite-based precipitation products have yet to become well integrated by the operational hydrology and water resources engineering communities. The main reason for slow adoption in operational hydrology can be traced mostly to the lack of information about uncertainties associated with satellite precipitation estimates, and the potential for uncertainties to cascade nonlinearly in simulations of hydrologic processes (e.g., Nijssen and Lettenmaier, 2004). Runoff is highly sensitive to spatial and temporal variations in precipitation. As a result, satellite precipitation validation approaches may need to explicitly quantify uncertainties of the products and their variations over different space-time scales, storm systems, and hydroclimatic regimes (see e.g. Krajewski et al., 2006; and Hong et al., 2006 among many others).

Opportunities and Challenges

We believe that the use of precipitation products derived from sources other than gauges (surface radars and satellite products) is critical to improving operational hydrological predictions and to understanding hydrological processes. In our view, however, progress is being retarded by the need for increased space-time resolution, improved accuracy, and better quantification of uncertainty estimation in these products. Precipitation is the primary factor affecting the timing and stage of river discharge, especially for high-impact events such as flash

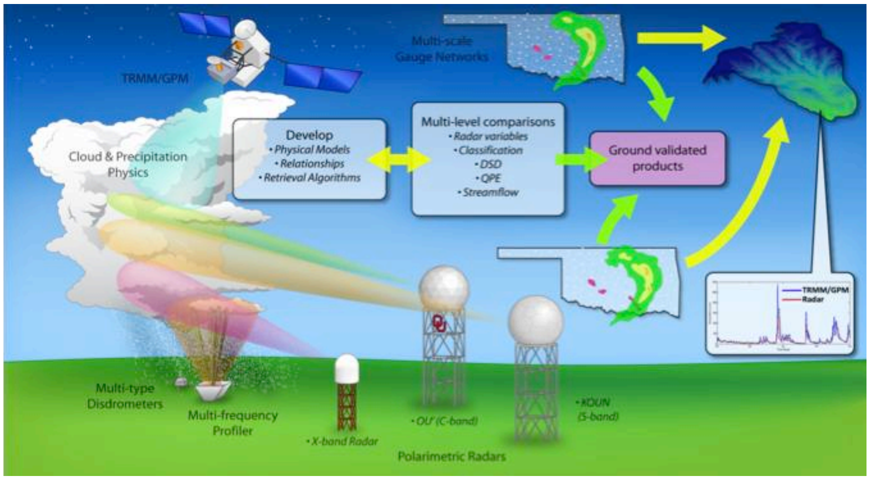

Figure 1: Schematic of multi-sensor synergistic precipitation retrieval and hydrologic application. (Source: http://arrc.ou.edu).

floods. Ultimately, a suite of coordinated precipitation observational networks that include ground-based precipitation gauges and radar, space-borne satellite platforms (e.g., Figure 1), and where needed, atmospheric model forecasts, is required for hydrologic applications that scale from small catchments to continental river basins to the global water cycle. Data should be quality controlled automatically to the extent possible, with human intervention as a final step whenever feasible. Simple but meaningful characterizations of the statistical distributions and space-time dependencies of precipitation estimation errors should be available to users at all levels. Toward this goal, there are a number of opportunities that require the development of advanced concepts to address key challenges in this integrated, multi-sensor, multi-source precipitation estimation framework:

- New observational techniques. These include: 1) development of telecommunication microwave links that have the potential to provide data at the temporal and spatial resolutions that are necessary to capture rainfall dynamics (Berne and Uijlenhoet, 2007); 2) smaller (X- or C-band) polarimetric radar networks that have the potential to fill the current S-band network coverage gaps; and 3) the development of multi-frequency, dual-polarization, and phased-array space and ground radars that will greatly improve QPE's accuracy and spatiotemporal resolutions.
- More attention to multi-spectral, multi-platform satellite and ground dual-polarization radar precipitation retrieval techniques. This will enhance the ability to obtain the best possible estimation of precipitation with the highest resolution at national and global scales. Currently, comparisons of very high-resolution rainfall estimates from space and ground observations show large discrepancies, and rain rate distribution comparisons from these estimates reveal a large shift in the peak distribution that is critical for many hydrological applications (e.g., Amitai et al., 2009). Resolving these discrepancies between the space and the ground based estimates presents an important set of challenges that constrain improvements in remote-sensing estimates of precipitation.
- Gauge-adjusted radar estimates of rainfall, when merged with satellite estimates, could provide the observational basis for learning how small-scale extreme events are connected with the large-scale atmospheric circulation and how this connectivity changes in time and space. Efforts to investigate the near-real-time bias adjustment and integration of heterogeneous space-borne and ground-based precipitation estimates are only beginning.
- Development of validation and uncertainty analysis metrics of precipitation for hydrologic applications. Errors/uncertainty from individual sensors and sources should be identified in order to reduce the uncertainty in merged precipitation products. Identification of uncertainties and their propagation into combined products and ensemble hydrological modeling is vital for future developments. Furthermore, transferability of the validation studies and test cases to basins with different scales, physical characteristics, and hydroclimatic regimes should be considered for future research.
- To date, realistic schemes for transitioning precipitation products from the research community to operational hydrologic predictions applications remain a work in progress. There is

a gap between the research community and operational personnel in their preferences and needs; greater efforts need to be made to bridging this gap. Several heavily instrumented hydrometeorological testbeds (see e.g., http://hmt.noaa.gov/) are extremely important in transitioning information from research to operations in this area.

- Coupling land surface information and multi-sensor precipitation estimates can provide critical information about floods and landslides. TRMM scientists have developed a prototype flood and landslide alert system (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html) that merges hydrologic models, soil type, slope stability and QPE/QPF. These types of coupled and integrated datasets need to be developed for other applications, such as linking droughts to famine and health.
- Data assimilation methods in hydrologic prediction are lacking in decision-making settings. This is mainly due to the difficulties caused by the deficiencies in hydrologic model structures that are amenable to the types of observations that are available, and also to the lack of research on reliable data assimilation techniques. More research needs to be devoted to integrating data assimilation techniques as a part of the multi-sensor precipitation retrieval algorithm development and also the operational hydrologic ensemble predictions, such as streamflow forecasting with quantified data uncertainty propagation.
- Models that utilize high-resolution precipitation as forcing (e.g., land surface models and rainfall-runoff models) often require a long, consistent data record to estimate parameters and warm up the model states. Instruments and algorithms to estimate precipitation are updated frequently and can result in precipitation error characteristics that change over time. Efforts should be focused on precipitation reanalysis for periods ~10 yrs, and bias correction on historical remote-sensing data to yield consistent datasets.

[1]This article was prepared by the authors on behalf of the Precipitation Technical Committee.

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Unsaturated zone hydrology and multiphase flow and transport: Current challenges and opportunities[1]

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Multi-phase fluid flow through porous media is fundamental to a broad range of topics that include both environmental and industrial processes. The hydrology community's interest in multiphase flow has historically been focused upon the unsaturated (or vadose) zone - the region of the subsurface that lies between the ground surface and the water table. This region provides the link between groundwater and surface/atmospheric water and is thus of fundamental importance to understanding water fluxes and storage within the hydrosphere. During the last three decades, hydrologists have become interested in other examples of multi-phase fluid flow in the subsurface such as the migration of organic solvents, which are persistent contaminants in groundwater at thousands of sites worldwide. These problems tend to be more complex (e.g. three-phase flows) than the air-water system encountered in the unsaturated zone. Though it has been more than a century since Buckingham (1907) first introduced a theory for the movement of moisture through partially saturated porous media, persistent challenges to our understanding of multiphase flow processes in porous and fractured media remain, and new challenges continue to emerge. Persistent challenges are a result of the inherent complexity of multiphase flows, where, in addition to problems encountered in saturated flows (e.g., multi-scale heterogeneity), the interactions of two or more fluid phases must be considered and, ideally, quantitatively described at the continuum scale. New challenges emerge largely from evolving human activity. Two recent examples include: 1) the rapid growth of the nanotechnology industry, which provides both opportunities for new remediation technologies and potential environmental concerns; and 2) efforts to use geologic CO_2 sequestration as a possible tool for mitigating greenhouse gas emissions. We summarize below these two active research areas and discuss related research challenges.

Nanotechnology

Nanotechnology is an emerging industry throughout the world which has derived from the great promise that engineered nanoparticles hold across a range of applications. The unique properties of engineered nanoparticles (ENPs) have led to their application in a wide variety of industries (e.g., composite materials, drug delivery, optical sensors). In the environmental community, there is concern related to human health and ecological consequences after dispersal of nanomaterials to the environment, as some ENPs can have detrimental environmental impacts. Many regulatory bodies are actively investigating ENP risks and considering amending their policies and regulations surrounding their disposal. On the other hand, there is also tremendous excitement in the environmental community surrounding the application of ENPs for remediation of contaminated sites. For example nanoscale zero valent iron particles (nZVI) have significant potential for the rapid degradation of in-situ free phase chlorinated solvent contamination. One challenge prior to the widespread application of nZVI for site remediation is its poor mobility in porous media, which can hinder its delivery to the contaminated source zone. As such, the mobility of ENPs is the focus of research from both a risk assessment perspective and a contaminated-site remediation perspective. Unfortunately, there is currently a lack of basic scientific understanding of both unsaturated and saturated transport of ENPs in the subsurface. While the colloid transport literature can serve as a starting point in our understanding of ENP transport behavior, many researchers have found that colloid transport theories are not directly applicable to ENP transport without modification. Because of the possibility of additional retention mechanisms, the unsaturated zone has the potential to influence the environmental mobility of ENPs, so comprehensive risk assessment will require a quantitative understanding of fate and transport of ENPs in both the unsaturated and saturated zones. As such, considerable efforts are now focusing on improving our understanding of the factors that control subsurface ENP transport in both unsaturated and saturated porous media. As an example, the *Journal of Contaminant Hydrology* has put together a special issue entitled *Manufactured Nanomaterials in Subsurface Systems* (Kibbey and O'Carroll, 2010). The special issue contains contributions examining both the beneficial environmental uses of ENPs and potential environmental risks, with papers examining both saturated and unsaturated ENP behavior. There is a need to continue to improve our understanding of ENP transport to complete risk assessments and develop nanoparticles for remediation of contaminated sites.

Geologic CO_2 sequestration

Geologic CO_2 sequestration is a promising carbon capture and storage (CCS) approach aimed at minimizing the climate impact of emissions from fossil-fuel-burning power plants. Effective deployment will require the annual injection of gigatons of CO_2 worldwide into depleted oil and gas reservoirs and deep brine aquifers (e.g., Haszeldine, 2009). Even slow leakage of injected CO_2 may reduce the long-term effectiveness of sequestration as a means to reduce warming (e.g., Shaffer, 2010). Thus, it is critical that we incorporate a robust understanding of the physical and chemical mechanisms that control the long-term fate of CO_2 in the subsurface into our predictive models. Effective geologic sequestration of CO_2 relies upon four primary trapping mechanisms (e.g., IPCC, 2005): i) structural trapping, where the geometry and integrity of low permeability layers help to trap the buoyant CO_2; ii) capillary forces trapping residual CO_2 as the injection-induced pressure perturbation diffuses; iii) solubility trapping results from dissolution of the CO_2 into the resident fluids; and iv) in certain formations mineral reactions will lead to trapping in carbon-bearing minerals. Formations targeted as good candidates for long-term CO_2 storage are typically at depths greater than 800 m. While these depths involve pore pressures that are sufficient to significantly increase CO_2 density, which is necessary to store large volumes of CO_2, they pose significant characterization and monitoring challenges. Thus, models that effectively represent the migration, trapping and

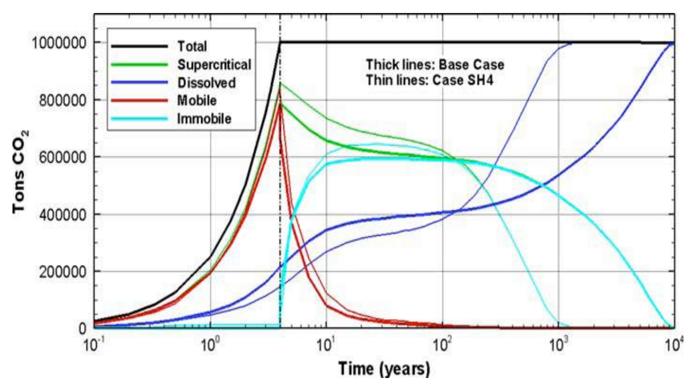

Figure 1: Results from a simulation of injection of 1 million metric tons of supercritical CO_2 over a 4-year period into a 2-km deep sand formation in the Southern San Joaquin Valley. The results (from Doughty (2010)) highlight the relative importance of different trapping mechanisms over a 10000-year post-injection period. Early on, most of the injected CO_2 remains as a separate supercritical phase (green), some of which is mobile and continues to migrate through the formation (red) and the remainder is immobile due to capillary trapping (cyan). Over time, an increasing amount of CO_2 dissolves into the resident brine (blue) until at ~1000-10000 years, all CO_2 is dissolved. Though trapping resulting from precipitation of carbon-bearing minerals may also play a role, particularly at later times, this process was not included in this recent study. Figure reprinted courtesy of Springer under the terms of its Creative Commons Attribution Noncommercial License.

dissolution of CO_2 in aquifers and reservoirs at elevated pressures (typically >80 bar) and temperatures (>30°C), where CO_2 exists as a supercritical phase, are necessary to effectively quantify uncertainty in the long-term fate of injected CO_2. While much insight can be gained about the relative importance of different trapping mechanisms using existing multiphase flow simulators (Figure 1), quantitative estimates of the potential for leakage will require coupling multiphase flow and transport models with models that predict injection-induced stress changes (e.g., Morris et al, 2010). Including the potential for fracturing or fault activation, as well as processes that may compromise the integrity of existing wellbores, is a fundamental challenge to estimating potential rates of long-term CO_2 leakage. Development of such coupled models in conjunction with ongoing and planned pilot studies and larger scale field deployments is necessary to establish the long term viability of geologic CO_2 sequestration as an effective means for mitigating climate change.

We conclude by noting that the same multiphase flow processes related to CO_2 sequestration and nanotechnology applications in the subsurface play important roles in a range of industrial processes. Examples include, fuel cell operation, pulp dewatering, and biomedical applications of microfluidic devices – all areas that have experienced significant recent advances. Because the fundamental processes involved with these various environmental and industrial problems are often closely related, exchange of ideas and methods between these often quite different groups of scientists can be beneficial to advancing our collective understanding of important multi-phase flow processes. The recently established International Society of Porous Media (www.interpore.org) aims to foster such connections between industrial and academic researchers working on the wide range of topics that involve flow through porous media.

[1] This article was prepared by the authors on behalf of the Unsaturated Zone Technical Committee.

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Water quality: New approaches to solving old and new problems[1]

Thomas Bullen (U.S. Geological Survey) and Irena Creed (Western Ontario University)

Water quality affects everyone, and everyone should be concerned about trends in water quality globally. Once viewed as inexhaustible, supplies of high-quality fresh water for drinking, as well as domestic, agricultural and industrial purposes, are increasingly under pressure due to numerous anthropogenic influences. For example, over-abstraction of groundwater from aquifers can lead to changes in cross-aquifer communication. Reserves of high quality water in one aquifer can become contaminated by poor quality water from underlying and overlying aquifers that may be more prone to natural and anthropogenic contamination (Takizawa, 2008). Such changes in hydrology can lead to parallel changes in biological and geochemical processes within the aquifers, causing the release of geogenic contaminants such as arsenic into water (e.g., Polizzotto et al., 2008). And to top things off, potentially toxic chemical compounds of largely pharmaceutical and industrial origin have been increasingly introduced into the aquatic environment via waste water discharge and atmospheric pathways (e.g., Kolpin et al. 2002; Siegel, 2002). It is becoming more and more difficult to identify water bodies that remain pristine and have not been affected in some manner by anthropogenically caused or influenced contamination.

Notable examples of globally important contaminants that continue to be of concern include nitrate, monomethyl mercury, arsenic, transition metals such as chromium, and the broad group of organic endocrine disrupters. The challenge for scientists is to determine the origin of these contaminants and to identify processes that can detoxify them in the environment. For example, nitrate can come from a variety of sources such as fertilizer, manure, municipal waste and the atmosphere. Nitrate can be toxic when found in high concentrations in surface water or groundwater. Nitrate can be detoxified through the process of denitrification, a series of enzymatic reactions in which N-O bonds are progressively broken, leading to the production of N_2 gas as the end product. Although the commonly recognized denitrification processes involve heterotrophic bacteria that use organic matter as the electron donor (Knowles, 1982), recent work has demonstrated that nitrate can be denitrified by autotrophic bacteria in aquifers when coupled to oxidation of reduced minerals such as pyrite (Torrentó et al., 2010). Dissolved hexavalent chromium, which can be highly toxic, comes largely from industrial spills and potentially through airborne (dust) pathways. Hexavalent chromium can be detoxified through chemical reduction to trivalent chromium, either inorganically or through microbial mediation using organic matter or a reduced reactive metal such as ferrous iron as the electron donor (Ellis et al., 2002; Sikora et al., 2008). A variety of chemical and isotopic characterization tools have been developed that aid scientists in determining both the sources of and processes that affect nitrate, hexavalent chromium and other inorganic and organic environmental contaminants. The most powerful of these tools are multi-isotope approaches that analyze, for example, the oxygen and nitrogen isotope compositions of the nitrate molecule, the oxygen and chromium isotope compositions of the chromate molecule, or the carbon, hydrogen and oxygen isotope compositions of organic molecules as unique source and process fingerprints.

As pointed out by Westcot (1997) (see Figure 1), there are substances that impair water quality that have been around for a long time, for which we have a solid knowledge base in part because the substances are relatively simple, easy and cheap to measure, and their fate in water is easy to track (e.g., salinity, nitrate). However, societies continue to evolve, creating ever more complex substances (e.g., toxic trace elements, pesticides), without the knowledge or understanding of the potential consequences to our water supplies. Thus the challenges are equally great for water quality managers, who need to develop the means to monitor and perhaps stimulate processes, such as denitrification and reduction of chromate and arsenate in aquifers, but often do not have access to tools and techniques available that are only now being developed.

While it might be relatively straightforward to

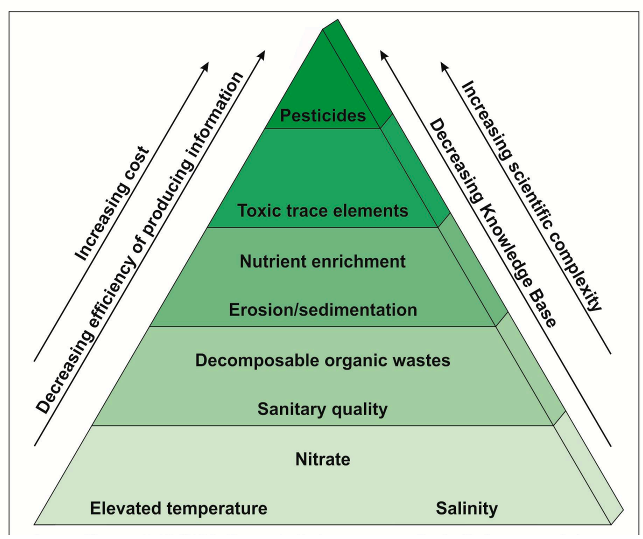

Figure 1: Conceptual relationship of knowledge base, scientific complexity, and cost of measurement for different classes of water quality constituents. From Westcot (1997).

identify suitable chemical reductants or microbial cocktails that could be effective for contaminant remediation at the large scale, the trick is to disperse them sufficiently through the contaminated aquifer to maximize detoxification. An intriguing approach to detoxifying aquifers contaminated with hexavalent chromium is currently being attempted at the site in southeastern California made famous in the movie *Erin Brockovich*. At this site, engineers working with the local water management district will inject organic compounds such as ethanol and vegetable oil into the aquifer in order to stimulate reduction of the hexavalent chromium contaminant to non-toxic trivalent chromium (Lahontan Regional Water Quality Control Board, 2010). A healthy population of chromium reducing microbes is likely to flourish under these conditions, and there is every reason to believe that reduction of hexavalent chromium will be effectively achieved. One potential problem with this approach may be that once the stores of hexavalent chromium have been exhausted, a new population of opportunistic chromium oxidizing microbes could invade the aquifer and work to reverse the process. Thus, even if remediation of the aquifer is effective, water quality managers must remain vigilant in assuring that the new chemical and biological condition persists. One might envision a robust new science of "post remediation aquifer maintenance" developing in response to the pressing need to clean up the results of the numerous environmental disasters that have impacted so many aquifers over the past several decades.

Although contaminant remediation is clearly of utmost importance, on a scientific basis we need to better understand how water evolves at water sources, and how it interacts with the environment. Frontier research areas aimed at improving our understanding of water quality patterns and trends are numerous. The importance of hydrological processes in determining water quality has been recognized by the emergence of several hybrid disciplines. For example, "hydropedology" is a new research area that focuses on understanding how soils develop in watersheds in response to factors such as topography, structure of the geologic substrate and precipitation patterns, and how the quality of water discharging to streams from those soils develops as a function of water flow paths, water retention times and biogeochemical reactions. "Hydroecology" (or ecohydrology) is a truly inter-disciplinary effort that seeks to understand how ecosystems and hydrology influence each other at a variety of scales. "Hydroepidemiology" is a challenging new field in which efforts are made to link disease clustering and vectoring to hydrologic phenomena such as rainfall distribution, humidity and contaminant transport. Some novel research areas have yet to be formally named but are nonetheless causing a stir. For example, the study of nanomaterials, in terms of both their biochemical impact on water quality and their potential to be used for contaminant remediation strategies, is a rapidly expanding inter-disciplinary research thrust with huge societal implications. Finally, sediment transport is an under-appreciated factor influencing water quality, one that may have increasingly important consequences considering the ability of sediment to move contaminants long distances in the adsorbed fraction. Sediment transport via atmospheric and hydrologic pathways to surface water, and potentially to groundwater, is becoming a topic of serious concern for water quality, particularly in areas vulnerable to intensive urban development and climate change (e.g., in developing countries).

At this year's AGU Fall Meeting in San Francisco (December 13-18), there will be several sessions devoted to providing new insights into these and other important issues related to water quality. The sheer number of sessions related to water quality issues underscores the importance of this increasingly inter-disciplinary field.

Monday: "Hydroepidemiology: Understanding connections between hydrology and human health" (H11D, H14D) and "Water security and sustainability" (H11I, H14F);

Tuesday: "Groundwater/surface water interactions: Dynamics and patterns across spatial and temporal scales" (H21B, continues on Wednesday H31J, H32C, H33J), "Groundwater/surface water interactions: Linking physical and biogeochemical processes in modeling and management frameworks" (H21C, H24C) and "Large regional aquifers: A precious resource at risk" (H21L, H23D);

Wednesday: "Ecohydrology of groundwater-dependent ecosystems" (H31A, H33H), "Groundwater inputs to rivers, lakes and oceans" (H31C, H33I), "Groundwater/surface water interactions: Stream tracers and techniques" (H31D, H34A);

Thursday: "Behavior and remediation of deep vadose zone contaminants" (H41A, continues on Friday H51H), "Microscale information needed in reactive transport models?" (H41D, H44A), "Nutrient sources and cycling in aquatic systems" (H41E, continues on Friday H52D), "The future of arsenic: Emerging threats and scalable solutions" (H41H), "Coastal hydrogeology: Physical, chemical and biological characterization of variable-density systems" (H42A, H43A), "Transport of particles and biocolloids in surface waters and groundwaters: From sediment-sized particles to nanoparticles, emerging contaminants and microorganisms" (H42C, H43K, H44D, continues on Friday H51F).

Friday: "Climate forcing of surface and subsurface hydrology and biogeochemistry: Processes, models and management" (H51A, H53G, H54A), "Isotopic and chemical approaches in watershed/ecosystem interactions" (H51B, H54B), "Mixing and reactive transport: From pore to field scale" (H51C, H53I, H54C), "New challenges for ecohydrology and water quality investigations at the watershed scale" (H51D, H53J), "Agroecosystems and water resources" (H51G), "Emerging topics in interdisciplinary hydrology: Biogeochemistry, ecology and geomorphology" (H51J, H52B, H53B) and "Water quality of hydrologic systems posters" (H53F).

[1]This article was prepared by the authors on behalf of the Water Quality Technical Committee

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From the CUAHSI Director: CUAHSI Announces Release of HydroDesktop v 1.1

Richard H.Hooper (Executive Director, Consortium of Universities for the Advancement of Hydrologic Science)

CUAHSI, the Consortium of Universities for the Advancement of Hydrologic Science, Inc., is a consortium of 136 universities and research institutes in the U.S. and 9 other countries. CUAHSI has been funded by the U.S. National Science Foundation to design and to develop infrastructure to support research by the hydrologic science and broader environmental science community. One of these projects is the Hydrologic Information Systems (HIS), led by David Maidment (University of Texas) with co-investigators Ilya Zaslavsky (San Diego Supercomputing Center), David Tarboton (Utah State), Dan Ames (Idaho State), Jon Goodall (University of South Carolina), and Michael Piasecki (Drexel University). The HIS project has the objectives of improving access to the vast data holdings of governments and universities relevant to hydrologic science for the academic research community, supporting regional observatories, improving the informatics basis of hydrologic science, and supporting education through better data access.

A culmination of this 6-year effort has been the release of HydroDesktop (Figure 1), an open-source client for HIS. HydroDesktop combines an open-source GIS (Dot Spatial) and a data base to manage time series. Data can be found through a keyword search of the measured property for physical, chemical, or biological parameters. An underlying ontology harmonizes the naming conventions of the different data publishers. The user also specifies a spatial domain (in the US, this can be a county, state, or 8-digit Hydrologic Unit Code) and time range for the data retrieval. HydroDesktop then searches a central catalog of metadata that currently has more than 60 different services registered from universities and government agencies at regional, state, and federal levels, representing 15,000 variables, 1.8 million sites, 9 million time series and billions of data values. The user chooses which of the data series are to be downloaded, which are then brought into a local database for export or further analysis in a uniform format, regardless of the data source. Although most data currently are from the US, some international data are available in HIS currently from airports around the world. CUAHSI encourages all government and academic institutions to publish their data using HIS, including those outside the US, and has support services to assist universities in data publication.

HydroDesktop is extensible through its plug-in

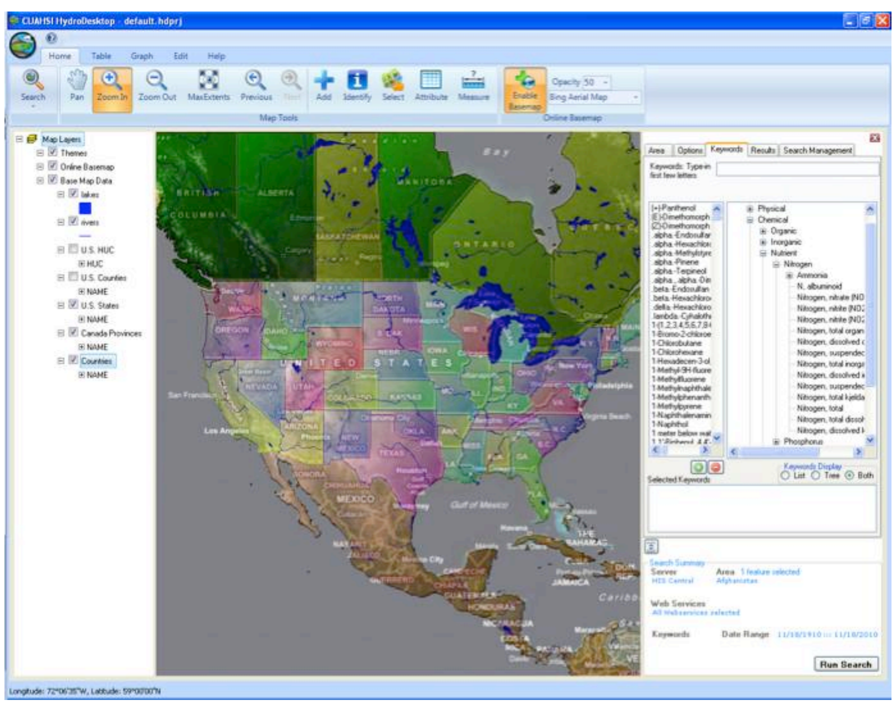

Figure 1: Screen shot showing the HydroDesktop user interface. A hierarchical keyword search (right) enables users to navigate to the data of interest.

architecture. In addition to graphing and tabling functions, an R plug-in allows access to the entire R analysis package. Additional plug-ins include a workflow management palate using the OpenMI standard, metadata fetchers, and watershed delineation tools. Further contributions are encouraged to this open-source project. Visit the developer's forum at http://www.hydrodesktop.org,

HydroDesktop may be downloaded free of charge at http://his.cuahsi.org/hydrodesktop.html. Currently, the software runs only under the Windows operating system, but a Mac-compatible version will be released shortly. Demonstrations of HydroDesktop will be performed at the CUAHSI Booth during the Fall AGU meeting in San Francisco in December. A video demo is available on-line at http://his.cuahsi.org/movies/JacobsWellSpring/JacobsWellSpring.html.

University scientists are encouraged to publish their data through HIS, which meets the new NSF requirements for data release. For more information, please consult the HIS web page at http://his.cuahsi.org/ or contact Rick Hooper at CUAHSI (rhooper@cuahsi.org).

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Jazmin E. Aravena	Department of Civil & Environmental Engineering, University of Nevada, Reno, NV, United States
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Aditi Bhaskar	Civil and Environmental Engineering and Center for Urban Environmental Research and Education, University of Maryland, Baltimore County, Baltimore, MD, United States
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