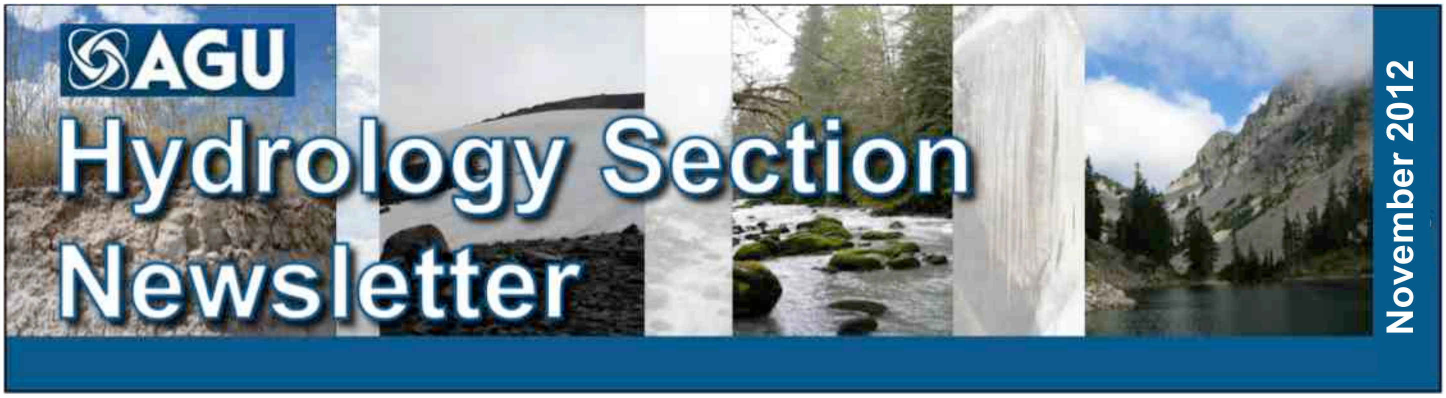
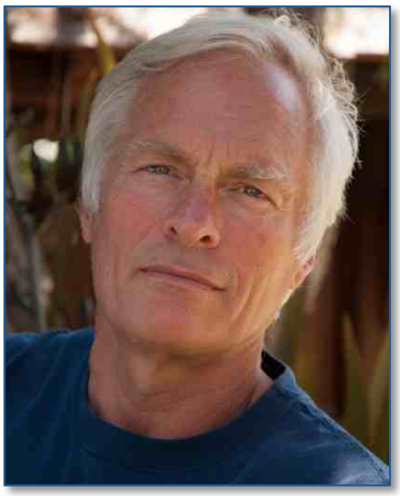


From the Section President

Dennis Lettenmaier (University of Washington)

I want to take this opportunity to congratulate our new Section officers, President-Elect Efi Foufoula-Georgiou and Section Secretary Terri Hogue. Both Efi and Terri take office on January 1. Efi will serve for two years as the President-Elect and then two years as President, while Terri will serve a two-year term. Also on January 1, Eric Wood will become the Section President, and I will step down.



As the end of my term draws near, there are many Section members that I'd like to thank – unfortunately far too many to list. Certainly though, the other two members of the Section's leadership team, Secretary Martha Conklin and President-Elect Eric Wood, merit special mention. Eric has chaired the Section's fellows committee for the last two years. This is a job that requires a great deal of attention to detail and a broad understanding of hydrologic science. Elsewhere in this newsletter, six of the nine new Fellows from the Section have written "The Fellows Speak" articles (articles by the other three Class of 2012 Fellows appeared in the July newsletter). The fact that the number of new Fellows from the Section has fairly consistently exceeded the Section's allocation speaks both to the care that nominators and supporters have taken in assembling the nominations packages, and the supporting information that Eric and his committee assembled and forwarded to the Union Committee. For her part, Martha has worked very hard to improve the Outstanding Student Paper Award (OSPA) process. Over the last three years, there have been continuing improvements made at the Union level (many of them the result of recommendations made by Martha and her committee) in the OSPA process. Some of you are participating in the OSPA process as liaisons for Fall Meeting sessions (designation of an OSPA liaison is now a requirement for approval of any oral or poster session proposal for the Fall Meeting). If so, you have, and will continue to receive, email blasts from me over the next week or two encouraging you to complete judge assignments for your session. I apologize for the irritation if you've already completed the job, but we have a total of 165 liaisons, and it's pretty much impossible to manage the process without blanket emails. Kolja Rotzoll, who is a member of Martha's OSPA committee, has produced (on a near daily basis during the critical week before the Fall Meeting) plots showing the number of judges assigned for each day's sessions, information that Martha and her committee have used to target problem sessions. All of this represents a much more organized approach than the old one which more or less consisted of chasing people around at the meeting with forms and asking them to judge presentations. Making all of this work takes a lot of effort – but Martha and her committee can take credit for much more thorough and consistent judging of OSPA-candidate oral and poster presentations at the Fall Meeting than we've had in the past.

I'd also like to reflect a bit on some of the strengths of the Section and how they relate to the evolution of priorities at the Union level. In several of these columns over the last two and a half years, I've relayed information to you about what amount to changes in how the Union does business. There are many facets to this – far more than I can do justice to in a few paragraphs. But among the ongoing changes, two are key. The first is a desire to do a better job of conveying AGU's science to a broader audience – i.e., not just those of us in the research world. The second is to do a better job of entraining our student and early career scientists in AGU governance, and activities more generally.

With respect to a broader audience –in my view, the Section is well positioned due to the thin line that separates water science and water policy. Going back several decades, there was a strong water policy focus within the section, which also was manifested in *Water Resources Research* (while the management of *WRR* is separate from Section governance, *WRR* originated as an archival outlet for the Section's science, and there has always been a close relationship between the journal and the Section). That focus had diminished over the last 20 years or so, but it is being reconstructed both in WRR, and in the Section's activities. With respect to the latter, we now have a thriving Water and Society technical committee (chaired by Casey Brown). Casey was also instrumental in helping AGU staff to create a stronger water segment of the first AGU Science Policy meeting last spring, and in the drafting of a white paper on the water energy nexus. These are just a few examples of the sort of actions that can help the Section to play a leading role in a Union-level transition.

With respect to students and early career scientists – our technical committee structure (which goes back to the early days of AGU) turns out to be somewhat unique. In addition to helping to foster strong meeting programs (both at the Fall Meeting and other fora, such as the Chapman Conference on Remote Sensing of the Terrestrial Water Cycle organized by the Section's Remote Sensing Committee), the technical committees essentially are entry points for young scientists into the Section's activities. With the formation of the Water and Society and Critical Zone Processes technical committees (the latter jointly with the Biogeosciences Section), we now have 11 committees, with a total of almost 150 section members involved. One way that we can continue to entrain young scientists in the committee structure is by systematically rotating their membership (and leadership). Eric and I have discussed a strategy for doing so, which essentially will rotate some fraction of the committees' membership at the end of my term (technically, under our bylaws, all members of technical committees have terms the same as the officers – i.e., all terms come to an end when the section president who appoints them leaves office). Clearly, some corporate memory is desirable, but there also is a strong motivation for rotating a substantial fraction of each committee's membership.

In concluding, I want to thank all of you that I have asked to help with Section activities one way or another. I am sure that if I think carefully, there are one or two instances where I've been turned down. But the number is astoundingly small – in almost all cases, when I've asked people to sit on one committee or another, lead some activity, or be available for a Union level appointment, you've accepted, and done the job well. Taking all of the technical committees, and honors and awards committees together, there are around 200 Section members involved. That's a tremendous resource, and your willingness to serve is greatly appreciated.

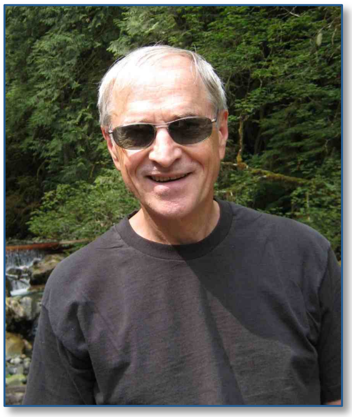
Fall Meeting Highlights

Function	Start Date	Start Time	End Time	Location	Room
Student Representative Meeting	12/2/12	5:00 PM	6:00 PM	Moscone North	Room 121
Soil Systems and Critical Zone Processes Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 125
Ecohydrology Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 111
Ground Water Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 112
Hydrogeophysics Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 113
Precipitation Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 121
Water and Society Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 110
Large-Scale Field Experimentation Technical Committee Meeting	12/3/12	6:15 PM	7:15 PM	Moscone North	Room 114
Student Breakfast	12/4/12	6:45 AM	7:45 AM	Marriott	Salon 8
Hydrology-Remote Sensing Technical Committee Meeting	12/4/12	6:45 AM	7:45 AM	Moscone North	Room 111
Surface Water Technical Committee Meeting	12/4/12	6:45 AM	7:45 AM	Moscone North	Room 112
Unsaturated Zone Technical Committee Meeting	12/4/12	6:45 AM	7:45 AM	Moscone North	Room 113
Water Quality Technical Committee Meeting	12/4/12	6:45 AM	7:45 AM	Moscone North	Room 114
Langbein Lecture (preceded by presentation of Hydrology Section Early Career Award and Hydrologic Sciences Award)	12/4/12	10:20 AM	12:20 PM	Moscone South	Room 104
Section Luncheon	12/4/12	12:30 PM	1:30 PM	San Francisco Marriott Marquis	Salon 8
Technical Committee Chairs Meeting	12/5/12	6:45 AM	7:45 AM	Moscone North	Room 111
Hydrology Students Meeting	12/5/12	6:45 AM	7:45 AM	Marriott	Sierra H
Hydrology Section Executive Committee Meeting	12/6/12	6:45 AM	7:45 AM	Moscone North	Room 111

From the Section President-Elect: Passing the baton

Eric Wood (Princeton University)

On January 1, AGU goes through its biennial change of section, focus group and committee volunteers – passing the baton, so to say. It's a great time to thank everyone for their hard work and dedication to the Section, and to solicit members to help with the various Section award and technical committees. As your incoming Section President, I



want to thank Dennis Lettenmaier for his dedicated work on behalf of the section as our President over the last 2 ½ years. Not only did he serve the Section, but he sat on the Union Council Leadership Team (CLT) that essentially carried the Council work throughout the year with meetings and monthly telecons. Below I will have more comments about Council activities and how the Union will be looking to the Section for input to Council initiatives.

A tremendous strength of our section is the Technical Committee system. These committees help organize the sessions at the Fall Meeting, and in so doing, help develop an exciting program that is at the cutting edge of their disciplines. At the upcoming Fall Meeting, the Section has 167 sessions (!!), which demonstrates the scientific depth and interests of the Section members.

The Section by-laws state that "the (Section) President shall appoint members to Section committees and task groups" whose terms coincide with the biennial term of the President. Thanking the section volunteers will be Dennis's task, and populating these committees for the next two years will be my task.

Becoming involved with a technical committee is a great way to become involved with the Section beyond just attending the Fall meeting. Technical committees are a particularly good way for our early career colleagues to become involved in the Section. I will be discussing these opportunities with various colleagues, but with over 7,000 Section members I personally only know a small percentage. Thus, I'm interested in hearing from those of you who would like to volunteer in serving on technical committees and other Section committees. I expect to have a link on the Section web page where you can fill out a volunteer information page, or you can email me (efwood@princeton.edu).

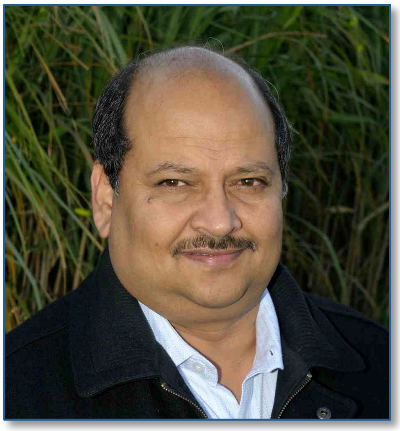
Over the last two years, the Union Council has started to develop plans that involve a number of task forces that will work on a variety of activities that are intended to advance the AGU strategic plan in support of Earth and space sciences. Thus the Union is looking to its members to volunteer (and to the Sections to suggest volunteers) for a variety of committees and task forces. To help identify members who are interested, the Union has set up a web site (http://fossil.agu.org) where members can fill out a form indicating their interest in volunteering. If you are interested, please visit the site and submit a form.

Whether it's at the Union or Section level, being involved in AGU activities enriches ones professional activities and strengthens our Union. I encourage your participation and look forward to seeing you at the Fall Meeting.

From the Water Resources Research Editor-in-Chief

Praveen Kumar (University of Illinois)

In all likelihood, the next article for the newsletter will be written by a new Editor-in-Chief. This offers an opportunity for me, on behalf of my colleagues on the editorial board, to offer our deep gratitude for the support that the community has provided during the past four years to ensure that *WRR* remains a strong journal. The credit goes to the authors for sending us outstanding work, and to the reviewers and Associate Editors who spend tireless hours to provide feedback and evaluation that is of the highest quality. The reviews provide fresh perspectives to the authors, which are integrated into the narrative. Often these reviews have gone even further and spawned new research – an anonymous collaboration that doesn't get an explicit attribution, but is nevertheless highly significant. The sense of ownership of the journal by the community is truly outstanding, and this is what makes it a compelling outlet for the science and a privilege for us to have served.



The previous editorial board provided us a strong foundation to foster new initiatives. These include Feature Articles that are exposed to a broader audience as Research Highlights in *EOS*, News Releases, and Editors' Choice Awards (the latter comprise about one percent of the published articles each year). Our approach has been to be inclusive and grow the journal by embracing the emerging areas while keeping the core values of scientific quality and integrity as the standard of publication. This has resulted in new publications or expansion in emerging areas such as psychology of water use, human health, carbon sequestration, water infrastructure networks, and hydroinformatics, to name a few. At the same time the traditional areas have continued to strengthen and diversify. The statement of scope for the journal was revised to reflect this evolving field where human and natural systems are evermore deeply coupled. Going forward, the partnership of AGU with Wiley-Blackwell is expected to bring new opportunities for both authors and readers. Article submission will continue to be handled by the existing GEMS system; however, post acceptance journal production and marketing will be managed by Wiley-Blackwell. As the electronic media changes how we produce and consume information, this partnership offers potentially compelling avenues for the evolution of publication platforms. So keep an eye out for this starting next year. We would love to hear back from the community so please feel free to drop me a note.

Last Call at the Oasis

Special Screening

Come see a documentary about national and global water issues, made by the same company that produced *Food Inc.*, *An Inconvenient Truth*, and *Waiting for Superman*. The film features AGU members and an appearance by comedian Jack Black!

The screening will be followed by a panel discussion and Q&A with water experts from the film, including Jay Famiglietti and Peter Gleick.

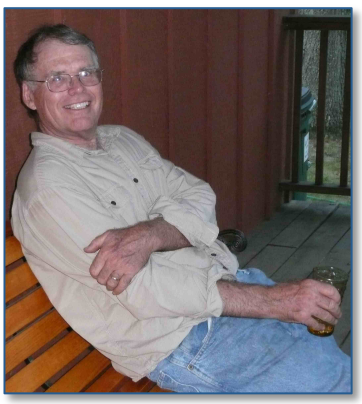
Date: Monday, December 3, 2012
Time: 7:30 pm
Location: AMC Metreon 16 theater (across the street from Moscone Center – West), San Francisco, CA
Admission: $10
Host: University of California Center for Hydrologic Modeling

For more information and a link to pre-purchase tickets, please visit the event page at http://www.tugg.com/events/2238 or contact Sasha Richey (arichey@uci.edu).

The Fellows Speak: Will the California snow pack survive the next century of climate warming?

Dan Cayan (Scripps Institution of Oceanography and U.S. Geological Survey) 2012 Fellow

Similar to other parts of the western United States, California is dependent on mountain precipitation, much of it in the form of snow. Mountain runoff, particularly during spring and summer snowmelt, is used to support ecosystems and to supply water for agriculture, industry, and urban populations. Long-term changes in hydro-meteorological variables have already been documented across the western US, including shifts toward more rainfall and less snowfall (Knowles et al., 2006), less spring snow pack (e.g. Hamlet et al., 2005; Mote et al., 2005), and earlier streamflow in snow-fed rivers (Dettinger and Cayan, 1995; Stewart et al., 2005).



Although there is considerable influence on seasonal snow accumulations by variations of precipitation on interannual to decadal time scales, much of the multi-decadal decline in snow pack, and associated hydrologic change, has been caused by warming temperatures (Mote et al., 2005; Pierce et al., 2008). In aggregate, it is estimated that early spring (April 1) snow water equivalent over the western United States has declined by about 10% since 1950 (Mote et al., 2005). The State of California is particularly concerned about potential losses of its snow pack, due to limited reservoir storage and a high exposure to winter storm-generated floods from mountain watersheds, and heavy demand for water during its long arid warm season. Temperature increases have a wide uncertainty, but even the lower projected increases are still substantial at about 1.5°C by 2100. Given the sensitivity of spring snow pack, findings that recent change can partly be attributed to anthropogenic warming (Maurer et al., 2007; Barnett et al., 2008) and the strong likelihood that further warming is underway, we are compelled to investigate how spring snow pack will respond in future decades—will the California snow pack survive?

We used a set of CMIP3 GCM outputs, from 16 Global Climate Models (GCMs) employed in the recent Southwest Climate Change Assessment (Cayan et al., 2012), a contribution to the forthcoming U.S. National Climate Assessment (www.globalchange.gov/what-we-do/assessment). The GCM simulations are taken from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (www.pcmdi.llnl.gov/ipcc/about_ipcc.php). For each GCM, one high (SRES A2) and one low (SRES B1) emissions scenario (Nakicenovic et al., 2000) simulation were included. The GCMs provide historical simulations in addition to projected 21st Century climate simulations. Downscaling to 1/8° (about 12 km in the N-S direction) of GCM precipitation and temperature was accomplished using the Bias Correction and Spatial Downscaling (BCSD) method (Maurer et al., 2010).

To simulate land surface variables, including the snow water equivalent (SWE), we used the Variable Infiltration Capacity (VIC) model (e.g., Hamlet et al., 2005), a semi-distributed macro-scale hydrological model that balances water and energy fluxes over a rectangular grid mesh. VIC incorporates a detailed energy balance snow model and has been used successfully to explain the variability of snow accumulation over the western United States (Hamlet et al., 2005; Das et al., 2009).

Simulations of SWE were carried out from 1950 through 2100. The median of April 1 SWE, aggregated from the model grid cells in California's Sierra Nevada that are 800 meters or higher elevation (inset in Figure 1), was determined from the combined set of A2 and B1 GCM simulations, relative to historical levels (Figure 1). Median SWE undergoes a steady decline from the historical period continuing through 2100. It is interesting that in these simulations, the decline in SWE begins in approximately 1980, when greenhouse gas concentrations began to have a significant effect in altering Earth's energy balance. The VIC-modeled decline in SWE is consistent with the observed SWE decline in recent decades (Mote et al., 2005), largely owing to reductions at low and intermediate elevations.

Concerning future changes, median SWE drops to about 70% of historical by 2050 and to about 35% by 2100. By 2050, the 90th percentile value has fallen to 80% of its historical value, and by 2100 it has fallen to 50%. The 10th percentile also decreases—by 2100 it has fallen to little more than zero—one of every 10 years has almost no April 1 SWE. By 2050 the odds of reaching or exceeding historical median SWE have fallen to about one in four years and by 2100 the odds are only slightly higher than one in ten. The VIC model results (Figure 1) can be used to diagnose mechanisms that produce the loss in spring snow pack, including precipitation volume effects, changes in SWE from changes in rain vs. snow, and changes in snowmelt (Pierce and Cayan, 2012). But the VIC model simulations also can be used to explore effects of seasonal (October-March) precipitation (P) and temperature (T) in driving changes in aggregate snow water storage. To this end, we seek simple relationships to interpret how regional P and T will effect the change in spring snow pack. Importantly, over the historical period the seasonal P and T fluctuations are essentially uncorrelated (observed T and P correlation for 1961-1999 is about 0.1). This indicates that P anomalies and the T anomalies are essentially independent influences. Building from this, a multiple linear regression was derived, in which VIC April 1 SWE, aggregated over the Sierra Nevada (inset, Figure 1), was regressed on P and T anomalies over this region, e.g., SWE = a P + b T. The regression was built from the set of model (not observed) historical (1950-2010) simulations. The regression accounts for 86% of the variance of the VIC area-aggregated April 1 SWE over 1950-2010.

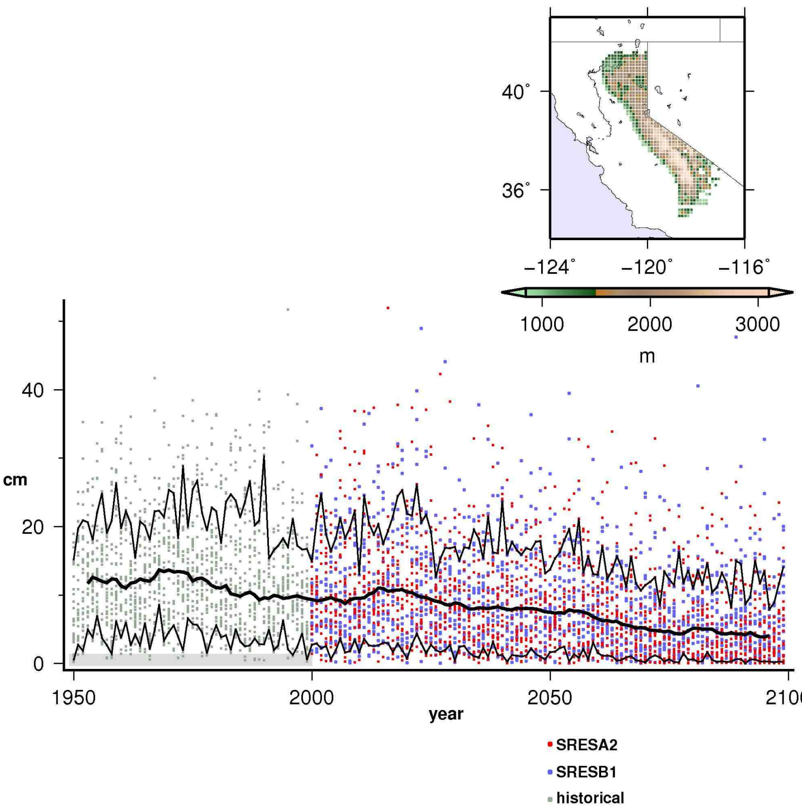


Figure 1: Change in April 1 snow water equivalent (SWE) from VIC simulations forced by downscaled T and P from 16 SRES A2 and 16 SRES B1 GCM historical and 21st Century climate projections. The April 1 SWE (in cm) is the average over the California Sierra Nevada having elevations of 800 m and greater (see inset). The median (of the 32 scenarios), smoothed by a 7-year running mean, is shown by the heavy black line. 90th and 10th percentiles (not smoothed) are shown by the light black lines. Simulated SWE during the model historical period is shown by the green dots. From about 2050 through 2100, the A2 projected SWE values (red dots) tend to be lower than B1 projected values (blue dots) because of greater warming under the A2 scenario than B1.

The standardized version of the regression shows that the influence on SWE of P is greater than that of T during the historical period. On interannual time scales, a reasonable approximation of SWE fluctuations can be made by only considering P anomalies. The influence of T anomalies on historical SWE fluctuations is relatively small, but not insignificant—a +1°C anomaly equates to a decrease of almost 20% of historical average SWE. Described below, this temperature effect is crucial in explaining changes over the longer period.

Somewhat surprisingly, this simple regression, built from the historical period, performs quite well in predicting the VIC-simulated SWE changes over the climate change period. The median, from 32 simulations, of P and T anomalies is plotted in Figure 2. P undergoes considerable short period variability but average P changes little (perhaps a slight reduction) from historical levels over the long term. In contrast, median October-March temperature warms steadily, reaching +3.2° C by 2100. Good performance of the regression model, trained on the observational period but applied to 1950-2100, is indicated by its close correspondence to that from VIC simulations (Figure 3, lower). The regression accounts for 90% of the variance of the 32 simulations during 2011-2100. Separating the P and T contributions, (Figure 3, upper), it is clear that P anomalies account, primarily, for interannual anomalies in SWE. In contrast while the T component does not explain so much of the interannual SWE fluctuations, it is very clearly responsible for the multi-decade decline in SWE (Figure 3, upper), which falls below half of its historical average by 2100.

Throughout most of the 21st Century, the regression-based SWE specification holds up quite well. But in the last two decades of the 21st Century, a bias appears, wherein regression-predicted SWE values are lower than the VIC simulations. Presumably this bias reflects the inability of the historically-based regression to capture non-linear effects associated with diminishing losses per unit temperature increase when the snow pack is already depleted.

In summary, in today's climate, the seasonal variation in precipitation is the dominant factor in determining the spring water storage in the aggregated California Sierra Nevada snow pack. In the future, climate warming shifts this balance, wherein temperature change becomes increasingly important, whereby projected warming drives a progressive decline in spring snow pack. An analysis of an ensemble of VIC model simulations shows that the loss of spring snow pack is nearly linearly related to the change in temperature. A seasonal increase of 1°C produces a reduction of almost 20% of the historical median aggregate April 1 SWE over California.

The median of the set of simulations is only one indication of future change, but is probably a useful index to begin scoping. A temperature increase of 3°C, which is about the projected median warming by 2100 relative to recent climatology, would diminish the California April 1 snow pack to about 45% of its historical level. Precipitation changes are still quite uncertain (in both sign and magnitude), but increases in winter precipitation could mitigate some of the loss of snow pack. On the other hand, if cool season precipitation declines,

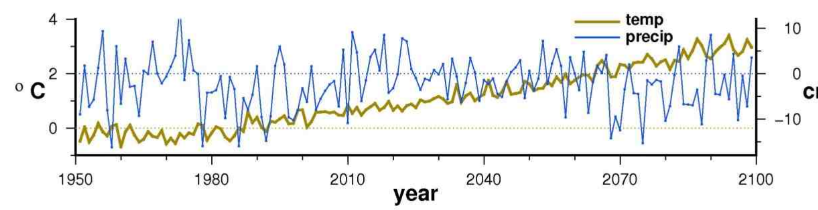


Figure 2**:** Median from 32 simulations of precipitation (blue, cm) and temperature (brown, °C) averaged over the Figure 1 study region, expressed as departures from 1950-2010 climatology.

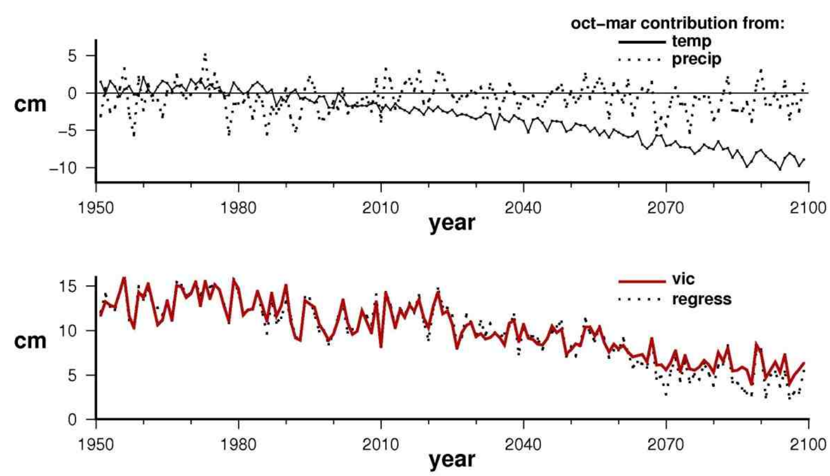


Figure 3: Upper: regression model P (dotted) and T (solid) contributions to change (cm) of April 1 snow water equivalent (SWE) from 32 simulations. Contributions are shown as median value (32 simulations) of anomalies to 1950-2010 base period. *Lower*: Regression modeled (dotted black) estimate of VIC modeled (solid red) SWE (cm) time series. Values plotted in upper and lower graphs are median of 32 simulations. The regression model was developed over the historical period of the VIC simulations. Median values of the T and P input to the regression model are shown in Figure 2.

as some model simulations indicate, it would amplify the reductions due to warming.

The projected downward trend in SWE may not qualify as a "tipping point", since the simulations contain considerable variability even during the latter half of the 21st Century, and occasionally even produce years with relatively high snow packs. However, the rapid pace of projected snow reduction, should it occur, will challenge both natural and human managed systems that have developed under less-warm and steadier climate. Changes in natural systems are already being noticed and some of these (e.g. forest mortality, species decline) are not easily reversed. Sustained and improved monitoring and modeling with focus on understanding processes (e.g. Bales et al., 2006) and more effective interactions with key decision makers will be needed to generate and provide the information needed for effective adaptation.

Acknowledgements: Thanks to numerous colleagues, but especially to Tapash Das for model calculations, Mary Tyree for programming and graphics and Mike Dettinger and David Pierce for insight and discussion.

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The Fellows Speak: Statistical post-processing to improve hydrologic forecasts

Qingyun Duan (Beijing Normal University)
2012 Fellow

Since I started as a graduate student at the Department of Hydrology and Water Resources at the University of Arizona in 1984, I have seen many truly accomplished people in the hydrology field be elected AGU Fellows and I have great admiration for all of them. Today I am humbled by the honor of joining this distinguished group. After I graduated from Arizona, my career path has intersected with both the academic and the applied side of hydrology. I take great personal pride in seeing research results (of my own or others) used in real world applications and encourage my students to pursue the same goal. I summarize here work, including some of my own, on a topic linking state-of-the-art research and real world applications: statistical post-processing to improving hydrologic forecasts.

Computer-based models are now accepted as an indispensible tool for generating hydrologic forecasts. For hydrologic forecasts to be useful to end users, however, we cannot just take whatever outputs come out of a hydrologic model directly. That is because direct model outputs (DMOs) from hydrologic models contain significant uncertainty from various sources, including model inputs, initial/boundary conditions, and model structure and model parameters. One type of uncertainty, referred to as aleatoric uncertainty, is due to the random variability of the natural system (e.g., uncertainty in observed or future meteorological forcing such as precipitation and temperature). Another type of uncertainty can be attributed to our lack of knowledge about the natural system we model, referred to as epistemic uncertainty. An example of epistemic uncertainty is the uncertainty arising from representing a watershed as interconnected, lumped blocks because we cannot accurately represent the space/time heterogeneity of the watershed. In making hydrologic forecasts, we need to quantify aleatoric uncertainty and reduce epistemic uncertainty.

There are many ways to quantify and reduce uncertainty in hydrologic predictions, including data assimilation to treat uncertainty in initial and boundary conditions, and model calibration to treat parametric uncertainty. Post-processing is a statistical technique that can be used to treat uncertainty in both model inputs and model outputs. It works by using statistical models to relate observed variables and model predictions. If the model prediction over a pre-specified space/time window is given, the statistical model can provide a conditional probabilistic estimate of the observed variable (i.e., probabilistic forecast of the observed variable).

The usefulness of post-processing has long been recognized in meteorological forecasting. The Model Output Statistics (MOS) method has a long history and is widely used to post-process DMOs from numerical weather prediction (NWP) models (Glahn and Lowry, 1972). In recent decades, a wide variety of approaches for post-processing meteorological forecasts have evolved, ranging from multivariate regression and Bayesian multimodel approaches to non-parametric methods such as artificial neural network (ANNs) and wavelet theory (see Glann et al., 2008).

Like DMOs from NWP models, DMOs from hydrologic models need to be post-processed in order to remove various biases due to uncertainties in meteorological forcings, initial and boundary conditions, model structure and parameters. Many of the post-processing techniques developed in meteorological forecasting have been used by hydrologists to post-process precipitation and temperature forecasts so they can be used as inputs to hydrologic models (in the hydrologic forecasting community, this is often referred to as pre-processing). Hydrologic models require meteorological (e.g., precipitation and temperature) forecast inputs in the form of time series that are not only accurate and reliable, but also statistically coherent in both space and time. Some commonly used post-processing methods cannot meet this requirement. For example, MOS-processed meteorological forecasts remove systematic biases in meteorological forecasts, but do not preserve the space-time statistical relationships of the forecasted variables (Clark et al., 2004).

To overcome limitations of MOS type approaches, Krzysztzyfowicz and Sigrest, (1999) developed Bayesian-based approaches to post-process precipitation and streamflow forecasts. Clark et al. (2004) improved the MOS method by introducing a procedure they termed the "Schaake shuffle" to generate precipitation and temperature forecast time series that have similar statistical correlation structure as historical observed time series. With the launch of the Hydrologic Ensemble Prediction Experiment (HEPEX) project in 2004 (see Schaake et al., 2007), the literature on hydrologic post-processing methods has proliferated. A wide variety of mathematical approaches to post-processing of hydrologic forecasts have been suggested, including general linear regression, probability mapping, ANNs, wavelets, and Bayesian approaches. I will not get into details of those post-processing approaches here, but rather I offer two examples that demonstrate the usefulness of post-processing in improving hydrologic forecasts.

The first example is post-processing of 1-14 day precipitation forecasts in the Huai River basin in China (Liu et al., 2012). The original raw precipitation forecasts were generated by the Global Forecast System (GFS), which is the operational weather forecast model of the U.S. National Center for Environmental Prediction (NCEP). The GFS forecasts contain 21 ensemble members, which provide global coverage at a 2.5^{o}x2.5^{o} spatial resolution and a 14-day lead time. Retrospective GFS forecast data from 1/1/1979 to present are archived by NCEP. We used the National Weather Service's Ensemble Pre-Processor version 3 (EPP3) to post-process the GFS precipitation forecasts over the Huai River basin in China from 1/1/1981 to 12/31/2003.

Figure 1a shows the average biases in the raw and post-processed precipitation ensemble forecasts for a sub-basin in Huai River basin in four different seasons, with the horizontal axis denoting lead times and the vertical axis the bias per day. The bias patterns for the raw forecasts depend on season, but the post-processed ensemble forecast means show no biases, indicating that post-processing effectively removes the systematic bias. Figure 1b displays the Brier Skill Score (BSS) of the post-processed ensemble forecasts. BSS measures how well the forecast of probability of a binary event (e.g., rain or no-rain) matches the observed frequency. The reference forecast used for computing BSS is climatology. Any skill score greater than zero indicates improvement over the reference. As Figure 1b shows, post-processed ensemble forecasts are significantly better than climatology. The improvement is the biggest for winter and the smallest for summer because summer convective precipitation storms are harder to predict. Figure 2 exhibits the Continuous Ranked

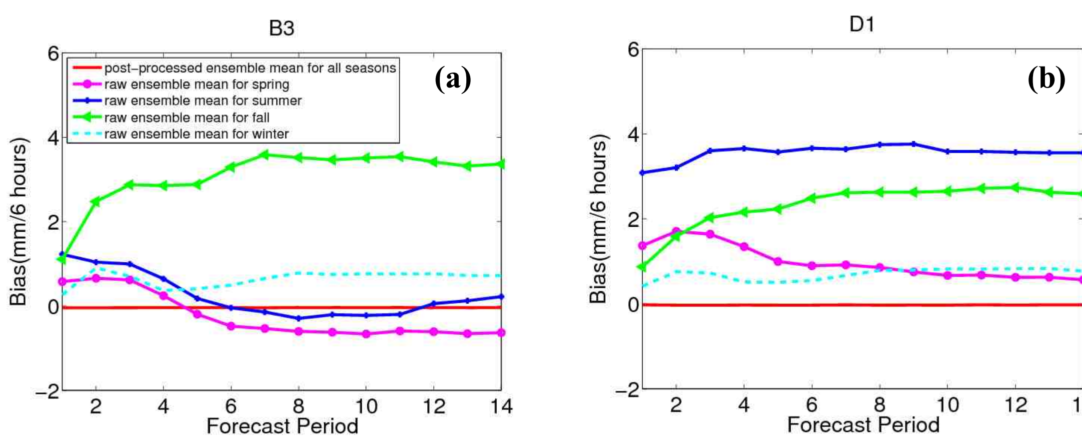

Figure 1: Comparison of raw and post-processed mean ensemble forecasts of daily precipitation values for different lead times (1-14 days): (a) Bias; (b) Brier skill scores (BSS).

Probability Skill Score (CRPSS) of the post-processed cumulative precipitation forecasts. CRPSS measures how forecast precipitation probability matches observed frequency. Again, the reference forecast is climatology. Figure 2 indicates that the CRPSS is improved substantially for all lead times and for every day of the year. The improvement decreases with lead times and is seasonally dependent.

The second example is post-processing of hydrologic model outputs. In this example we used generalized linear regression (GLM) to post-process streamflow simulations generated by the Sacramento model (Zhao et al., 2011). Simulated streamflow for the French Broad River near Asheville, NC were taken from Duan et al. (2006). Two sets of streamflow simulations were post-processed: one set used a priori model parameters and another set used calibrated model parameters. The forecast lead time was 30 days.

Figure 3 illustrates the effect of post-processing on streamflow simulations. In Figure 3a, the two dotted lines denote the raw streamflow simulations averaged over the forecast period using a priori parameters and calibrated parameters, respectively. The solid red line indicates the corresponding observation. The two solid lines with symbols are the post-processed streamflow simulations. This figure shows that the raw simulation (a priori parameters) has considerable bias. Calibration reduces the bias, but does not completely remove it. Post-processing removes most of the bias in simulations using both the a priori and calibrated parameters (calibrated parameters slightly outperform a priori parameters in this respect). Figure 3b shows how the standard deviation of the streamflow simulations changes with lead times for raw and post-processed streamflow simulations. Again, the standard deviation of the raw streamflow simulation using a priori parameters does not match that of the observations, while the standard deviations of other three sets of streamflow simulations are much closer to those of the

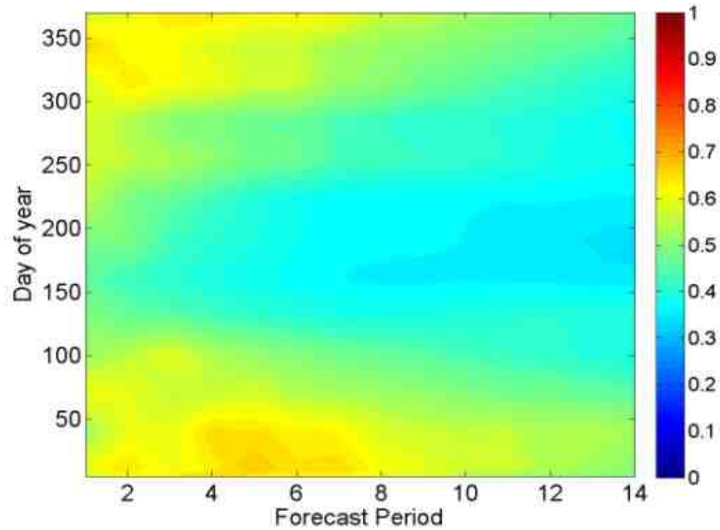

Figure 2: CRPSS of post-processed ensemble forecasts of cumulative precipitation over the climatological ensemble forecasts for different lead time (1-14 days).

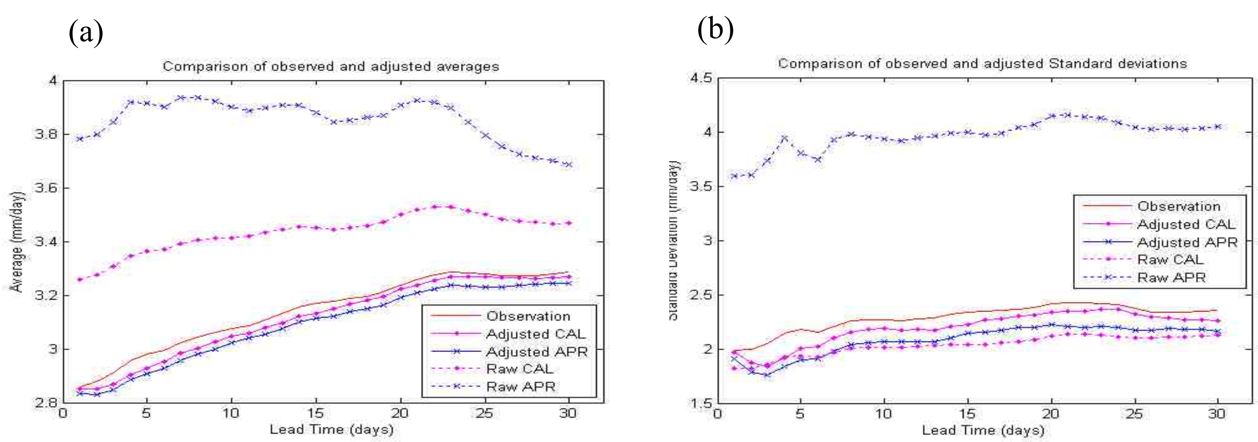

Figure 3: The comparison of the pre- and post-processed streamflow forecast simulations against observations at the French Broad River basin in Asheville, N.C. (a) Comparison between average ensemble forecast with lead times; (b) comparison of ensemble standard deviation with lead times.

observations. This suggests that calibration improves the representation of the streamflow ensemble spread, as does post-processing. Figure 3 clearly suggests that post-processing achieves the same degree of improvement or better in streamflow simulation as calibration. This result is meaningful in that, for basins where calibration cannot be performed due to data issues (e.g., streamflow regulation), post-processing can be used to compensate the lack of model calibration. The same reasoning applies to post-processing as an option for compensating for a lack of data assimilation to account for the effects of initial condition uncertainty.

Post-processing in hydrologic forecasting is still a relatively young field. Most statistical methods make explicit or implicit assumptions about the underlying probability distributions of the hydrologic variables. It is often difficult to characterize accurately the statistical relationships between hydrologic model forecasts and the observations because of our inadequate understanding, scarcity of forecast and observation data, and changes in climate and the environment (e.g. land cover). For these reasons, post-processed results may still be subject to large uncertainty. Knowledge of the forecaster is therefore essential to making a good forecast, but is very hard to represent in mathematical expressions and incorporate in forecast products in a consistent and reproducible manner. As research in hydrometeorological, statistical and computational theories and techniques continues to progress, there will be an opportunity to incorporate new methods in post processing methods. New thinking on how to make use of improved hydrologic forecasts in optimizing water resources allocation and in emergency management of water hazards should also be a priority research topic for interested hydrologists and water resources managers.

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The Fellows Speak: On the increasing complexity in experimental contaminant hydrology research

Peter R. Jaffé (Princeton University) 2012 Fellow

It is an honor to write a contribution to this newsletter, and I would like to take this opportunity to reflect on the range of research approaches and challenges in the field of fate and transport of pollutants in porous media. I will take the liberty to use my own path and experience over the last 30 years as the general thread for this discussion.

Superfund, (CERCLA) was established in 1980 and made research on fate, transport, and remediation of Priority Pollutants a major focus area in our field. Initially, fundamental knowledge was gained from projects led by single-investigators or small teams. Modelers developed tools to simulate the transport of conservative constituents in groundwater, and processes such as retardation, followed by more complex mass transfer processes, and biogeochemical reactions were incorporated successfully over time. There is still much exciting work and fundamental insights that can be gained by single/small group PI projects, but the general trend now is towards research teams with a broader range of expertise.

While significant progress has been made over the last decades in understanding the fate and transport of contaminants in the environment, disciplines such as geochemistry, microbial ecology, and molecular biology, have also provided a wealth of new fundamental knowledge of biogeochemical transformations and experimental techniques. Such new information needs to be integrated to more accurately assess the fate of pollutants. This requires larger research teams, not only because a single PI may not have the expertise in geochemistry, mass transfer processes, hydrology, molecular biology, numerical simulations, etc., but also because no single laboratory has the capabilities to do experimentation and measurements across such a wide range of disciplines.

Examples from my own research include the reduction of iron during biostimulation. I have been a Co-PI on a DOE Field Research Site (Integrated Field Research Challenge: Rifle, Colorado), where we (12 PIs and many collaborators) have been conducting experiments on uranium bio-immobilization via the stimulation of *Geobacter sp*., an iron reducer. We, as well as many investigators in this field, have modeled the use of electron acceptors via their sequential utilization, starting with oxygen, which yields the most energy, and then followed by nitrate, manganese, iron, sulfate, etc. (Wang et al., 2003; Yabusaki et al., 2007). No distinction was made in terms of what Fe(III) phases were being utilized and the assumption was that as long as bioavailable Fe(III) is present it is being reduced, and after it is exhausted the system shifts to sulfate reduction. Field observations from acetate injection into the subsurface showed that iron reduction was dominant for about a month after which sulfate reduction became prevalent, and it was assumed that bioavailable iron had been depleted by that time (Anderson et al., 2003).

Via carefully designed laboratory soil column experiments and collaborating with iron geochemists that have access to Moesbauer Spectroscopy we learned that different iron phases were being utilized sequentially (Komlos et al., 2008a). We could even see that iron phases were being reduced during sulfate reduction, but it was not clear if that was a biotic or abiotic (driven by sulfides) transformation. This later question could be answered by collaborating with microbiologists that could determine that iron reducers such as *Geobacter sp.* did reproduce (they produced RNA) while the system was under strong sulfate reducing conditions (Moon et al., 2010). These results were incorporated into a model developed by another team member, and actually improved predictions significantly. We have conducted multiple such experiments, some to support the design of field experiments, some to aid in interpreting field results, and others to develop more mechanistically-based model formulations (MacDonald et al., 2011).

For such multidisciplinary experiments, having the right team members and carefully planning an experiment from the onset, what to measure, and what it will yield is crucial. Putting the right team together is certainly a challenge for all of us, but especially for our younger colleagues. Much successful collaboration happens by chance, but one can't plan on that. For individuals starting out, I suggest to first focus on individual PI projects, and then ask what insights from other fields would provide the most gain and who can provide that. Once one has exciting results and a clear idea how other disciplines will further the research, it is much easier to find the right collaborator and have a successful multidisciplinary collaboration.

Focusing next on scales of experimentation, laboratory experiments, as opposed to field experiments, have the advantage that they allow us to "simplify" a system and rigorously study the effect of selected variables independently. They are in general faster and much less expensive to carry out than most field experiments. Experiments that are only time dependent (i.e. no spatial gradient) have the advantage that they provide detailed information into processes such as sorption/desorption, dissolution, volatilization, and chemical/biological transformations. Such experiments are extremely useful to allow testing of mathematical formulations of specific processes, since they do not include complexities such as diffusion limitations, spatial heterogeneities, etc. More complex setups that include transport, such as porous medium column experiments, provide further insights, for example the effects of planktonic vs. attached microorganisms under flow conditions and/or concentration gradients. They may mimic more realistically actual flow conditions in porous media and can be used to either design or help interpret/augment results from field experiments. For our Rifle work, such laboratory column experiments allowed testing of different hypothesis and biostimulation conditions (e.g., effects of iron (Moon et al., 2010) and sulfate (Komlos et al., 2008b) levels on uranium reduction, and effects of oxidants on reduced uranium stability (Moon et al., 2009) that require controlling variables difficult, if not impossible, to manipulate in the field). Most important, such experiments allow for running many identical columns in parallel and sacrificing them at regular intervals, which gives valuable insights into the temporal geochemical/microbiological dynamics. To do this in the field requires coring at the desired time increments, and, given the spatial heterogeneity in the field, several cores would be required to determine meaningful trends. Reassuringly, the trends as well as kinetic coefficients we measured in our laboratory column experiments mimic well what was observe in the field. Figure 1 illustrates examples of the controlled laboratory column, field in-well column operation, and full field biostimulation experimentation for our Rifle project.

Larger, more complex, laboratory experiments can be conducted, but one should always ask what additional information is gained by increasing the size and/or complexity of the experimental effort. Currently we are focusing on uranium biogeochemistry in the wetland rhizosphere, where we need to sample chemical speciation and microbial distributions on the root surface, near the root, and at locations where roots are absent, resulting in much more complex experiments. Plants need nitrogen and phosphorus. The system might need a buffer, but phosphate will precipitate uranium and nitrate will oxidize reduced uranium. We want to focus on iron cycling near roots, but carbonate buffers might result in the production of siderite and sequester Fe(II), etc. The larger planted mesocosms, having variability in the flow direction as well as laterally, need to be disenabled for their chemical and microbiological characterization under anaerobic conditions so as not to oxidize reduced species that need to be quantified. It is easy here to set up experiments that will not yield what they were designed for without extremely careful planning.

Field experiments are required to test if the understanding we obtained from laboratory experiments have been integrated correctly and can be extrapolated to the field-scale. If it works, it is incredibly rewarding, if not it gives us the feedback

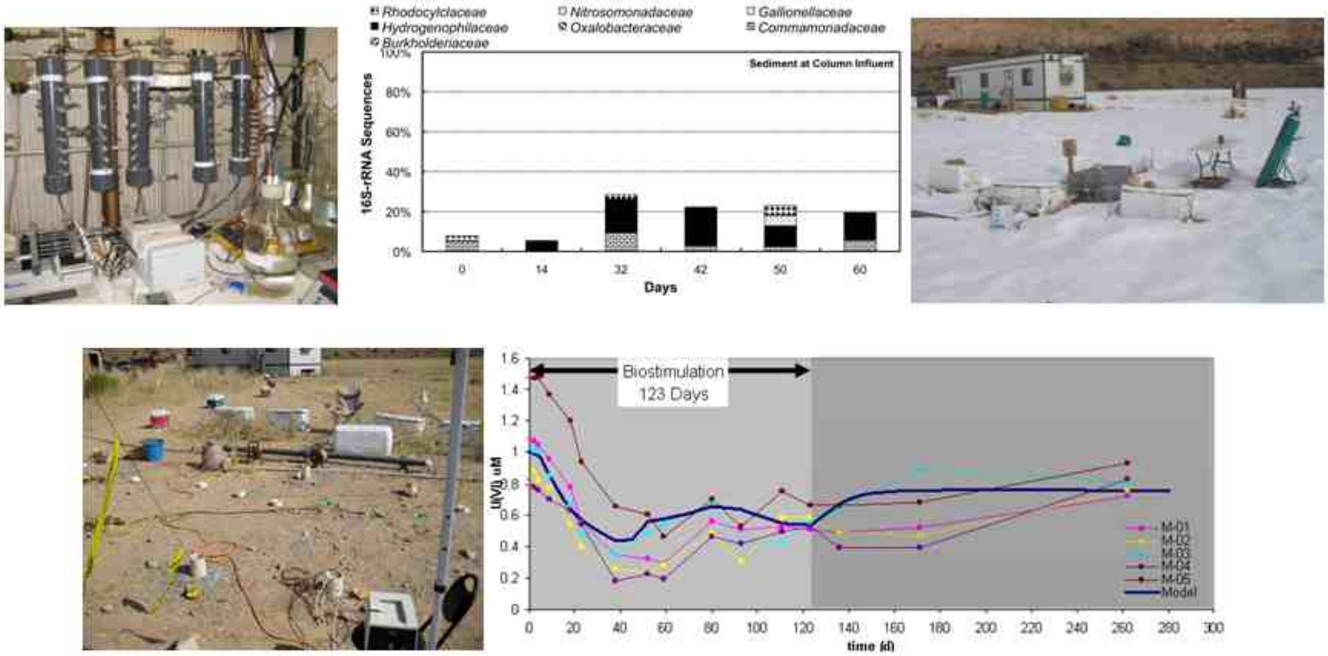

Figure 1: Clockwise from top left panel. Laboratory sediment columns; Attached biomass characterization from column experiments; Field column incubation in wells while maintaining constant flow and collecting influent/effluent over a year (a challenge when ambient T ~ -15 to 95 ^{o}F); Field injection gallery; Field simulated and measured uranium profiles. Figure redrafted from N'Guessan et al. (2010) and Yabusaki et al. (2007).

to ask what is it that we have missed. Experiments, laboratory and field, have additional value in that they can result in totally unexpected outcomes. For example, in a recent project we studied how nitrogen runoff into riparian wetlands would affect iron oxides and hence sorption of phosphates and trace metals. To our surprise we noted that ammonium was decreasing under iron reducing conditions in these wetland sediments (Shrestha et al., 2009). In a follow-up study, we are close to identifying a consortium of an autotrophic iron reducer coupled with ammonium oxidation to nitrite and followed by nitrite/ammonium removal via anammox. Initial qPCR analyses indicate that both are species not previously reported. This will open new research questions, like how prevalent is this process in natural systems, and can we implement it in constructed wetlands and/or even in bioreactors?

In the experiments discussed above, we go from incubation experiments (~10s of ml), to flow-through column experiments (~ 10s of cm), to field experiments (~10s of m). We have been successful spanning that scale of experimentation coupled with modeling. Rate coefficients measured in the laboratory can usually be used to do simulations at the field scale, as long as the spatial heterogeneity in the field is known. For contaminated sites this characterization can be challenging, but is generally possible.

As large watershed-scale hydrologic models and global circulation models become more powerful, we want to incorporate transport of trace contaminants or nutrients into these simulations to understand how different land use patterns and climatological variability might affect water quality. These models have a resolution, usually 10 km x 10 km or larger, while the scale at which different redox conditions and microbiological transformations occur is usually much smaller. Modelers use soil moisture as a "proxy function" for redox conditions since water logged soils, especially in organic rich strata will turn anoxic. Unfortunately rates that we have measured at in the laboratory to field experiments described earlier do not translate to that scale. More difficult is the characterization of riparian zones. When implementing large-scale models, we need to know what fraction of water in streams or discharging into streams is exposed to more reducing conditions in riparian zones and for how long? What kind of "proxy functions", if any, can we develop to quantify transformations in such zones? What is the effect of seasonal water level fluctuations and/or of droughts on redox changes and contaminant dynamics once sediments/soils flood again? These are exciting questions which require interdisciplinary teams and carefully designed field measurements for a large set of environmental conditions. Clearly, carefully conducted laboratory experiments will be crucial, but will require very different simulation approaches to be extrapolated to the field-scale.

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The Fellows Speak: Ecohydrology: Complexity and sustainability

Amilcare Porporato (Duke University) 2012 Fellow

We forget that the water cycle and the life cycle are one.

Jacques Yves Cousteau

I am very grateful to have been elected an AGU fellow. I would like to thank the colleagues who nominated me, as well as our AGU Hydrology president, Dennis Lettenmaier, who is providing the new fellows with the opportunity to present some of our research interests. There is a long list of collaborators and friends to whom I owe a good deal of my research results, but the list is too long to thank them individually here. Many of their names, however, can be obtained by Googling my publication list. As the quote above suggests, one of my main interests is the *two-way interaction between hydrologic cycle and the biosphere*. Not only do I think that the problem is quite important practically, but I also find it very fascinating from a scientific viewpoint. Ecohydrology has, in fact, all the elements that are typical of complex systems, i.e., the simultaneous presence of strong nonlinear interactions and a high

number of degrees of freedom (Rodriguez-Iturbe and Porporato 2004; Katul et al. 2007). Looking at the soil-plant-atmosphere system, for example, one is immediately struck by heterogeneity in the structure of the plant canopy and the soil matrix, by the variability of the turbulent fluctuations, and by the uncertain occurrence of future rainfall events. With a bit more attention, however, it soon becomes apparent that relatively simple (macroscopic) rules are also present. These rules are responsible, for example, for the regularity of the soil moisture drydowns after rainfall events. Soil drydowns are dominated by soil and plant characteristics, rather than the irregular fluctuations in atmospheric conditions (Daly and Porporato 2006). It is this regularity that allows us to predict the timing and amount of future irrigation, conditionally on the occurrence of rainfall, and ultimately permits a probabilistic description of irrigation needs (e.g., Vico and Porporato 2010). Our research tries to take advantage of this existing separation between high-dimensional and low-dimensional components in the dynamics: we use relatively simple, but physically based, nonlinear differential equations for the macroscopically predictable, low-dimensional components, and replace the unpredictable, high-dimensional forcing terms, which cannot be modeled in detail, with suitable noises (e.g., random functions). I am also interested in *how water cycles affect the dynamics of nutrients*, in particular nitrogen and phosphorous, and the related carbon cycle. Hidden to our direct observation, the ecohydrological activity in the soil is in fact much more dynamic than one would perhaps expect. In particular, we have tried to disentangle the impact of hydrologic fluctuations from the constraints imposed by plant and microbial stoichiometry on soil organic mineralization and the related microbial activity (e.g., Manzoni et al. 2008, 2012). I will only provide here a pictorial example (see Figure 1) of the impacts of hydrologic fluctuations on the competition for mineral nitrogen between soil microbes (which try to immobilize it) and plants (which try to uptake it). Figure 1 is also a vivid example of the interplay of strong nonlinearities (i.e., thresholds of wilting of plants and different types of microbes) and the unpredictable hydrologic fluctuations (soil moisture jumps), noted above.

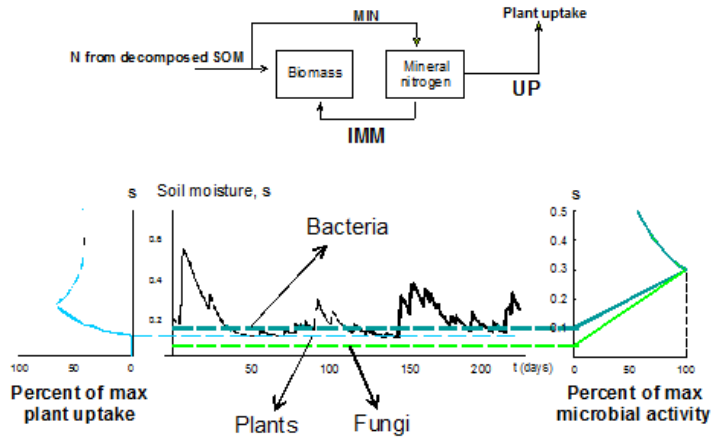

Figure 1: Pictorial sketch of the impacts of hydrologic fluctuations on the competition for mineral nitrogen between soil microbes and plants. The mineral nitrogen decomposed by microbial biomass becomes available for both plant uptake and microbial immobilization (top). However, plant and soil microbial activity is strongly impacted by soil moisture, which –with its random fluctuations—imparts a strong modulation to such a competition (bottom).

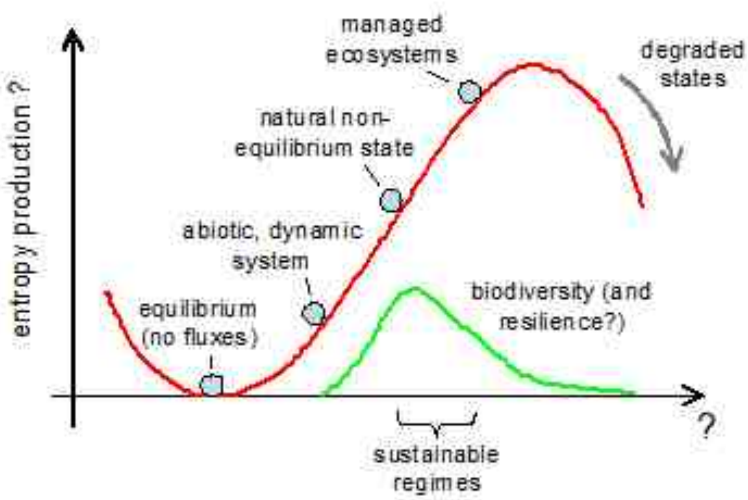

Figure 2: Conceptual (and incomplete!) sketch of the hypothetical landscape for ecosystems as open thermodynamic systems out of equilibrium as a framework for a quantitative approach to sustainability.

Finally, my research is increasingly more concerned about the 'engineering' aspects of ecohydrology or, in other words, the *sustainable use* *of soil, water and nutrient resources.* While we modify our environment to make it less extreme, more productive and safer, we also alter the water cycle and the ecosystems. However, we do not yet have a measure to know to what extent we can push such alterations. *Quantification of sustainability* is, in my view, one of the greatest challenges we face as geophysicists and environmental engineers. Looking at watersheds, river basins and ecosystems, natural or managed, as open thermodynamic systems in non-equilibrium, our sustainability challenge becomes the quantification of how far from the 'natural' non-equilibrium state our management can take these systems without pushing them beyond potential barriers that would 'irreversibly' lead towards degraded states (Figure 2).

Along with the current efforts in ecohydrology, there is a lot of interesting new activity in nonequilibrium thermodynamics and statistical mechanics (Martyushev and Seleznev 2006; Jarzinsky 2011) with interesting links to ecohydrology and biogeosciences (e.g., Ulanowicz et al. 2009; Kleidon 2010) that could help us in this challenge. The potential for new contributions is indeed great, especially when taking advantage of more traditional engineering concepts like optimal design and operation of engines (Hoffmann et al. 1997; Bejan 2006), or optimal and stochastic control (Anderies et al. 2007) with careful quantification of uncertainties (Tartakovsky 2012).

I will conclude by mentioning some work I have begun to do along these lines where, by extending the tools developed in stochastic ecohydrology to include human activities such as irrigation and fertilization, we have started tackling problems related to phytoremediation, soil salinization and optimal irrigation. As an illustration of these results, Figure 3 reports analytical calculations (Vico and Porporato 2010) of the differences in irrigation volumes required by traditional irrigation (e.g., concentrated irrigation as sprinkler, flood irrigation) and microirrigation (drip irrigation) as a function of rainfall frequency λ and intensity α. As these quantities will likely be affected by climate change, analytical results of this type, which are easily applicable to different types of soils and crops and to global scales, may have useful implications for the current and future pressing problems of sustainability and food security.

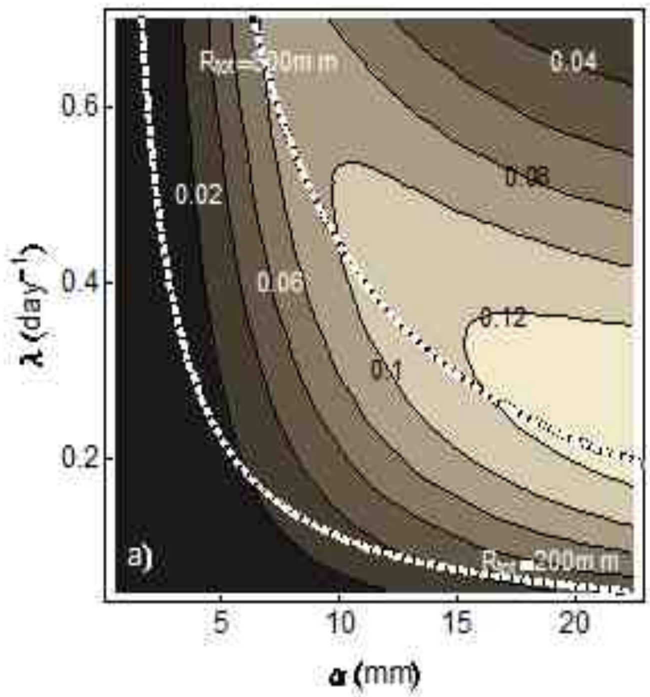

Figure 3: Difference in required irrigation volumes between traditional and microirrigation (units are m of applied water over a 180-day growing season), as a function of rainfall regime (mean event depth, α, and frequency of events, λ). Dashed lines represent combinations of rainfall parameters leading to the same total precipitation over the growing season. After Vico and Porporato (2010).

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Twitter at the Fall Meeting

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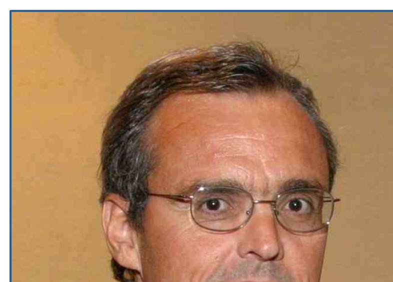
The Fellows Speak: Numerical modeling of subsurface flow and transport processes

Jirka Šimůnek (University of California Riverside)
2012 Fellow

The greatest rewards in research are earning the respect of your peers and noticing that your work is having some impact. While it is difficult, if not impossible, to quantify the former, the latter may be quantified by the number of citations in the scientific literature, or by seeing the results of your work (e.g., mathematical or numerical models) being used by others in their research, teaching, or for other applications. I have been tremendously fortunate that some of the numerical models I developed with my friends and colleagues over the years have found their way not only into the research community, but also into many university classrooms and offices of environmental consulting firms and regulatory agencies.

In terms of numerical modeling of subsurface flow and solute transport processes, I believe that we have made quite significant progress over the past 25 years. My journey in this started in the mid-1980s when I became part of a small group in Prague, at that time far behind the Iron Curtain, that was trying to develop one- and multi-dimensional, variably-saturated water flow and solute transport models on a personal computer (an Atari ST). I am using here "personal" in its very literal meaning, as opposed to mainframes and computers owned by institutions. The Atari was the personal property of Prof. Milena Císlerová, who enabled a few of us to "play" with her computer to test various numerical schemes and techniques. This was at a time when most or all governmental



research institutions in Czechoslovakia did not have access to any computer. I will be always grateful to Milena for this. Later on, I got my own Atari and installed it in the bedroom of my apartment to the great dismay of my wife, Alena. In the early nineties, after the fall of communist systems in central Europe, I came to Riverside, CA where I began working with one of the most influential soil physicists of the twentieth century, Dr. Rien van Genuchten. I have been working with him ever since.

During the past two decades, subsurface hydrologists have made tremendous progress in developing mathematical and numerical models for simulating flow and transport processes in the subsurface, especially as related to the vadose zone. In the late 1980s and early 1990s, most or all graduate students in soil physics and hydrology were forced to write their own numerical code, while the regulatory and consulting world mostly ignored the vadose zone since few tools existed for analyzing unsaturated flow and transport processes. Subsurface water started (or ended) at the groundwater table. This situation has changed radically. Many numerical models are now only a few clicks of the mouse away. This allows graduate students and researchers to focus on the real questions of their research, and many regulatory agencies now also force practicing engineers or consulting companies to include the vadose zone in their analysis.

After starting with the "gaming" computers, our goal over the years has always been to make our models available for commonly available computing devices, without the need for supercomputing capabilities. I have also always tried to follow the tradition that was started by Rien of sharing our software. This includes making the latest results of our research (such as on modeling preferential water flow, root water and solute uptake, or reactive transport) available to anyone interested in our codes, and providing detailed documentation (manuals) so that users can fully understand the invoked physical, chemical, and biological processes. Initially, our programs were used mainly by the scientific community. However, this changed when Dr. Miroslav Šejna, my old high-school friend from Czechia, started building sophisticated, graphical user interfaces for the programs in order to make them much easier and intuitive to use. The software then made its way very quickly into university classrooms and the offices of environmental consulting companies.

While Rien's models were initially being distributed using punch cards, our programs (such as the early versions of the Hydrus codes) were later distributed using various types of diskettes and CD ROMs. And then finally, in the 1990s, we started to distribute the programs using the internet, thereby reaching people around the world. We had no idea at the time that there would be so much demand for the software. For almost a decade now, we have annually had more than ten thousand downloads from our website. The wide use of the Hydrus models is also reflected by the ever increasing number of citations, with the Hydrus website listing more than one thousand peer-reviewed journal studies in which Hydrus and its variants have been used.

While the earlier versions of the Hydrus models (Šimůnek et al., 2008) were relatively simple in simulating only one-dimensional uniform water flow and linear solute transport in variably-saturated media, later versions included multi-dimensional, preferential/nonequilibrium flow processes, nonlinear and nonequilibrium solute transport, and/or coupled water, vapor, and energy transport. We continue to expand the capabilities of the Hydrus modeling environment by developing specialized modules for more complex applications that cannot be addressed using the early, standard versions. The following specialized modules have just been developed very recently:

HP1/HP2: These two modules not only simulate variably-saturated water flow and solute and heat transport, but also a broad range of biogeochemical reactions in the vadose zone and/or ground water systems, including interactions with minerals, gases, exchangers, and sorption surfaces, based on thermodynamic equilibrium, kinetic, or mixed equilibrium-kinetic reactions. The HP modules (Jacques et al., 2008) couple Hydrus with the PHREEQC geochemical code (Parkhurst and Appelo, 1999); they significantly expand capabilities of the individual programs, while preserving most of their original features.

C-Ride: This module (Figure 1) simulates the transport of particle-like substances (e.g., colloids, viruses, bacteria, and nanoparticles), as well as colloid-facilitated solute transport (Šimůnek et al., 2006), which often occurs for strongly sorbing contaminants (e.g., heavy metals, radionuclides, pharmaceuticals, pesticides, and explosives). These contaminants are predominantly associated with the solid phase, which is commonly assumed to be stationary. However, the contaminants may also sorb/attach to mobile and deposited colloidal particles (e.g., microbes, humic substances, clays and metal oxides), which then may act as pollutant carriers to provide rapid transport pathways for the pollutants. This module fully accounts for the dynamics of colloid (attachment/straining) and solute (kinetic/equilibrium sorption to soil and mobile/deposited colloids) transfer between the different phases.

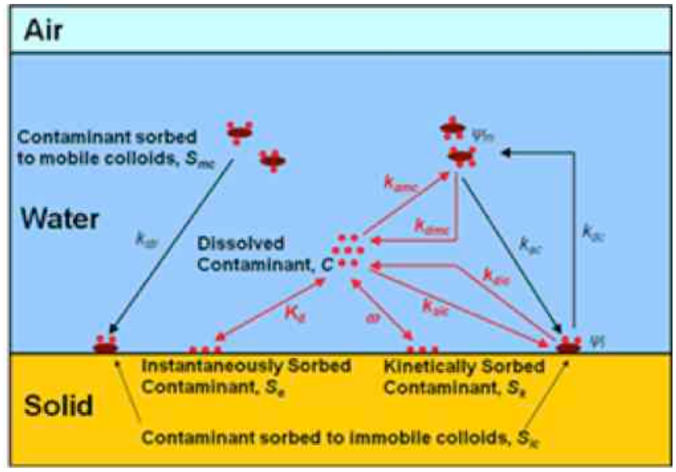


Figure 1: Schematic of the colloid-facilitated solute transport model.

DualPerm: This module (Figure 2) simulates preferential and/or nonequilibrium water flow and solute transport in dual-permeability media using the approach suggested by Gerke and van Genuchten (1993). The module assumes that the porous medium consists of two interacting regions: one associated with the inter-aggregate, macropore, or fracture system, and one comprising micropores (or intra-aggregate pores) inside soil aggregates or the rock matrix. Water flow can occur in both regions, albeit at different rates. Modeling details are provided by Šimůnek and van Genuchten (2008).

UnsatChem: The geochemical UNSATCHEM module (Šimůnek and Suarez, 1994) has been implemented into both the one- and two-dimensional computational modules of Hydrus. This module simulates the transport of major ions and their equilibrium and kinetic geochemical interactions, such as complexation, cation exchange and precipitation-dissolution (e.g., calcite, gypsum, and/or dolomite). Possible applications include studies of the salinization/reclamation of agricultural soils, sustainability of various irrigation systems, and the disposal of brine waters from mining operations.

Wetland: This module (Figure 3) simulates aerobic, anoxic, and anaerobic transformation and degradation processes for organic matter, nitrogen, phosphorus, and sulphur during treatment of polluted wastewater in subsurface constructed wetlands. Constructed wetlands are engineered water treatment systems that optimize the treatment processes found in natural environments. Constructed wetlands have become popular since they can be quite efficient in treating different types of polluted water and provide sustainable, environmentally friendly solutions. A large number of physical, chemical and biological processes are

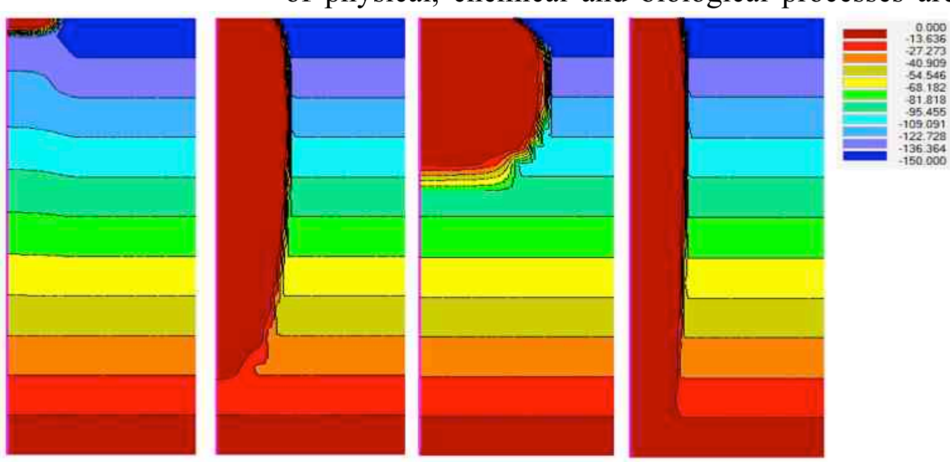


Figure 2: Pressure head profiles for the matrix (left), isotropic fracture, and fracture with K_x^A/K_z^A=10, and fracture with K_x^A/K_z^A=0.1.

simultaneously active and may mutually influence each other. The Wetland module uses two biokinetic model formulations to account for complex conditions that may occur in various types of wetlands (Langergraber and Šimůnek, 2012).

Additionally, many solute transport models within Hydrus can be adapted to describe particle (colloids, microorganisms, and nanoparticles) transport and retention. However, additional complexities may need to be considered for particle transport because of differences in the underlying physics as a result of size constraints, solid phase mass transfer, particle interactions, flow velocity, and solution and solid phase chemistry (Bradford et al., 2011).

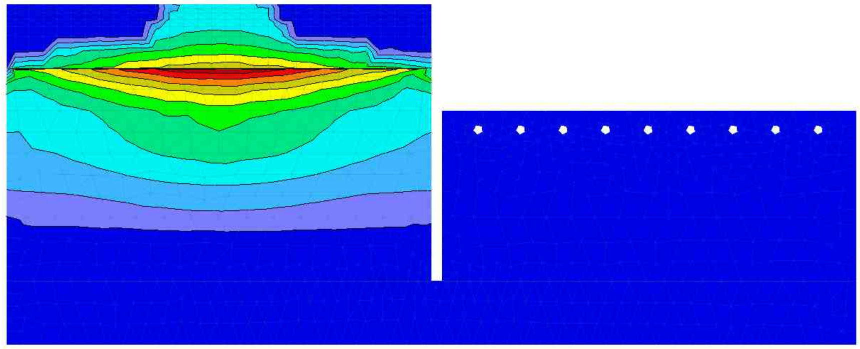


Figure 3: Steady-state distribution of heterotrophic organisms in a subsurface constructed wetland.

Our intent is to continue to develop new or improved modules for these and other processes, including surface runoff, freezing/thawing, and mechanical processes, as well as including more flexible global optimization tools. Additionally, we intend to apply these models and their specialized modules to various applications in order to increase our understanding of complex environmental systems.

Acknowledgments: I am indebted to my family and to many colleagues (in addition to those mentioned above) with whom I have been working over the years on development of various numerical models and their specialized modules: Scott Bradford, Jan Hopmans, Diederik Jacques, Max Köhne, Günter Langergraber, Dirk Mallants, Hirotaka Saito, Miroslav Šír, Navin Twarakavi, Tomáš Vogel, and many others.

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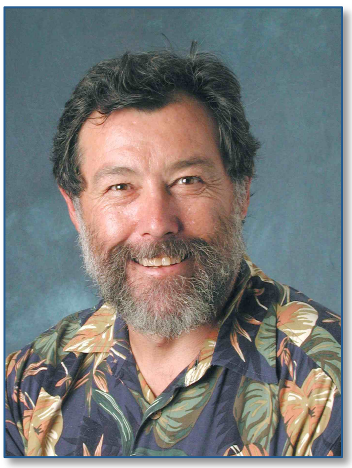
The Fellows Speak: Mountains as early warning indicators of climate change

Mark W. Williams (University of Colorado)
2012 Fellow

The panoramic splendor and complexity of mountain environments have inspired and challenged humans for centuries. These areas have been variously perceived as physical structures to be conquered, as sites of spiritual inspiration, and as some of the last untamed natural places on Earth. In our time, the perception that "mountains are forever" may provide solace to those seeking stability in a rapidly changing world. However, changes in the hydrology and in the abundance and species composition of the native flora and fauna of mountain ecosystems are potential bellwethers of global change, because these systems have a propensity to amplify environmental changes within specific portions of this landscape (Seastedt et al., 2004).



More than one-sixth of the world's population lives in river basins fed by snow or glacier melt, and thus seasonal shifts in stream flow and possibly reduced low flows caused by glacial retreat or decreased snow water storage are likely to adversely affect human and ecosystem functioning, particularly in semiarid regions. As a result, it is urgent that we improve our understanding of how hydrologic processes, biogeochemical cycling, and species distribution and abundance in high-elevation catchments will respond to a combination of changes in climate, atmospheric deposition of pollutants such as dissolved inorganic nitrogen ($NH_4^+ + NO_3^- = DIN$), and potential changes in the quantity and quality of dust deposition. Small changes in the flux of energy, chemicals, and water to high-elevation catchments may invoke large changes in climate, ecosystem dynamics, and water quantity and quality (Williams et al., 2002). The presence of a seasonal snowpack in mountain environments may amplify climate signals because of the storage and release of liquid water, solutes, and particulates from the seasonal snowpack (Seastedt et al., 2004). Moreover, meteorological, hydrological, cryospheric, and ecological conditions change greatly over relatively short distances in mountain areas because of their rugged terrain, and thus the boundaries between these systems are sensitive to small environmental changes. The harsh conditions characteristic of these environments suggest that organisms in mountain ecosystems are on the razor's edge of tolerance. Consequently, organisms – and the biogeochemical processes mediated by them in high-elevation catchments – are notably vulnerable to small changes in climate and other environmental parameters.

Hydrologic feedbacks in mountainous regions control the availability of water, influence the distribution of vegetation, dominate biogeochemical fluxes, and contribute to global and regional climate variability. Improved knowledge of the processes controlling these feedbacks will promote clearer understanding of Earth's water, energy, and biogeochemical cycles, and enable sounder management of increasingly stressed natural resources (Bales et al., 2006). However, our knowledge of these processes is limited by a lack of adequate understanding and monitoring of physical and biogeochemical processes, driven by logistical constraints associated with high elevations, including winter access problems, cold air temperatures, blowing snow, and limited oxygen availability.

Mountains are the water towers of the world, characterized by high precipitation and little evaporation due to lower air temperatures and longer snow coverage, resulting in large contributions of snow and ice melt to the runoff of lowland areas (Viviroli et al., 2007). This is especially true for the Hindu Kush-Himalaya (HKH) region, where the snow and ice stored in high-altitude glaciers in the Greater Himalaya are a source of water for almost every major river system in the region. However, a complete understanding of the regional hydrology and glaciology—including the actual contribution of snow and glacial meltwater to surface waters and groundwater—is lacking due to the same incomplete science and unresolved uncertainties discussed above. This lack of information has led to erroneous conclusions such that glaciers in the HKH region are retreating at the fastest rates in the world, that in turn major rivers such as the Ganges will become seasonally dry, and that water security for about 1.5 million people will be at risk (NRC 2012).

Recent advances in remote sensing provide new and important information on the current fate of snow and ice in mountain areas, and how changes in this resource affect biogeochemical cycling and other ecosystem services. For the HKH area, Kääb et al. (2012) used satellite laser altimetry and a global elevation model to show widespread glacier wastage in the eastern, central and south-western parts of the HKH during 2003-08. Maximal regional thinning rates were 0.66 ± 0.09 m per year in the Jammu-Kashmir region. Conversely, in the Karakoram, glaciers thinned only slightly by a few cm per year. The 2003-08 specific mass balance for the entire HKH study region was -0.21 ± 0.05 m yr^{-1}, water equivalent, significantly less negative than the estimated global average for glaciers and ice caps. This difference is mainly an effect of the balanced glacier mass budget in the Karakoram. For the mountain catchments of the Indus and Ganges basins, the glacier imbalance contributed about 3.5% and about 2.0%, respectively, to the annual average river discharge, and up to 10% for the Upper Indus basin. This new information from remote sensing instruments shows that glaciers in the HKH are not retreating at the fastest rates in the world, and that glacial ice wastage makes a very low contribution to the average annual discharge of the major rivers in High Asia.

Trujillo et al. (2012) recently examined the influence of interannual variations in snowpack accumulation on forest greenness in the Sierra Nevada Mountains of California between 1982 and 2006. Using observational records of snow accumulation and satellite data on vegetation greenness they show that vegetation greenness increases with snow accumulation and that variations in maximum snow accumulation explain over 50% of the interannual variability in peak forest greenness across the region of the Sierra Nevada. The extent to which snow accumulation can explain variations in greenness varies with elevation, reaching a maximum in the water-limited mid-elevations between 2,000 and 2,600 m. *In situ* measurements of carbon uptake and snow accumulation along an elevational transect in the region using eddy covariance towers confirm the elevation dependence of this relationship. Above 2,600 m vegetation becomes energy limited and the relationship breaks down. Their research suggests that mid-elevation mountain forest ecosystems could prove particularly sensitive to future increases in temperature and concurrent changes in snow accumulation and melt. Here we see how recent advances in remote sensing, combined with ground-based field measurements, allow us to better understand the interactions between snow processes and ecosystem structure and function.

Elser et al. (2009) show that increased atmospheric inputs of DIN to Colorado high-elevation lakes have differentially altered the supplies of N and P available to phytoplankton and shifted phytoplankton nutrient limitation from predominant N and joint N and P limitation to predominant P limitation. Lakes subjected to high amounts of deposition had higher NO3-N and total N concentrations and higher total N: total P ratios. Concentrations of chlorophyll and seston carbon (C) were 2–2.5 times higher in high-deposition relative to low-deposition lakes, while high-deposition lakes also had higher seston C:N and C:P (but not N:P) ratios. High rates of DIN deposition in wetfall thus alter planktonic community structure and trophic interactions and suggest that further increases in atmospheric DIN inputs such as those projected for many areas of the world may have major ecological ramifications for lake ecosystem structure and function, even in protected lakes far from direct human disturbance. These results show that high elevation areas of the world subjected to increasing amounts of DIN deposition have already switched from N limitation to N saturation.

An outstanding question is how will hydrologic connectivity be altered by climate change in mountain areas, and how might that change ecosystem structure and function. Hydrological connectivity in mountain areas is driven by the duration and timing of the seasonal snowpack and snow and ice melt. Robertson et al. (2012) have shown that under a warming climate, in combination with increasing windborne dust, snowpack and glacial melt will accelerate, which will result in the snowline's moving to a higher elevation, which will in turn decrease hydrologic connectivity (Figure 1). Climate change, in combination with elevated N inputs from windborne dust and regional air pollution, will cause plant species diversity to decrease as alpine areas shrink, shrubland will expand, and the landscape will become more homogeneous. Changes in wintertime temperatures and snowfall will thus dramatically affect community structure and ecosystem processes in mountain ecosystems, but the effects will be felt even in arid, low-latitude ecosystems that depend on mountain meltwater for seasonal water supplies—riverine, floodplain, agricultural, and urban ecosystems in particular. Many of these effects will be social, since some of the most populous cities and productive farmland throughout the world depend on these water supplies.

Mountain areas are sentinels of climate change. We are seeing those effects today. Furthermore, these ecosystem changes are occurring in mountain areas before they occur in downstream ecosystems. Thus, mountains are early warning indicators of perturbations such as climate change. However, the sensitivity of mountain ecosystems begs for enhanced protection and worldwide protection. Our understanding of the processes that control mountain ecosystems—climate interactions, snowmelt runoff, biotic diversity, nutrient cycling—is much less developed compared to downstream ecosystems where human habitation and development has resulted in large investments in scientific knowledge to sustain health and agriculture.

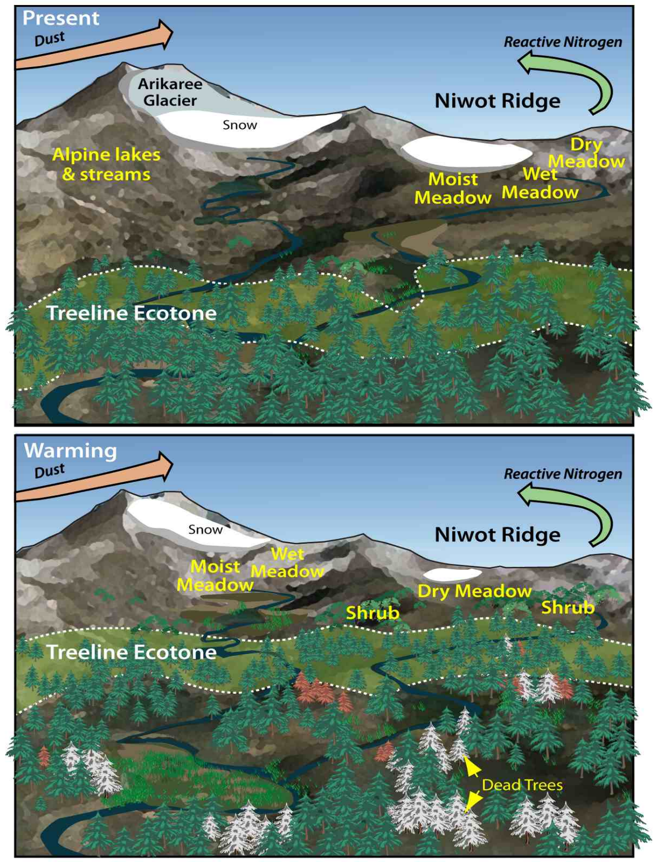


Figure 1: Expected changes in hydrologic connectivity related to cryosphere loss at the Niwot Ridge Long Term Ecological Research Network site in Colorado. As windborne dust deposition increases in a warming climate (bottom panel), snowpack and glacial melt will be accelerated, which will result in a higher snowline, a shrunken alpine area, and the expansion of shrubland, exacerbated by a climate-induced mountain pine beetle outbreak that is now decimating the subalpine forest. This figure was created by Eric Parish, adapted from Robertson et al. (2012).

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Why should hydrology, soils and critical zone research embrace the ecosystem services approach?

David A. Robinson (Centre for Ecology and Hydrology, Wallingford, UK)
Bridget Emmett (Centre for Ecology and Hydrology, Wallingford, UK)

The Millennium Ecosystem Assessment (MEA, 2005) had a huge impact on the political agenda globally. It reported on the decline of the world's ecosystems, and argued the vital importance of our life support systems in relation to human wellbeing. It was heralded as a framework bridging the science/policy divide, capable of translating our best science, and process understanding, into an easily digestible policy relevant format using values. There are those who question what the ecosystems approach delivers (McCauley, 2006), but it is still in its early days. However, it is beyond question that as a framework, 'ecosystem service' concepts shape and impact policy development and implementation at the highest levels. The ecosystems approach to sustainable development has been promoted by many international organizations including: the Conference of the Parties to the Convention on Biological Diversity (CBD), the Food and Agriculture Organization of the United Nations (FAO), The Organisation for Economic Co-operation and Development (OECD), the United Nations Environment Programme (UNEP), and the United Nations Development Programme (UNDP). Moreover, governments of countries such as the United Kingdom are adopting an ecosystems approach for national-level environmental policy development. Thus, as science communities, hydrology and soils cannot ignore this framework if we are to address wider stakeholder needs.

With it, the ecosystems approach brings a new set of terminology. Nature's stocks are termed 'natural capital', functions from which we derive benefit are 'ecosystem services', and ecosystems can be considered 'green infrastructure'; giving nature a more economic/policy-relevant feel. The definition of ecosystem services has transitioned from being, "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily, 1997) to being "the benefits people obtain from ecosystems" (MEA, 2005). Central to the ecosystem services approach is the attempt to value the benefits we obtain from nature's services. Costanza et al. (1997) generated huge interest by publishing the annual value of nature's services as US $33 trillion. This was controversial and heavily criticized; Toman (1998) pointed out that any attempt to estimate the "total value of the world's ecosystem services and natural capital" (as per Costanza et al., 1997) would be a "serious underestimate of infinity", and a similar criticism could be levelled at total valuations of a nation's ecosystem services. Despite these criticisms valuation is being developed in different forms for a range of purposes, including national accounts and decision-making tools for land management.

As earth scientists, how should we respond to this increasingly influential framework that is not only shaping policy but also the funding landscape? For instance, the European Union (EU) has already identified soil ecosystem services (Figure 1) as a priority research area in the European Union Soil Thematic Strategy. The EU is financing a number of projects incorporating soil ecosystem services including the SoilTrEC project focused on the critical zone (Banwart, 2011). Many scientists are sceptical of new frameworks that come and go; however, there are important opportunities that the ecosystem services framework offers for us to extend the application and visibility of our science, valuation can be a useful tool to this end and something we are no strangers to in terms of water and land resources.

Edwards-Jones et al. (2000) argue that documenting ecosystem service values is useful because it:

- Highlights the importance of ecosystem functioning for mankind;

Figure 1: Soils support important ecosystem services that promote human well-being, including from top left to bottom, provision of food and fibre, storage of carbon, filtering of water, and soilscapes offering aesthetic beauty.

- Highlights the specific importance of unseen, unattractive or unspectacular ecosystems;
- At a local level, can aid in identifying ecosystem services and acting as a help to decision making;
- Can aid in understanding the impacts of change and feeding back to models to improve our understanding of ecosystem function;
- Is a way of communicating value by translating to a common reference, e.g. dollars.

All of these are important for the sustainable exploitation and management of water, soil and other natural resources. Given the prominence of this framework it is important that we engage from the scientific perspective in the continued development of the framework, rather than have it imposed. There are significant challenges that can be identified in order to combine ecosystem service concepts into a workable framework for earth sciences. We identify four areas where researchers can contribute:

1) Framework development: To date, there is no accepted ecosystem service framework for soils and hydrology, though there is active discussion on how we approach this (Brauman et al., 2007; Dominati et al., 2010; Robinson et al., 2012a; Robinson et al., 2012b). More broadly, there is still much discussion and refinement of the ecosystem services framework in general.
2) Quantifying water and soil resources, their stocks, flows, transformations: Combined monitoring and modeling of natural resources need to be improved, and indicators and metrics appropriate for evaluating natural capital and ecosystem goods and services identified; along with better understanding of how they change.
3) Valuing water and soil resources in terms of ecosystem services: Cost-benefit analysis is often used by economists to evaluate management options, but valuation is much broader than this, it may or may not be monetized, and is contextually dependent. Valuation can be used for better resource representation in national accounting, e.g. with GDP indicators, or as a means for decision making and trading-off management options. Valuation is already used in cases of soil and water pollution to assess restoration costs.
4) Developing management strategies and decision support tools: Good decision making requires underpinning by good evidence; this requires monitoring and/or decision support tools. Models are playing an increasingly prominent role in our everyday life from weather forecasting to irrigation scheduling. However, there is a need for broader, more integrated, environmental models, such as the InVEST model or LUCI, formerly known as Polyscape.

Hydrology and soil science should embrace this opportunity to promote the value of soil and water functions, going beyond food and water security for society and human well-being, so as to demonstrate that all soil and water life support functions need to be properly recognized within an ecosystems approach. This requires action by the hydrology and soils communities to develop the soil and water components of the ecosystems approach, by:

1) Creating the appropriate frameworks;
2) Identifying appropriate measurement and monitoring programs with agreed upon metrics to develop the evidence based on environmental ‘state and change’;
3) Developing the means to value soil and water ecosystem services;
4) Engaging in the development of decision support tools and models that incorporate ‘soil and hydrological change’.

Ecologists began to move forward with framework development and, in doing so, recognized the vital role of soil and water resources and processes. But now, our communities need to infuse the knowledge and wealth of information we have into robust, practical frameworks, from which we will also benefit from the resulting synergies with other disciplines. Involvement of multiple disciplines is needed to develop and agree on a way forward, and then apply this to the ecosystems approach. Enormous opportunities will be generated by the framing of future hydrological and soil science research needs in the context of contributing to an ecosystems approach that can inform policy and protect the vital functions of soil and water that support human well-being, the Earth’s life support systems, and the diversity of life on this planet.

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On the connectivity of groundwater and surface water

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Water, solutes, energy, and organisms continuously move between surface and subsurface hydrologic systems. These interactions take place over a wide range of spatio-temporal scales, from short-scale interactions, such as hyporheic exchange, to large-scale interactions, such as regional groundwater flow. Flow at the watershed scale can be conceptualized as a nested system of flow paths that evolve over time and space in response to weather and climate variability. The nature of these interactions is fundamental for the storage and yield of water, as well as its biogeochemical evolution, thus controlling the transport, retention, and transformation of solutes, and therefore playing a fundamental role in ecosystem functioning. A mechanistic understanding of groundwater-surface water (GW-SW) interactions is critical for consistent water resources management, restoration, and planning under present and future weather, climate, and human demand.

Complementary observational and modeling studies will continue to be critical for our understanding of GW-SW interactions. Laboratory and field observations are essential for identifying the dominant processes and spatio-temporal scales. These observations shape our conceptualization of the systems and guide the selection of key processes that need to be included in the models. Hyporheic zone restoration is an example of this approach, where extensive data collection and modeling are done before, during, and after restoration to quantify the success of different techniques and their ability to return natural systems as close as possible to their original state (Hester and Gooseff, 2010). The techniques used for quantifying both the magnitude and effects of GW-SW interactions depend on the type of interaction being targeted, as a result of the nested nature of these processes covering a broad range of scales, from exchange driven by ripples — occurring at scales of centimeters and minutes — to topography-driven, deep groundwater flow taking place at the regional scale and over thousands of years and longer.

Advances in instrumentation, tracers, and noninvasive geophysical techniques have made possible a more detailed quantification of GW-SW interactions. Schneider et al. (2011) present a review of some of the techniques commonly used to quantify short-scale interactions. For example, a suite of environmental tracers can be used to estimate sources of water, residence times, and the amount of exchange for both short-scale (e.g., Lamontagne and Cook, 2007) and large-scale (e.g., Gardner et al., 2011) interactions. At the reach scale, the use of artificial reactive and non-reactive tracers has become particularly useful, since they interrogate the system at spatial scales that involve multiple exchange drivers and give an integrated measure of short-scale interactions. The work of Payn et al. (2009) is an interesting application of this technique, where a series of tracer injections along consecutive headwater stream reaches are used to estimate net change in transient storage (a measure of short-scale exchange), discharge, and net gains and losses to longer flow paths along a mountain-to-valley transition stream. At the watershed scale, the use of artificial tracers is commonly impractical, and environmental tracers become a better tool. For instance, Gardner et al. (2011) and Frisbee et al. (2011) used a combination of water chemistry, stable isotopes of water, and Helium-4 or Carbon-13 to identify important contributions of deep groundwater to watershed runoff. In these cases, the techniques used are incapable of quantifying the importance of local scale interactions, but capture contributions from longer flow paths, which have important consequences for chemical evolution, weathering, and response to climate variability.

The GW and SW subsystems also exchange energy and solutes. This transport is reflected in observed temperature and solute patterns, which can be used as a proxy for the extent and magnitude of GW-SW interactions. Temperature within the stream sediment, along the stream channel, and in the shallow alluvial aquifer surrounding the stream (see Figure 1A-C) can be measured with nested in-stream temperature sensors, fiber optic distributed temperature sensors (FO-DTS), and temperature sensors in observation wells, allowing for the quantification of exchange both at the point and reach scale. The use of spatial mapping, time series analyses, and mathematical models is essential for an adequate interpretation of these observations. More recently, the use of non-invasive geophysical techniques, such as ground penetrating radar and electrical resistivity, has become common practice to characterize subsurface architecture and its role in the connectivity of SW and GW and to image the extent of the GW-SW mixing zones (e.g., Schneider et al., 2011). Figure 1E presents an electrical resistivity survey at a study site in northern New Mexico. This image shows the complex subsurface architecture of meander bends and captures high-resistivity (dark-red) and low-resistivity (dark-blue) layers, possibly associated with fine and coarse sediments, respectively.

At smaller scales, flume experiments

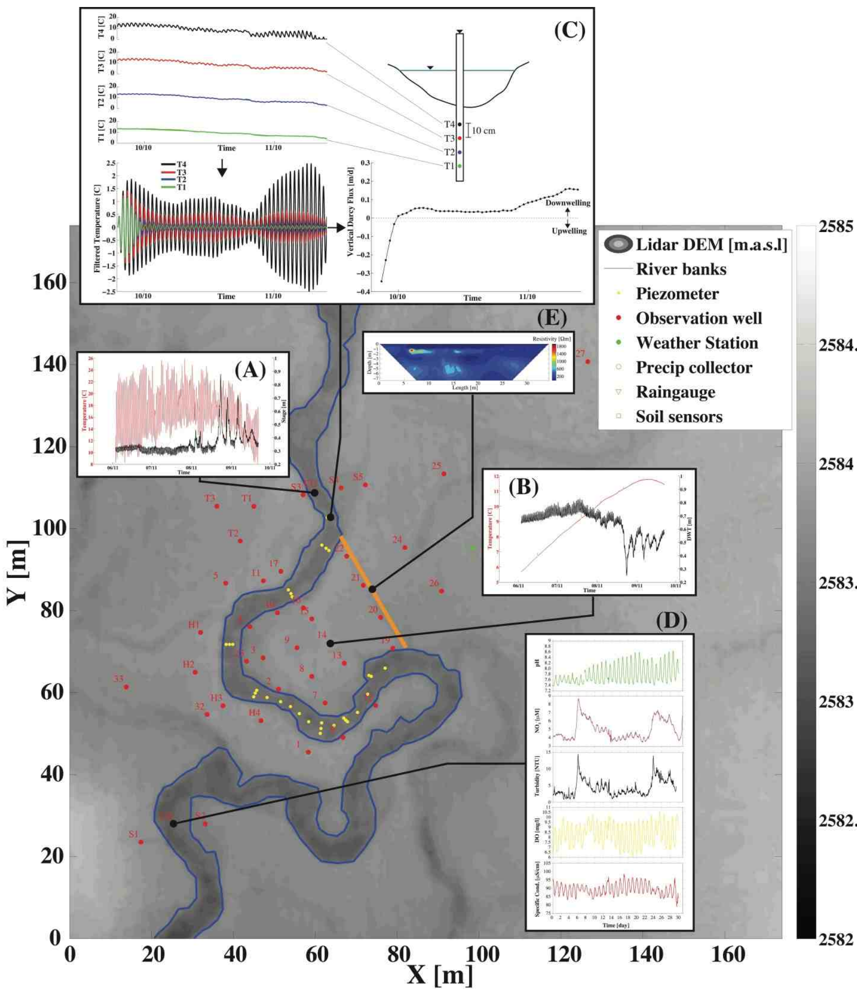

Figure 1: Experimental study of sinuosity-driven hyporheic exchange at the Valles Caldera National Preserve, New Mexico. Insets (A) and (B) correspond to the stage (black line) and temperature (red line) time series in the stream channel and observation well 14, respectively. (C) Illustration of in-stream multilevel temperature sensors and the estimation of vertical Darcy fluxes. (D) From top to bottom, high-resolution time series of pH, nitrate, turbidity, dissolved oxygen, and specific conductivity. (E) Electrical resistivity survey.

have led to mechanistic understanding of short-scale SW-GW interactions (Elliott and Brooks, 1997; Tonina and Buffington, 2007; Sawyer et al., 2012). These analog systems make it possible to separate the individual effects of geomorphic features driving exchange, e.g., ripples, dunes, and riffle-pool sequences; driving forces, e.g., discharge and groundwater upwelling; and signaling thermal, biogeochemical, and biological signals in a controlled environment. These experiments are also benchmarks for models.

Modeling has become critical for tackling the complexity of GW-SW interactions. The degree of complexity of these modeling efforts ranges from, for example, simple analytical solutions of groundwater flow (e.g., Elliott and Brooks, 1997), one-dimensional in-stream transport models (e.g., Runkel and Chapra, 1993), to complex models that incorporate multiple processes (e.g., Janssen et al., 2012) and to fully-coupled and physically-based watershed models. The computational demand of these models exponentially increases with the number of processes modeled and space and time domains. Thus, high-performance computing has become increasingly popular, leading to models with a degree of complexity and detail that was impossible a decade ago. At the local scale, multiple studies have focused on the role of individual topographic features driving exchange, for example, ripples and dunes (e.g., Janssen et al., 2012), riffle-pools (Tonina and Buffington, 2007), meanders (Gomez et al., 2012), and stream logs (Sawyer et al., 2012). At the reach scale, artificial tracers and transient storage modeling have typically been used to quantify short-term storage. This approach gives an integrated measure of the short-scale interactions taking place along a stream reach. The dominant processes within the reach are reflected in the measured breakthrough curve. In general, these types of models assume a dual continuum and are used to estimate in-stream and hyporheic transport properties by fitting the results of solute injection experiments. The one-dimensional transport with inflow storage model (OTIS) has been widely used for this purpose. Transient storage models like OTIS usually capture the early-time solute breakthrough curve, but have a poor representation of the late-time behavior, which characterizes longer and deeper hyporheic flow paths and, therefore, has important implications for biogeochemical evolution and retention. To overcome this drawback, new conceptualizations have been proposed, mainly focusing on more versatile residence time distributions. For example, the multi-rate mass transfer model, continuous time random walk model, solute transport in rivers model, and variable residence time model. At the watershed scale, multiple fully-coupled, physically-based distributed models that couple surface and subsurface processes have become popular, for example PARFLOW, HydroGeoSphere, and GSFLOW.

To summarize, GW-SW interactions are critical for assessing water availability and quality as well as the resilience of hydrologic systems to change. We have gained a great deal of understanding during the last three decades, and we expect a wave of new applied and theoretical advances as our observational and modeling capacity improves. Three aspects deserve special attention: (i) collection of high-resolution water quality data over long-term periods, (ii) better models capable of capturing the interplay between biological and hydrological processes, and (iii) an adequate treatment of heterogeneity. Figure 1D presents high-resolution stream water quality measurements at a temporal resolution of 15 minutes over 30 days during the monsoon season in the Jemez River, NM. The water quality at this location is highly variable at the seasonal, diurnal, and event scales and this variability can be associated to multiple and concurrent hydrologic, chemical, and biological processes, which cannot be observed or understood unless we sample at this temporal resolution. Traditional sampling campaigns have much coarser temporal resolution, disguising the variability associated with multiple complex processes and undoubtedly leading to incorrect interpretations. In this case, refinement in observations opens the door to new and exciting questions and hypotheses. Second, the use of multiphysics models is a critical stepping stone towards a holistic modeling approach that links the biological and physical drivers controlling exchange and water quality. These types of models are gaining popularity and require adequate benchmark observations that not only focus on the flow characteristics of exchange but also in the resulting biological and chemical patterns. Finally, we are able to observe and measure the degree of heterogeneity controlling GW-SW interactions; however, our modeling approaches usually assume simplistic representations of this variability, if they account for heterogeneity at all, so the question is whether heterogeneity is a first-order control and should be included in our models.

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Airborne electromagnetic surveys for hydrogeophysical applications

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Airborne electromagnetic (AEM) surveys play a unique and valuable role in hydrogeophysical studies. They provide substantially greater spatial coverage than can be achieved with ground-based geophysical methods (Robinson et al., 2008) and also facilitate access to remote or inaccessible terrain. Although AEM systems cannot match the spatial coverage of satellite-based remote sensing platforms, they have the advantage of being sensitive to subsurface physical properties to depths of up to several hundred meters. This combination of scale, depth sensitivity, and good spatial resolution allow AEM data to inform watershed-scale and larger problems that are difficult to address with limited point data.

Here, we discuss some recent advances in the use of AEM data for hydrologic applications. While originally developed within the mining industry, AEM systems have been applied in many groundwater-related studies, including saltwater mapping (Kirkegaard et al., 2011), developing hydrogeologic frameworks (Abraham et al., 2012), permafrost mapping (Minsley et al., 2012), and environmental studies (Lipinski et al., 2008). Numerous other examples can be found in several recent review articles (Siemon et al., 2009 and references within).

As the result of an electromagnetic method, AEM data are sensitive to subsurface electrical properties that, in turn, can often be related to lithology, volumetric water content, and/or salinity. Because of the non-uniqueness inherent to geophysical methods, it is necessary to calibrate results to known borehole or geologic information on a site-by-site basis to understand the controls on electrical properties in the subsurface.

AEM surveys rely on the physics of electromagnetic induction, governed by Maxwell's equations (Christiansen et al., 2006; Siemon, 2006). Measurements can be made either in the frequency domain (FDEM) or time domain (TDEM), and follow the same principles as their ground-based counterparts that have been widely used in hydrogeophysical applications. While FDEM systems tend to have better near-surface resolution, their depth of sensitivity is typically limited to 100 m or less, whereas TDEM systems can detect features at several hundred meters depth, but often with limited near-surface resolution. Both resolution and depth of investigation, however, are partly controlled by the actual subsurface resistivity structure.

There are numerous commercial and research AEM systems with different specifications (Christiansen et al., 2006; Siemon, 2006; Siemon et al., 2009). Groundwater-related AEM surveys are typically acquired with a helicopter-towed system, with nominal instrument elevation 30 m above the ground and speed 80 – 100 km/hr. Data are typically sampled at 10 Hz, resulting in one data point every ~3 m, which is highly oversampled compared with the lateral footprint of the system, which is tens to hundreds of meters. At this rate of acquisition, a 1 km electrical resistivity profile that might take one day to acquire on the ground can be flown in less than a minute. On a cost-per-line-kilometer basis, this makes AEM surveys extremely cost effective, though total survey costs are typically much higher than ground-based campaigns due to the large number of line-kilometers flown and mobilization costs.

A typical workflow for an AEM survey is illustrated in Figure 1. The system is flown over a series of regularly spaced flight lines (Figure 1A), with data recorded as a function of time or frequency, depending on the system, continuously along the line (Figure 1B). These data, along with system specifications and measured flight elevation, are inputs for an inversion algorithm that estimates the distribution of electrical conductivity (or resistivity) depth images (CDIs) as a function of depth (Figure 1C). By inverting an entire survey grid, high-resolution map products such as a conductivity depth slice (Figure 1D) can be produced at target depths of interest.

Inversions can be one-dimensional- i.e., they operate on each data sample independently; quasi three-dimensional, where one-dimensional physics is combined with spatial constraints enforced between neighboring models; or fully three-dimensional, where the physics and lateral constraints are in three-dimensions.

In western Nebraska, where water resources are a critical part of irrigation needs and accurate groundwater models are crucial for better informing management decisions, an ongoing project integrates AEM data with ground-based

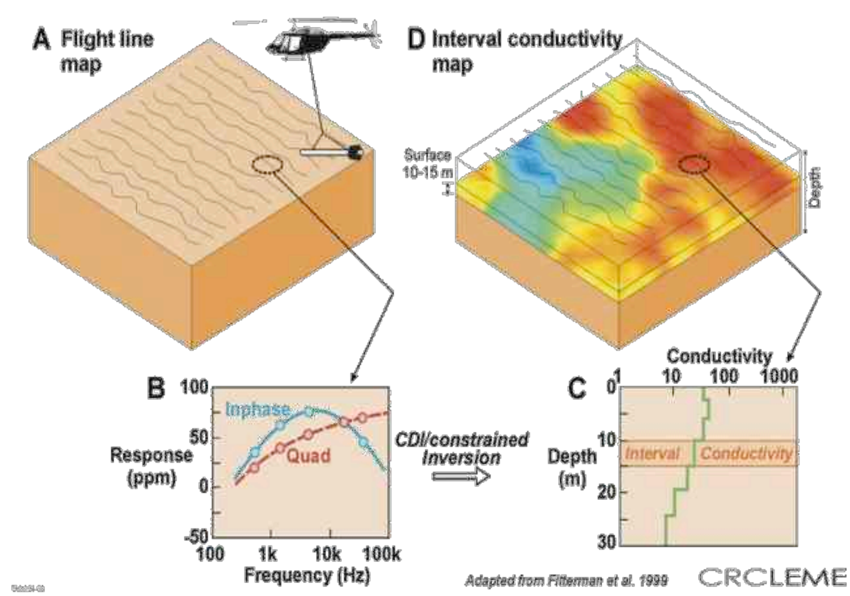

Figure 1: Typical work flow for an AEM survey (from Fitterman and Deszcz-Pan, 1999). Conductivity units in (C) are S/m.

geophysical and hydrologic information. More than 10,000 line-km of AEM data were acquired with multiple systems from 2008 - 2011 in the areas surrounding the North Platte River and Lodgepole Creek, a tributary to the South Platte River (Abraham et al., 2012). A large database of borehole logs helps provide context for the features identified by the AEM data, which, in turn, are used to extend interpretations away from the boreholes. Additionally, ground-based geophysical soundings, including TDEM and nuclear magnetic resonance, have been acquired to help validate and extend the AEM interpretations.

In the western Nebraska study area, AEM data are primarily sensitive to changes in lithology. A typical AEM section is shown in Figure 2A, where the upper resistive material (red-orange) corresponds to the Quaternary alluvial aquifer over a Tertiary siltstone aquitard (blue), and is in agreement with boreholes and ground-based geophysical soundings near the flight line.

What is useful for the project hydrologists, however, is not cross-sections of electrical properties, but rather interpreted hydrogeologic information that can be incorporated into a groundwater model. To achieve this, we manually digitized the base of aquifer geometry (dots in Figure 2A) based on the AEM cross-sections and borehole dataset. An example of a generalized hydrogeologic section is shown in Figure 2B. Here, it is clear that the AEM-derived base of aquifer (top of the brown region in Figure 2B) is more detailed and thicker (in portions of the section) than the base of aquifer defined from borehole data alone (black line in Figure 2B) and has also increased the estimated saturated aquifer thickness in portions of this section.

Substantial improvements in groundwater models have been realized by incorporating the three-dimensional geometry of the aquifer material inferred

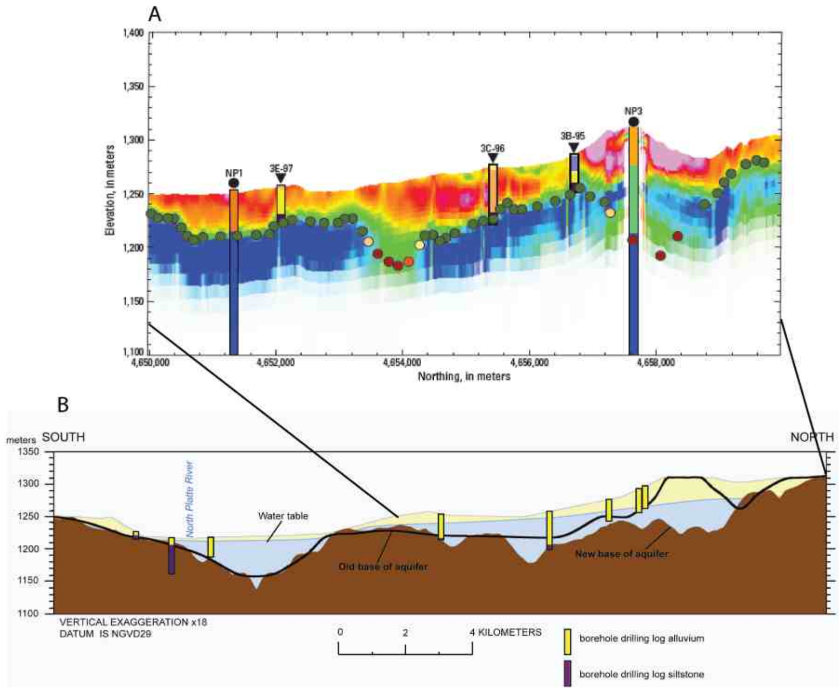

Figure 1: Typical AEM electrical resistivity section (A), with nearby boreholes and ground-based geophysical soundings overlaid. Dots represent the manually picked base of aquifer. (B) Interpreted base of aquifer geometry using the AEM data, compared with the previously assumed base of aquifer (Abraham et al., 2012)

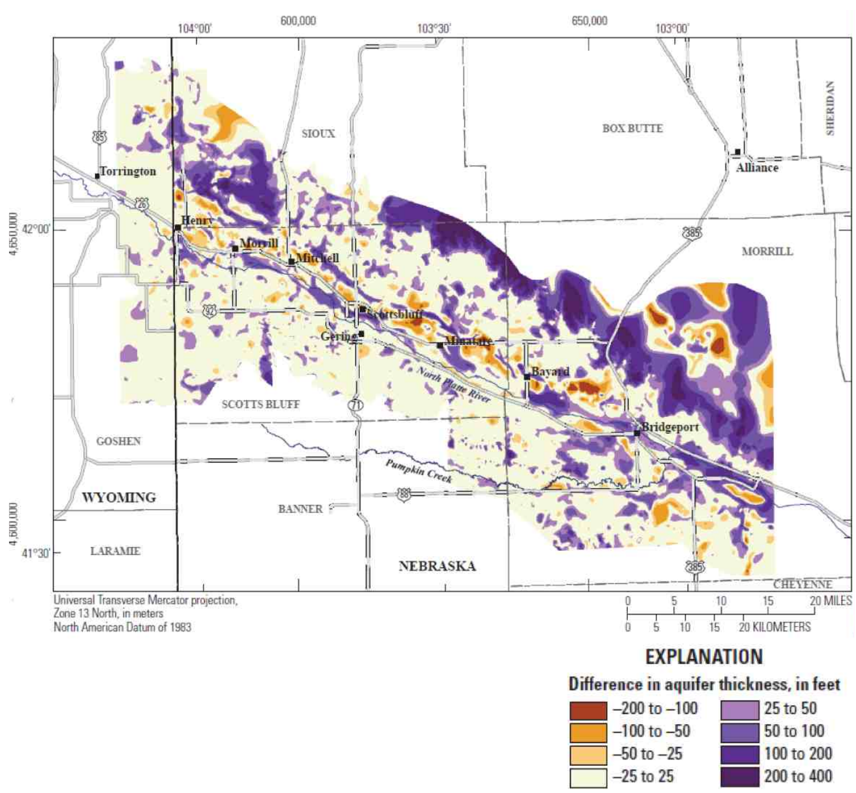

Figure 3: Change in aquifer thickness along the North Platte after integration of AEM-derived aquifer geometry (Abraham et al., 2012).

from the AEM results into the groundwater model. Figure 3 shows the change in thickness of the aquifer along the North Platte region of the study area where AEM data were incorporated. For the entire area of the airborne geophysical surveys, an additional 458 GL (3.7 million acre-feet) of additional water storage was identified (34% increase), with approximate value of $124M.

The use of airborne electromagnetics for informing hydrologic models is becoming widespread around the world. AEM data are unmatched in terms of spatial coverage and depth of investigation, and advances in instrumentation and processing methods continue to increase the value of these data. But because AEM provides an indirect measure of hydrologic properties, a primary challenge is the development of methods to directly integrate AEM data with other hydrologic, geologic, and geophysical information to produce improved groundwater models. Ongoing efforts to achieve these goals in Nebraska and other study areas are part of the HyGEM international collaborative project (http://geofysiksamarbejdet.au.dk/en/hygem/project-description/). We believe that there is a bright and important role for AEM data to play in the characterization and management of hydrologic systems.

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Hydrology Student Community Meeting

Rolf Hut (Delft University of Technology)

Let me introduce myself: I am Rolf Hut, Ph.D. student at Delft University of Technology and the student representative for the Hydrology Section (a position that is specified in the Section bylaws, but has been somewhat inactive in the recent past). During my term, I want to mobilize the hydrology student community to become more active. In my humble opinion, most students have their own ideas as to what they can do for AGU, and what AGU could do for them. It is therefore paramount to engage the students and hear their input. To that end, I am organizing a hydrology student get-together on Wednesday December 5, 6:45 AM-7:45 AM at the San Francisco Marriott, Sierra H. Based on a survey I conducted a few weeks ago, a fair number of students already have indicated their intention to attend this meeting. If you plan to attend and have not already done so, please confirm your attendance with an email to me (r.w.hut@tudelft.nl). The main goal of the meeting will be to compile a list of activities that we can undertake in 2013.

New conflict of interest policy for Section and Union Awards

At its November 15 (electronic) meeting, AGU Council adopted a new conflict of interest policy proposed by the Union's Honors and Recognition Committee. Key elements of this policy, which applies to all Union (e.g., medals, prizes, and fellows) and section (Hydrologic Sciences Award, Hydrologic Sciences Early Career Award, and Langbein Lecturer) awards are:

- The following relationships need to be disclosed (but are not disqualifying) in any nomination: dean, departmental chair, supervisor, supervisee, laboratory director, business partner, employer, employee, research collaborator or co-author within the last three years, and/or individual working at the same institution or having accepted a position at the same institution.

- The following relationships are disqualifying: previous doctoral or graduate advisor, graduate student, or postdoctoral fellow *can never* write a nomination letter. Individuals with such relationships *may* write a supporting letter *after five years of terminating their relationship with the nominee*. Termination of a relationship is defined as a) nominee no longer being paid by supporter; and b) nominee no longer supported under the same grant or contract.

These policies go into effect for new nominations starting 1/1/13; however, they will not apply to holdover nominations (apparently for a period of three years, although holdover nominations normally are not considered for more than two years beyond the initial nomination). It is not clear how new nominations that do not comply with the policy will be handled (i.e., will they be rejected outright, or will the nominator be asked to resolve the conflict?), so it is best to be sure that there are no conflicts at the outset. Questions regarding the application of the policies to Section awards should be directed to the Section President, and to Union awards to the Union Honors and Recognition Committee.

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