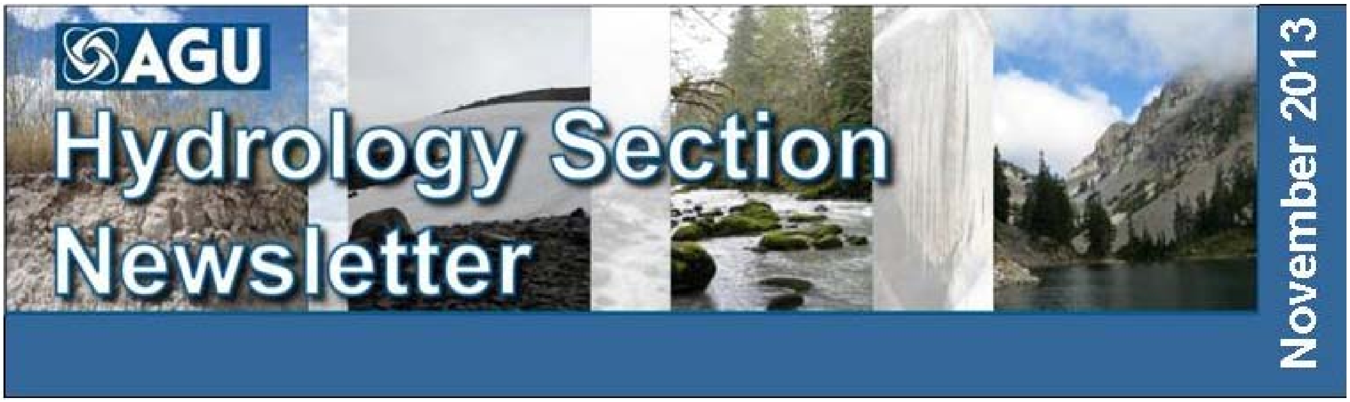

From the Section President

Eric F. Wood (Princeton University)

Paying for the Section – a Financial Report.

Recently I had lunch with a colleague and long-standing AGU Hydrology Section member. The conversation turned to the various section activities related to the Fall meeting and their costs. So my colleague asked "How much money does AGU Headquarters (HQ) provide to support the section's activities?" To his surprise, the answer is *zero* – like in nothing (except for partial support towards the luncheon at the Fall Meeting.).

Since then, I've asked a number of section members what they know of the section's finances – our budget and source of money to support the activities. The replies were uniform: they know little to nothing, and they have never heard it discussed. I must confess that I knew virtually nothing about the section's finances until I became the President-elect, but even then it wasn't until I became president that the details started to sink in!

I want to use this newsletter article to inform you on the section's finances. To the extent of my understanding I'll also try to provide a historical perspective and to share how "initiatives" from HQ impact what we do.

The section has two budgets: one is the Hydrology Fund, which funds all the section activities and thesecond is the "Horton Research Fund" that funds the two to three graduate research awards given out each year. The Hydrology Fund supports everything else we do. What is "everything else"? Let me list them.

<u>Expenses</u>

1. Subsidizing student tickets at the section's business luncheon. To foster inclusiveness across our section, we subsidize, to the tune of $20/ticket, 125 student tickets to our business lunch. As disappointed students will tell you, these sell out quickly. *The cost to the section: $2500*.

   (To the shock of the readers who've attended the business lunch to pay $38 for a cup of soup and chicken Caesar salad, AGU subsidizes that by

Call for Nominations: Student Representative, Hydrology Section Executive Committee

The Hydrology Section Bylaws (http://hydrology.agu.org/bylaws.html) state the Section's Executive Committee should include one student representative. We are seeking nominations for this position (they can be self nominations), which provides a unique opportunity for a student AGU member to gain practical experience and insights into the Hydrology Section. Attendance at the Fall Meeting (2014 and on), and attendance at the Executive Committee meeting held there, is required. Participation in one or more conference calls per year will be required as well. Nominees should expect to be student members (i.e., not complete their graduate studies) until at least June 30, 2015. Please make nominations to the Section Secretary, Terri Hogue (thogue@mines.edu). Candidates should provide a statement describing their participation at AGU meetings and student activities sponsored there, and the basis for their interest in the position. Nominations should be received by January 15, 2014.

$20/ticket, pays $2200 to have a computer and projector provided and $90 for a microphone – San Francisco isn't cheap!)

2. Outstanding Student Presentation Awards (OSPA). In recent years AGU has encouraged recognition of our younger colleagues, and in particular students who are first time presenters and primary authors. The OSPA program continues to expand and I thank those of you who have participated as participants and judges. Last year over 300 presentations were judged – the students request to participate. We've awarded the top 11 students at the FM (and 1 from the MoA) a $200 prize. *Cost $2400.*
3. Historically, the section has provided travel and meeting support for the section's awardees: Langbein Lecturer, Hydrologic Sciences Award, Hydrologic Sciences Early Career Award, following the lead of AGU for Union awardees. This has included some travel, registration and complimentary luncheon tickets. This year I've asked the awardees to forgo the travel and registration support unless it can't be secured from their research projects/institutions. Since I must submit a 2014 budget to AGU, which must be followed, I've budgeted 1-day registration, 2-days of hotel and airfare for the three awardees to attend and receive their awards. *Projected cost $4600.*
4. Other expenses of the Horton Research Grant awardees. Traditionally, the section has provided the students with registration for the Fall Meeting (~$225) and Section luncheon tickets (~$38) so they can actually attend and receive their awards! AGU HQ doesn't define these expenses as "travel", so the Horton Research Fund can't pay. *Cost is approximately $800*
5. Students and Early Career Reception. AGU's strategic plan has a thrust to enhance the participation of our students and early career colleagues in AGU and in particular the FM. Our student executive committee member, Rolf Hut, surveyed student members and held a meeting of interested students at the 2012FM. They asked if the section could sponsor a reception for the section's students and early career colleagues. I have agreed to sponsor this. It is a ticketed event (charge $7) on Tuesday evening (6-8pm) in the Marriott, but to provide a few snacks (chips and nuts), pay for the bartenders, and offset the beer cost, it'll *cost the section $3000.*

Total estimated Hydrology Fund expenses: $13,300

6. The "Horton Research Fund" provides a $10,000 award that can assist in the research expenses related to graduate research. Two or three awards are given each year on the recommendation of the section's Horton Research Grant Committee. In addition to the awards, partial travel support ($500 for domestic winners, $1000 for international winners) to attend AGU when receiving the award is also provided by the fund.) The Horton Research Fund is very healthy and sustainable to provide these awards from its investment returns. AGU is very clear that the gift's deed restricts the funds use to graduate student research support.

Total estimated Horton Research Fund expenses (for 2013): $31,500

Income.

As I mentioned before, the section runs on donations from our section members. The donations to the section over the last two years are: 2011: $10,089; 2012 $8,562. Looking at the 2013 donations to date, I project 2013 to be ~$6500. Thus the projected *deficit* for 2013 is approximately $6,800. *Last year we had only 53 donations*, which ranged in size from $5 to $500. I'm grateful for each one, regardless of size. To put this into context, we have over 7000 members who list the section as tier primary affiliation with AGU, and over 2700 presentations at this years Fall Meeting .

Currently the section has ~$35,000, down by $8,000 (the 2012 deficit), which is projected to fall further by $6,854 – the 2013 deficit – to end 2013 at $28,148. Clearly this isn't sustainable, and limits new or expanded activities. (For example having a Hydrology Section business reception would be much more expensive that the luncheon, even if it were ticketed at (say) $15.

Why are donations falling? I think there are two reasons for the number of donations and the amounts have fallen in recent years. Two years ago, AGU increased its membership fee from $20/year to $50/year. It is my belief that many members who use to donate (say) $25 on top of the $20 membership have stopped doing so. Also, AGU has increased its own list of "worthy", but non-section donation options – I counted over 65! So it's not surprising that the Hydrology Fund gets lost among all the others. I know colleagues who donate to other AGU activities in part because they are unaware of the needs at home – their section!

My plea….The hydrology section relies on your good graces and wonderful loyalty to help support our activities – most of which go to the section's students and early career colleagues activities. When you pay your 2014 dues, kick in the price of a few lattes, or a dinner for the section. It'll be highly appreciated. If you are a Supporting Member, direct that contribution, or most of the contribution, to the Hydrology Fund. Thank you .

FALL MEETING HIGHLIGHTS

Function	Date	Start Time	End Time	Location	Room
Langbein Lecture (preceded by presentation of an AGI award to John Bradehoeft, the Section Early Career Award and Hydrologic Sciences Award)	12/10/13	10:20AM	12:20PM	Moscone South	104
Hydrology Business Meeting and Lunch	12/10/13	12:30PM	1:30PM	San Francisco Marriott Marquis	Salon 8
Hydrology Student and Early Career Reception	12/10/13	6:30PM	8:00PM	San Francisco Marriott Marquis	Salon 9
Hydrology Section Student Committee Meeting	12/11/13	6:45AM	7:45AM	Moscone North	113
Hydrology Technical Chairs Meeting	12/11/13	12:30PM	1:30PM	Moscone North	125
Honors Ceremony	12/11/13	6:00PM	7:30PM	San Francisco Marriott Marquis	Golden Gate B
Honors Banquet	12/11/13	8:30PM	12:00AM	San Francisco Marriott Marquis	Salon 8-9
Hydrology Section Executive Meeting	12/12/13	6:45AM	7:45AM	Moscone North	110

FALL MEETING SESSION PICKS

Monday

Uncertainty in Water Management, part 2: Risk Analysis, Decision Support and Law, with special focus on Hydrometeorological Scaling from Continents to Watersheds.

Oral session H14G (Mascone West 3020. Posters H21I)

Invited talks by Dan Tarlock 4:15-4:30PM, Distinguished Professor of Law, Chicago-Kent College of Law "The Necessary Legal Elements of Adaptive Management" and Paul Weiland 4:30-4:45PM, Nossaman LLP, "Can law keep up with science: resource management in a fast-paced world"..

<u>Tuesday</u>

Hydrological change and water systems: feedbacks, prediction, and experimental management.

Oral sessions H21N, H23J, H24B (Virtual Option) (Mascone West 3002) Posters H31B

The IAHS Scientific Decade 2013-22, "Panta Rhei – Everything Flows". The session addresses the inter-connected problems of hydrology and society by promoting interdisciplinary approaches to monitoring and data analyses that connects socio-economic sciences and geosciences. Notable talks on the shrinking water supply in the Colorado River basin under climate change; global experiences in managing freshwater ecosystems through use of adaptive management, rain harvesting/conservation of wetlands to meet growing water supply demand; and strategies for dealing with evolving water markets.

<u>Wednesday</u>

Water Sciences Pop-Ups *Oral session ED31F (Mascone South 301*)

Great session for student networking. In this new session, graduate students will give 5 minute oral presentations on their research and vision of the future of water sciences. A hands-on workshop highlighting effective science communications skills will follow and is open to all.

<u>Thursday/Friday</u>

Progress, Challenges, and Opportunities for Water and Environmental Research in China and Southeast Asia

Oral session H44F (Mascone West 3011); Posters H51N (Friday)

AGU Hydrology opens an international dialogue of hydrology research in Fall Meeting 2013 with a focus on China's water and environmental problems. The session is cosponsored by the International Association of Chinese Youth in Water Sciences (CYWater).

Hydroclimatic Extremes.

There are a number of sessions focusing on hydrologic extremes. All the oral sessions will be broadcasted in real time through the AGU website. Of particular interest to the community may be:

H41E. Hydroclimatic Extremes: Estimation and Forecasting I Posters.

H41J. Statistical Modeling of Extreme Precipitation I Posters

H43N. Statistical Modeling of Extreme Precipitation II *(Mascone West 3011)*

H44C . Hydroclimatic Extremes: Estimation and Forecasting II (Virtual Option) *(Mascone West 3002*)

H51Q. Hydroclimatic Extremes: Estimation and Forecasting III (Virtual Option: On demand only), *(Mascone West 3002)* A special presentation on the revised Bulletin 17B guidelines (or Bulletin 17C) will be given by Dr. John England (H51Q-3, 8:30 – 8:45AM)

H52B. Hydroclimatic Extremes: Estimation and Forecasting IV (Virtual Option: On demand only). *(Mascone West 3002).* Invited speakers Dr. Ken Kunkel and Dr. Enrico Scoccimarro on the topic of changes in extremes due to climate change.

Open-Source Programming, Scripting, and Tools for the Hydrological Sciences

Oral Session H51R (Friday) (Moscone West 3020); Posters H43E (Thursday)

<u>Must see session for students interested in modeling</u>. Fernando Pérez, lead developer of the Ipython software and winner of the 2012 Award for the Advancement of Free Software, will speak at 8:15-8:30 AM. Fernando, a research scientist at the Brain Imaging Center at U.C. Berkeley, will present his work on interactive and parallel computing across disciplines using Ipython in an attempt to engage the geoscience and hydrology communities.

From the Section President-Elect Investing in the Next Generation

Efi Foufoula-Georgiou (*University of Minnesota*)

November 2013 marks the 83rd anniversary of the Hydrology Section of AGU. In its first annual meeting, Robert Horton (vice-chair of the section) presented his seminal analysis of the field of hydrology (Horton, R.E., 1931, "The field, scope, and status of the science of hydrology"). Since then, the AGU Hydrology section has grown tremendously in scientific scope, membership, and status, becoming the largest individual section of AGU (currently 7180 members). As hydrologic science stands at the epicenter of understanding our changing planet and its response to climatic and human actions globally, regionally and locally, our section will continue to grow in numbers, science, and impact. I want to propose that continuous healthy growth of our section rests on our efforts to foster the vitality of hydrologists of the next generation - through the fostering and mentoring opportunities we provide to them, and our willingness to both listen to them and let them lead.

I am very pleased to report that our young colleagues possess not only impressive talent in leading excellent science but also skills in leading change to better serve the future of our science. Indeed, our young hydrologists have already perceived the need for the creation of a tighter community for themselves: a forum within which they can exchange ideas, seek opportunities, interact more closely, grow intellectually, and reach out to "the establishment" with ideas for advancing their vision. They have advanced the idea of establishing a "Young Hydrologic Society (YHS)" and discussion is going on as to whether this should/could be an independent society or be organized around and across existing societies, such as AGU, EGU, IAHS, etc. It is our responsibility to respond and support such early-career networking ideas and assess what "organizational change" of our section would best facilitate them.

Along these lines, our initial step is to hold the first "Young Hydrologists Social Networking event" at the Fall 2013 AGU meeting (Tuesday evening). As discussed in our President's letter, this event requires resources to be sustained. The idea of adding a donation option to our Fall meeting registration in support of the "NextGen Hydrologists" event has been brought up to the AGU Council for discussion. Your contributions to the section are very important in creating a strong

community, and in advancing participation, recognition, and engagement of our section members.

The Fall meeting is a mixing place for academia, federal agencies, the private sector, and NGOs from all over the world. Moving between the three Moscone centers can be daunting and we need to pay attention as a section to the special events that bring us together as a community to reward excellence, foster participation, engage diversity, get inspired, and advance ideas and collaboration. The Hydrology Luncheon has been for many years our section's main "event". The question of how we could make this event more affordable, more inclusive, and more conducive to free flow of ideas and interaction among all of us is one worth thinking about. Healthy finances of our section are critical in that respect.

My students always tell me that they come back from the Fall meeting inspired, full of ideas and new energy for their research, and enthused by the new exciting contacts they made. A young student I met recently told me that her first AGU meeting opened so many opportunities for her: a summer internship, a graduate school offer and a membership on a research committee. We want more such stories! They provide clear evidence of a vibrant section, investing in its young generation and not resting on its status-quo.

So what about if we try to take advantage of a few more spontaneous networking opportunities at this upcoming Fall meeting? …. Young hydrologists out there: please introduce yourselves to the busy-looking senior researchers whose papers or books you are reading, approach your section leadership with your ideas, and please attend the Networking event and the Hydrology section luncheon (I hope you got a ticket!).

"Senior" hydrologists out there: please attend the presentations or posters of our young colleagues and engage in their science, offer mentorship and give them the benefit of your experience. Also, please donate to the section to keep our "NextGen Hydrologists" social event alive and to create opportunities for more and more inclusive section events.

I look forward to seeing all of you in San Francisco and discussing in person your ideas for making our section even more vibrant and inspiring to our "NextGen"

From the Water Resources Research Editorial Board

Alberto Montanari (University of Bologna) Editor-in-Chief
Günter Blöschl, Ximing Cai, D. Scott Mackay, Anna M. Michalak, Harihar Rajaram, Graham Sander (Editorial Board)

Writing a scientific paper is an art, where individual style and creativity shape the manuscript. Like any expression of human talent, writing style is measured subjectively and the imprint of each scientist on a paper is the reflection of the writer's personality and attitudes. As such, there is no agreed upon recipe for writing a paper. However, an experienced writer is certainly driven by personal rules, which do not take a rigorous form and often evolve over time. Few scientists make the effort to write down their personal rules. Indeed, it is difficult to identify a set of guidelines, because any strict criteria would limit the scientist's creativity. Would it be possible to elaborate agreed rules for sculpturing or painting? Of course not.

As editors of Water Resources Research (WRR) we have the valuable opportunity to see many manuscripts. During our first few months of editorial experience we have observed that many well-received papers do not convey their message effectively and as such are not appreciated by the referees. Therefore, although we clearly recognize the above individual character of the writing style, we decided to offer to the community, and in particular to young scientists, a set of personal opinions on how a scientific paper should be structured. So far, this effort has materialized in 10 + 5 suggestions for writing a WRR paper that we are summarizing here below (the reason for 10 + 5 instead of 15 will be clarified here below). Of course, the above premise implies that our suggestions should be taken as personal opinions that should be adapted to one's individual attitude and feelings. Above all, they should be adapted to the unique character of any scientific contribution. We believe that our suggestions may integrate the excellent and ironic contributions by *Kumar* [2012] and *Kumar et al*. [2012].

The 10 suggestions concern best practices to consider before submitting a paper. These are listed below:

1) Pay attention to the structure of your paper. From the introduction to the conclusions, sections and paragraphs should follow a logical train of thought that should be clear to the reader. You may ask colleagues to help you with an internal review to check whether your science questions, proposed solutions and take home message are clear. Do not presume that a valuable contribution should not also be easily understandable; actually, the opposite is true! Remember that a good paper is not unnecessarily long. Referees prefer concise contributions, and readers are more likely pay attention to papers with a clear message.
2) Consider with much care the tone of your manuscript. There are many different attitudes that can be taken when writing a paper and they affect the opinion of the referees. Although a low profile tone is the most appropriate way to follow in many cases, we do recognize the value and fashion of provocative contributions.
3) State clearly your novel contribution, in the abstract, introduction and conclusions. The referees and the readers like to immediately recognize what is the purpose of your study and its added value. Targeting WRR means that you have a significant message to deliver to the global community of water scientist; this message should be of general interest and should clearly emerge from your paper. Overstatement and excessive modesty should be avoided in favor of objectivity. Remember that WRR strives to publish innovative concepts and theoretical developments along with their applications. If you are essentially presenting a case study, make sure that the findings are interesting at the global level and not just locally.
4) The introduction is the most difficult section of the paper to write and therefore it is not easy to provide guidelines for it. The introduction section should start with a statement of the problem you are tackling, keeping in mind that the referees expect that a novel contribution to an open and interesting issue. Then, make a brief but comprehensive review of the literature: you may feel that "brief" and "comprehensive" are incompatible. This is not true: actually, excellence also implies the capability to achieve synthesis through creativity. An excellent literature review should synthesizes the relevant literature to place the present work in an appropriate context. A literature review is not merely a summary of work that has been done. Do not forget to look at recent papers and in particular at papers in press in the relevant journals. We know that this is a time consuming and demanding endeavor, but we have no doubt that it will pay you back. As a result

of the review of the literature state the research question you are interested in and then explain how you are addressing it, by emphasizing your novel contribution.

5) Explain new theoretical developments and methods clearly. State transparently any assumptions that you are introducing, discuss their validity and provide an adequate and substantiated motivation for any objective choice that you make.
6) Prepare figures and tables with care, noting that figures and tables should help not hinder understanding. Keep in mind that a figure (or table) and its caption must be self-contained, and so understandable even without reading the main text of the manuscript. Pay attention to their readability, by checking font size and usage of colors. Only necessary figures and tables should be introduced.
7) Read carefully the instructions for authors and make an effort to meet the journal's format. Even if WRR is tolerant with the format requirements for the submitted papers, there is always a reason behind a publisher's decision to adopt given standards and the referees appreciate the effort made by authors to meet these standards. Use the templates provided by the journal and pay attention to spelling errors and correct use of the English language. Details are important when writing a paper. Remember, the referees dedicate their time to your manuscript and therefore they should not feel that you did not dedicate enough attention to it.
8) Present the results clearly and objectively, by providing quantitative assessments.
9) The concluding section is very important; it should not be a mere repetition of what has been already described in the body of the paper. It should rather present original concluding remarks that address the goal of the manuscript and clearly inform the reader what has been learned.
10) Beware that the number of authors should be directly related to the essence of your contribution. Any author is expected to provide a significant contribution in the development of the research and the manuscript and all those who have significantly contributed to the paper should be on the author list.

Finally, we would like to make mention to the most important, challenging and time taking phase of the writing process of a paper, namely, the first revision after review (assuming that the outcome from the first editor's decision was not negative). Indeed, we realize that in many cases the authors do not reserve enough time and attention to it, therefore getting into difficult and controversial situations. To provide useful guidance we offer the additional 5 suggestions below.

1) Carefully consider all the remarks raised the referees, including minor ones, and address them in the revised paper. If you disagree with the referees explain your reasoning in the rebuttal document.
2) Do not be concerned to make additional work. Often the referees get the feeling that the authors refuse to follow their suggestion for the very simple reason that they are concerned by additional analyses or experiments. It is important to prove that you are willing to put time into your study. If you feel that the additional work required by the referees is not worth including in the paper it is advisable to carry it out anyway and to illustrate the related results in the rebuttal document.
3) Clearly describe any change that has been introduced in the paper in your rebuttal document by referring to line numbers in the manuscript. Do not make the rebuttal document unnecessarily long.
4) Use a proper tone in the rebuttal document: its writing style is heavily impacting the fate of a paper. For example, do not be dismissive of a reviewer comment. Sometimes reviewers miss a key point or have a different viewpoint. Remember that it is the author's resposibility to make the paper clear to the reviewer.
5) Do not forget to thank the referees in the acknowledgements of the paper. We suggest not acknowledging the editor and associate editor unless there is a very special reason.

We hope that the above suggestions may help our readership to shape their scientific contributions. We are always ready to provide feedback: please do not hesitate to contact us!

References

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Iowa Flood Studies: A Field Campaign in Support of the Ground Validation for the Global Precipitation Measurement Satellite Mission

Witold F. Krajewski[1], Walt Petersen[2], Christa Peters-Lidard[3], Michael Cosh[4]

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Overview

In the spring of 2013, NASA, in collaboration with other government agencies and members of the U.S. academic research community, conducted a field campaign in northeastern Iowa called Iowa Flood Studies, or IFloodS. The main goal of the campaign was to support ground validation program activities of the international Global Precipitation Measurement (GPM) satellite mission. GPM observations of precipitation will serve the scientific goals of developing a better understanding of our weather and climate and the operational purposes of flood and landslide hazard forecasting and water resources management worldwide. Ground validation is an integral element of the mission, designed to develop and mature relevant algorithms for converting data collected by the radiometers and radar on-board the GPM satellites into useful information about rainfall and snowfall and to provide a credible assessment of the associated uncertainties needed for local decision-making.

IFloodS is the first of several integrated hydrologic field experiments that will support GPM's goals. Iowa was chosen as a site because of its relatively uniform land use, the absence of difficulties due to orographic or coastal effects, the state's frequent flooding with a climatological peak in May and June (e.g. Groisman et al. 2004; Villarini et al. 2011a), and the existing observational and logistical support provided by the Iowa Flood Center at the University of Iowa. Iowa has experienced several severe floods in recent years (e.g., Budikova et al. 2010; Gupta et al. 2010; Villarini et al. 2011a; Smith et al. 2013), and indications suggest that the frequency of heavy rain and floods may even increase (e.g., Groisman et al. 2004; Villarini et al. 2011b) in the future due to intensification of the hydrologic cycle. Studying floods in Iowa enables considerations of scale effects, as the well-instrumented watersheds span a wide range of scales from ~10 km^2 to 50,000 km^2 (e.g. Gupta et al. 2010; Smith et al. 2013).

IFloodS' science objectives revolve around the production of accurate, high-resolution time and space ground "reference" rainfall and stream flow datasets as a means to assess uncertainties in the satellite algorithms and products. The collection and production of high-quality reference rainfall estimates helps improve the representation of the physical processes in the algorithms and reduce the uncertainty in the products. The impacts of these uncertainties are evaluated in coupled weather, land-surface, and distributed hydrologic modeling frameworks as related to flood prediction. A key question the hydrologic community hopes to answer is, "What is the spatial-temporal scale at which satellite-based precipitation products have adequate skill to prove useful in flood prediction worldwide?"

Participants

Participation in the campaign included two groups of researchers: (1) those who visited Iowa in person and helped deploy and/or operate various instruments, and (2) those who were involved virtually through data analyses and modeling efforts. On-site student participants represented the University of Iowa, Iowa State University, Colorado State University, École Polytechnique de Lausanne, Duke University, Georgia Tech, University of Wyoming, University of California at Irvine, and St. Cloud University. Their colleagues at NASA/GSFC, Princeton University, University of Washington, and University of Maryland participated remotely, setting up hydrologic models and examining the collected data. NASA, the IFC, and the Colorado State University provided key technical personnel who set up and operated the instruments. Iowa State meteorologists provided daily weather briefings, and NASA's data support group in Huntsville, Ala., built and supported a data portal that will ultimately host all data collected during the campaign.

IFloodS has the potential to benefit synergistic satellite missions (e.g., SMAP, SMOS, GRACE) through refined hydrologic models and improved water cycle predictions. The Agricultural Research Service of USDA collaborated with NASA GPM GV and the IFC by deploying a long-term network of rainfall and soil moisture and temperature measurements in support of

SMAP GV and its own crop yield modeling efforts. Other federal and state agencies participated as well. These included the National Weather Service, the U.S. Geological Survey, and the Iowa Department of Natural Resources. Additionally, local non-profit groups organized as Watershed Management Authorities provided logistical support in the Turkey River and Upper Cedar River basins.

Instrumentation and Experimental Design

The main instrument deployed by NASA was an S-band polarimetric radar known as N-POL, with the nominal operating range of about 150 km. NASA selected a site just south of Waterloo, Iowa, to locate the N-POL, thus filling the existing "weak spot" in the coverage of this area by the network of four NEXRAD operational radars (see Figure 1). This region includes large basins of the Iowa and Cedar rivers, as well as smaller basins of the Turkey, Volga, and Wapsipinicon rivers, all flowing to the Mississippi River.

Collocated with the NPOL was NASA's new mobile Dual-frequency (Ka/Ku band) Dual-polarimetric Doppler radar (D3R) (Chandrasekar et al. 2012). The D3R frequencies are similar to those designed for use by the space-borne radar onboard the core GPM satellite. Co-scanning NPOL and D3R observations collected during IFloodS will enable testing of GPM satellite radar retrieval algorithms used to estimate precipitation characteristics, such as intensity, type, vertical profile, and drop-size distribution (DSD). Relevant ground-based instruments included clusters of optical disdrometers and Vertically Pointing Radars (MRRs) along a radial connecting the location of the N-POL with the Iowa City Municipal Airport. Deploying ground-based instruments along a single radial provides information about range effects of the NPOL in terms of its ability to estimate rainfall intensity and DSD.

The Agricultural Research Service (ARS) deployed a network of 15of its double rain gauges and soil moisture platforms together with 5 NASA GPM dual rain gauge and soil moisture platforms in the South Fork River Basin, west of the N-POL site. The soil moisture and temperature probes were placed at standard depths of about 5, 30, and 60 cm. The IFC deployed a NASA-owned network of 20 similar platforms in the Turkey River basin. The Center also operates numerous double-rain gauge platforms in the Clear Creek basin, west of Iowa City, which has recently become part of a Critical Zone Observatory. See Figure 1 for the relative location of these watersheds.

Coincident satellite datasets were provided by CSU-CIRA, including microwave imaging and sounding radiometers flying on NOAA, DMSP, NASA, and EU (METOP) low-earth orbiters, and rapid-scanned IR datasets collected from geostationary (GOES) platforms. Goddard Profiling algorithm (GPROF) rain rate estimates were also provided by Prof. C. Kummerow, (CSU) for the associated satellite platforms and region.

The rainfall observing instruments were complemented by some 150 stream discharge and stage gauges operated by the USGS and IFC.

Observed Cases

The IFloodS timing and instrument deployment logistics were decided in 2012 when Iowa was in a severe drought. The early concerns that the drought might affect the campaign were quickly put to rest in the spring of 2013. Extreme and widespread storms began in early April, prior to the deployment of the NPOL, and continued throughout the area until late June, after the end of the official campaign dates. The storms caused flooding, which was severe in some areas (60 Iowa counties were declared disaster areas).

The field experiment turned out to be a gold mine of data to address all scientific objectives of the GPM GV and support many other hydrologic studies. The wide variety of atmospheric conditions and storms structures experienced will serve to improve the satellite algorithms. The collected cases include some unexpected wintery storms (cold rain, mixed phase, snow), followed by large MCSs with attendant mixes of deep convective and stratiform precipitation, and subsequently at least one event associated with widespread tornadic activity. The hydrologic response was seen in elevated streamflows propagating from small watersheds to form flooding in large rivers. Early in the experiment, frozen ground in the northern part of the domain led to quick runoff. Relatively cool spring temperatures and absence of crops resulted in high runoff coefficient values and low evapotranspiration. Groundwater played an insignificant role, as it was depleted by the earlier drought. Only by the end of the campaign had the groundwater table rebounded to the pre-drought levels.

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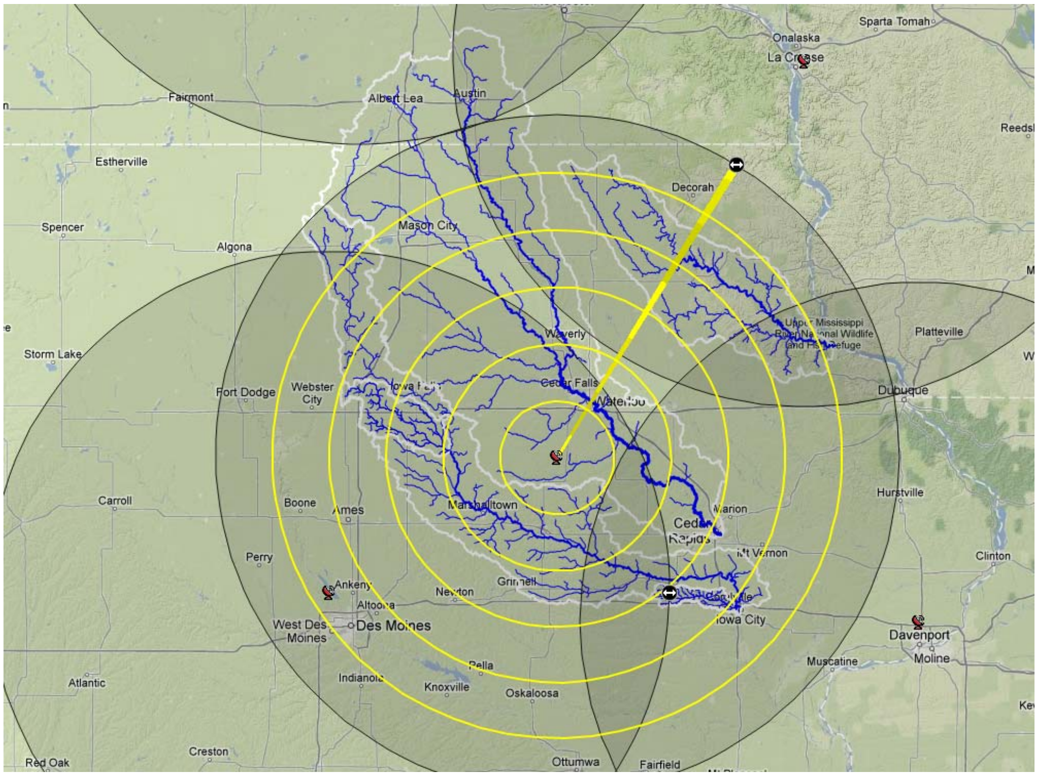

Figure 1. The IFloodS domain, with the 150 km range of the four NEXRAD radars and the NPOL radar. Three basins are also shown (Turkey, Cedar, and Iowa rivers).

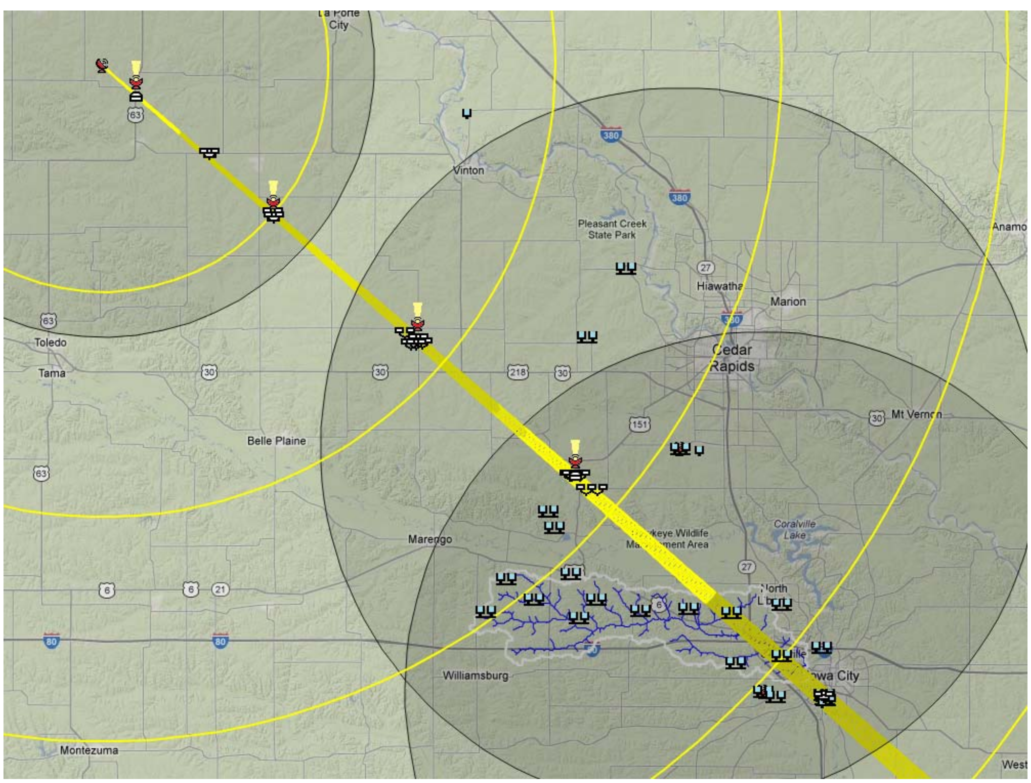

Figure 2. The main radial of the N-POL and D3R radars and the clusters of disdrometers. The yellow rings are 25 km apart. The two overlapping shaded rings denote the 40 km range of the two Iowa X-band polarimetric radars. The blue points show the IFC rain gauge network. Outline of the Clear Creek watershed is also shown.

The campaign, with its wealth of collected data, provides a major opportunity for hydrologic studies, in particular for testing and evaluating rainfall-runoff models and their skill in flood forecasting. GPM Science Team researchers are working to provide a wide variety of rainfall products to drive the models. The products will range from the operational rainfall maps based on data from single polarization data NEXRAD radars (Stage IV, Q2, and IFC), to multiparameter new products both corrected and uncorrected with the in-situ data from rain gauges and disdrometers, to several satellite-based products. The availability of multiple products will allow partitioning streamflow predictive uncertainty at a range of spatial scales. As several modeling groups are already engaged in data analyses and modeling studies, the campaign is shaping up as a DMIP-2 follow-up (see Smith and Gupta 2012 and the references therein).

The data collected during IFloodS and many of the derived products will be available from the NASA portal at https://fcportal.nsstc.nasa.gov/ifloods/. The campaign rainfall, as estimated in real time by the Iowa Flood Center (e.g. Seo et al. 2011), can be viewed at http://ifis.iowafloodcenter.org/ifis/more/ifloods/.

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Seasonal to Interannual Hydroclimatic Forecasts and Water Management: Progress and Challenges

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Recent advances in seasonal to interannual hydroclimate predictions provide an opportunity for developing a proactive approach towards water management. Key areas of development include integrated weather-to-climate scale ensemble predictions and hindcasting, improved techniques for downscaling and forecast calibration, physically-oriented hydrologic and land surface models, exploitation of remote sensing datasets, accessible high performance computing and cyber-infrastructure for earth science applications, and incorporation of probabilistic information in water and energy management models. These advances motivated a recent AGU Chapman Conference, held over 3 daysJuly 29-31, 2013, in Portland, Oregon, at the PSU University Place Hotel and Conference Center. Approximately 80 participants discussed the state of the science and the practice, drawing perspectives from climate scientists, hydrologists, forecasting agency personnel, water utilities and consultants, students, reservoir operators and other stakeholders. Detailed program and abstracts of the presentations could be accessed here: http://chapman.agu.org/watermanagement/. The overarching goal was to identify challenges and opportunities in developing hydroclimate forecasts that are relevant to water resources management. We briefly summarize the successes, challenges, and areas of promising potential that emerged from the presentations and panel discussions in three main topic areas.

Climate and Streamflow Forecasting

The first day's presentations and panel discussed a range of forecasting approaches and their skill, focusing on climate and streamflow forecasts at seasonal to interannual time scales, and particularly on those from dynamic models. Overall, presentations and panelists recognized that dynamical models have achieved parity with statistical models in seasonal climate and ENSO forecasting. And yet, while predictability is highly dependent on models, predicting climate extremes remains a vexing challenge, and one that will be difficult to improve. In this regard, effective statistical methods to enhance the skills in extremes prediction are necessary. To this end, for example, ensemble approaches provide useful spread information and shifts in probability density functions can be exploited to characterize the probability of extremes. Ultimately, however, it is impossible to eliminate forecast variance -- thus we must develop methods that contend with uncertainty, as well as variability and change. Streamflow forecasting talks and panelists pointed the significant strides made in operational hydrologic forecasting, which link atmospheric fields from weather and climate models to watershed models, both lumped and distributed. Improvements have been made in model assessment, data assimilation and skill measures. The continued improvements in model assessment, data assimilation, skill measures, weather and climate forecasting, and tools for hydrologic forecasting has spurred the successful rise of operational hydrologic prediction services around the globe over the last decade. A number of promising techniques exist to improve hydrologic forecast skill further, such as the use of stochastic weather generators to translate seasonal forecasts to input for hydrologic models. All the panelists expressed the view that greater outreach and communication, and in particular forecasters working closely with resource managers to help communicate the forecast outputs, especially probabilistic information, is crucial for continued development and represents a low hanging fruit to move the practice forward.

Water Management Applications of Hydroclimate Forecasts

The second panel focused on the use of seasonal hydroclimate forecasts in water management applications, and included representatives from the private sector, the US Army Corps of Engineers, and academia. Their observations and the ensuing discussion made clear that such forecasts are a central input ("hugely important") to management decisions in many if not most water systems in the US, from regional, federal systems to local utility assets. In all such settings, the managers have available a wide array of information beyond the forecasts alone. In some systems, this obscures the connection between forecasts and, ultimately, releases, while in others (typically larger, multi-stakeholder ones), the linkage between inflow forecasts and releases is highly prescribed. Such a lack of operational flexibility can be a hurdle for the adoption of low-skilled forecasts, or forecasts that change drastically in response to single weather events. Forecast busts on events that are large enough to have real impacts but smaller than 'Acts of God' can have career-scale consequences for water managers. Verification and skill information have lukewarm acceptance: there is clearly not enough of it, yet what there is needs to be expressed in more intuitive terms, e.g., through categorical metrics such as hit rate. The influence of climate change on forecast skill and relevance is an open question. Next steps for the field include designing decision support tools to better leverage forecast information, demonstrating forecast value for the small, simpler systems, and improving forecast communication and verification through the use of better evaluation metrics.

Hydroclimate Forecasts and Decision Support – A Water Utilities Perspective

The final day saw presentations and discussion from panelists from water utilities, which provided an end-user perspective on several forecast issues such as the effective lead time for application, critical/desired variables, forecast communication and other institutional factors. The panel felt that for regions strongly influenced by ENSO (e.g., Florida), the effective lead time is often seasonal, since many utilities with mixed sources (desalination vs groundwater) benefit through qualitative or quantitative ENSO forecasts, whereas when climate forecast signals are less skillful (e.g., Midwest), the effective lead times are shorter (i.e., sub-seasonal) requiring applications to consider weather-to-climate forecasts for effective integration. In this context, the panelists felt that improved understanding/prediction of weather-scale dynamics such as atmospheric rivers could provide useful information for system management. Panelists also noted that seasonal forecasts trigger risk minimization (e.g., spill reduction), but water demand prediction is often ignored, which could be critical in carrying over the existing storage over subsequent seasons. Forecast information on additional variables such as turbidity, water temperature, nutrient loadings would be of extreme value, but developing models for such variables poses significant challenges due to limited data availability. Panelists felt that forecast communication in the form of probabilistic information is desirable, but forecast products could be better tailored (e.g., deterministic forecasts or tercile categories) toward to assist the operational processes of end users. Regarding institutional factors governing forecast adoption, attendees felt that while federal and state agencies support research, greater participation in focused interactions, conferences (e.g., the AGU Chapman) and workshops with participants having different portfolios related to water and energy management could help speed the transition of research successes to effective application/implementation in practice.

Concluding Remarks

The key success of the conference was in bringing forecast producers –climate scientists and hydrologists – and forecast consumers – water managers and policy planners – under one roof to discuss about the possibilities and challenges in the application of seasonal to interannual hydroclimatic forecasts for improving water management. The meeting also inspired a Nature news article: http://www.nature.com/news/forecasts-turn-tide-on-silt-1.13576. Participants felt that the science and technology were mature enough to provide a foundation for better climate-informed water resources management, and identified the better outreach, integration and communication as the highest priority avenue for advancement. Ironically, this message comes at a time when far-reaching agency and research budget cuts have left most relevant public sector groups unable to interact face to face and attend meetings at which such communication has traditionally been effected. Further, participants stressed that continued support for research and data collection (e.g., water quality) from agencies and co-operative institutes are needed to improve the science and models behind the forecast development. The meeting also emphasized that a comprehensive, multi-disciplinary national assessment of various hydroclimatic-forecast applications could be of value to planners in both private and public sectors as well as to the public.

Acknowledgements: Authors would like to thank the joint support of three programs – Environmental Sustainability, Hydrological Sciences and Environmental Engineering – of the National Science Foundation for the travel support through the award # CBET-1311751. The authors also would like to acknowledge the Bureau of Reclamation for providing travel support to students through CIRES.

2013 Horton Grant Awardee: Ecohydrology at the watershed scale

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(Main Advisor: Brian McGlynn ; Secondary advisor Ryan Emanuel)

Ecohydrology has received increased focus as a sub-discipline in the hydrologic sciences, especially over the last 10-15 years as evidenced by a growing body of literature focused on the interactions of the hydrosphere and the biosphere. The soil-plant-atmosphere continuum has been the subject of detailed, stochastic and empirical descriptions at varying scales with punctuated contributions from *Eagleson* [1978] and *Rodríguez-Iturbe* [2000]. This research builds on the legacy of ~150 years of forest hydrology that began in the mid 19th century in Europe with experiments focused on how forest cover influences precipitation amounts, affects groundwater levels, and modifies streamflow. *Zon* [1927] provides a detailed summary of those early experiments that provided historical context for the paired watershed approach popularized ~100 years ago at Wagon Wheel Gap, Colorado. Our knowledge of forest hydrology has increased significantly from that time thanks to well known hydrological experiments such as those documenting and quantifying plant water use by different tree species at the watershed scale at the Coweeta Hydrologic Laboratory beginning in the 1930s and 1940s [*Hoover*, 1944; *Swank and Douglass*, 1974], an epoch sometimes referred to as the "golden age of forestry," and related studies worldwide.

The series of long-term forest manipulation experiments at Wagon Wheel Gap and Coweeta showed early on that the effects of vegetation removal on hydrological responses are not the same everywhere. The percentage increase in water yield at Coweeta was much greater than at Wagon Wheel Gap, suggesting that the timing and amount of water inputs (spring melt in Colorado vs. more temporally distributed precipitation in North Carolina) in combination with different physical watershed characteristics can exert influence on how much water can be stored in the soil and how much can be transpired by vegetation. Common research objectives for watershed forest (eco-) hydrologists today are similar to those outlined by hydrologists 100 years ago: *"It is not enough to know whether forests influence stream flow; it is necessary to know how much, at what seasons, and under what conditions of climate, soil, and topography, and the variations between different kinds of forest, as well"* [*Bates and Henry*, 1928]. Despite marked progress, many of these challenges remain.

The deconvolution of whole watershed runoff response into its constituent spatial and temporal runoff components remains a grand challenge in watershed hydrology. Watershed structure (e.g. topography, geology, and soil patterns) has since been recognized as a primary driver of spatial patterns of soil moisture, hydrologic response, and biogeochemical processes in forested mountain landscapes. Vegetation patterns and their feedbacks to soil moisture, runoff dynamics, and climate variability/change are becoming increasingly recognized and accordingly investigated across various temporal and spatial scales. Despite this effort, the combined effects of landscape and vegetation structure, and the superimposed effect of climatic variability on water redistribution and hydrologic response remain poorly understood. This is partially due to the complex interactions between climatic variability, watershed storage, and landscape water redistribution that introduce largely unknown memory effects.

This rich history and articulation of these and other grand challenges in watershed ecohydrology motivate our research. The specific questions we seek to address harken back to the history of forest and watershed hydrology and include: (1) How does watershed structure influence hydrologic response? (2) How do lateral water redistribution and vegetation processes mediate spatial patterns of water storage and connectivity of upland portions of watersheds to the stream network? (3) How do past climate and hydrologic conditions influence the hydrologic behavior of the present?

We are working to begin to address these challenges / questions through a combination of spatially and temporally intensive and extensive observations synthesized as (1) application and extension of a simple lumped model to distill complex watershed behavior into comparable metrics across nested watersheds, (2) development of a parsimonious but fully distributed ecohydrologic rainfall-runoff model to characterize the effect of topographically driven lateral water redistribution and water uptake by vegetation on landscape scale hydrologic connectivity, and (3) combination of empirical analysis of long-term hydroclimatic data sets and transfer function modeling to investigate the effect of watershed memory on the hydrologic response of watersheds.

We initially utilized a simple transfer function rainfall-runoff model to characterize the effect of landscape structure (topography and vegetation) on watershed mean response time across 7 adjacent subwatersheds in the Tenderfoot Experimental Forest (TCEF, central Montana). MRT is a measure of the time required to discharge an amount of water equal to a precipitation input. We examined runoff and precipitation data from 7 watersheds (5 pristine, 2 with silvicultural treatments) over 12 years of record to answer the question: What drives the intra- and inter-watershed variability of hydrologic response (streamflow)? The analyses indicated strong relationships in the unharvested watersheds between MRT and landscape metrics including watershed slope, watershed flowpath distances to the stream network, geology, and vegetation height.

While the lumped approach offers insights into general watershed response, one drawback is that they provide little insight into internal watershed processes and behavior. To test the hypothesis that both the amount and spatial organization of vegetation in a watershed can mediate hydrologic connectivity, especially during watershed dry-down and the growing season, we developed a parsimonious modeling approach that allows for simple assessment of spatial (eco)hydrologic dynamics (runoff, ET, and storage) at the grid cell, hillslope, and watershed scales. Storage state (in a cell) is mediated by precipitation and lateral water redistribution as well as evaporation and water uptake by vegetation (transpiration). Different spatial configurations of vegetation can therefore result in different patterns of watershed connectivity (Figure 1).

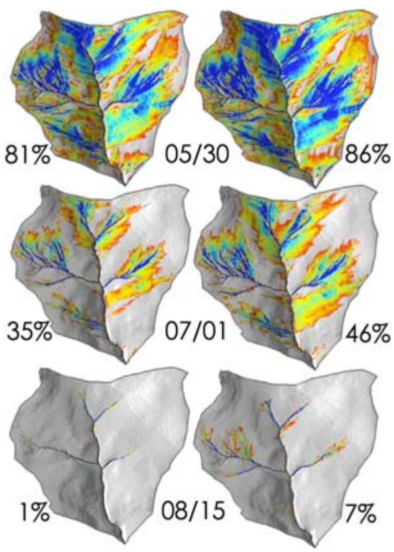

Figure 1: Evolution of active watershed areas for two vegetation scenarios (columns) from peak flow to summer low flow (rows). Colors indicate watershed storage above a saturated connectivity threshold from wetter (blue) to drier (red). Gray areas don't contribute water to the stream network and are considered inactive.

While spatial patterns of watershed storage influence contemporary hydrologic response, watershed storage itself may be highly affected by past precipitation and climate. We are beginning to address long-term runoff behavior and potential non-linearities introduced by past climatic variability by exploring how watershed hydrologic memory is propagated through time across watersheds of contrasting vegetation and watershed structure. Utilizing more than 50 years of high-resolution precipitation and runoff data from multiple headwater watersheds in the southeastern US, we will examine runoff behavior from single events, to seasons, to years, and decades to quantify the effect of past precipitation on watershed storage and hydro-logic response. Initial empirical data analysis suggests strong memory effects across all time scales. Furthermore, initial modeling results suggest fast/quick-flow response as relatively insensitive to climate variability, while the slow/ baseflow component is more sensitive, suggesting long-term memory in the system and corroborating the findings of our empirical analyses.

I believe that ecohydrological research will continue to be vital to addressing contemporary and future water related issues, especially in consideration of the new challenges that global climate change poses to water resources. Increasing magnitudes, frequencies, and extents of disturbance such as mountain pine beetle infestation in the Rocky Mountain west, wildfires, human-made large-scale alterations like mountain top mining and land cover change can introduce acute and chronic changes to ecohydrologic systems. Increasing pressure on these valuable resources gives new urgency to understanding and predicting the space-time linkages and legacies of coupled ecological and hydrological systems. Our research is part of a larger community wide effort to combine experimental, empirical, and modeling based approaches to addressing these grand and emerging challenges in ecohydrology as we build on the knowledge and legacy of past ecohydrologic research.

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2013 Horton Grant Awardee: Towards novel observations in hydrology

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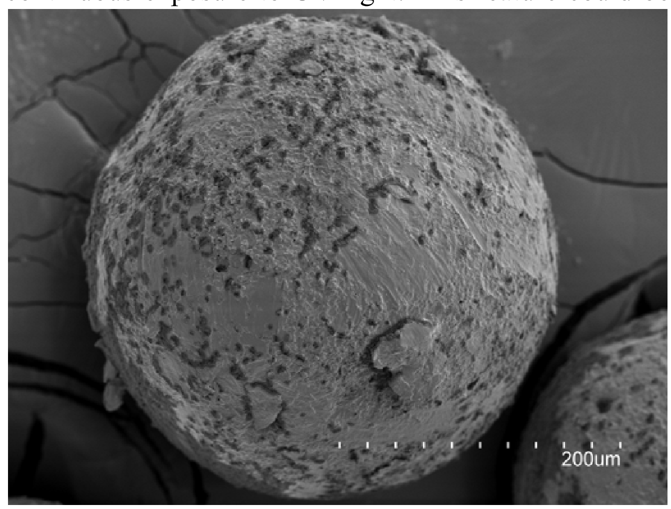
(*Advisors: Salvatore Grimaldi and Maurizio Porfiri)*

Surface phenomena control a variety of interlaced and competing phenomena including runoff processes, waste and pollutant diffusion, erosion mechanics, and sediment transport [1 - 4]. As surface flows are largely dominated by ephemeral drainage networks, multiscale transport, and multiphase flows, their observation and monitoring is challenging.

Traditional experimental monitoring methodologies, such as hydrological tracers and optical flow visualization, have contributed to disclose crucial features of watershed processes as well as their inherent complexity [5 - 7]. For instance, uncertainties in the interpretation and analysis of data gathered through isotope and geochemical tracers have highlighted the impossibility of characterizing and understanding watershed mechanisms through the exclusive use of conventional tracers [8--14]. In case of optical and remote methodologies, highly user-assisted and data-intensive procedures have limited their implementation and upscaling to severely accessible or large scale natural areas in real time [15]. Flow sensing technologies need to cope with detrimental effects deriving by water turbidity, flow path heterogeneity, and natural flow obstructions. Furthermore, experimental observations require non-invasive, flexible, and low cost measurement systems that can potentially operate in remotely-controlled or unmanned conditions.

To partially alleviate limitations of traditional systems, a novel tracing methodology has recently been proposed for surface hydrology measurements in natural environments. This technique leverages on the efficiency and versatility of tracers and the non-intrusiveness of optical methodologies while improving their practical feasibility. Specifically, the methodology is inherently designed to be applied to a variety of real-world settings spanning from small scale streams to few centimeters rills in natural hillslopes. The sensing system is based on the acquisition of the trajectory of 100 -- 2000 μm fluorescent particles through digital cameras for direct flow measurements. Videos captured by the cameras are processed by computationally-inexpensive algorithms that detect the transit of highly-visible particles underneath the sensing station and estimate the particle velocity in the field of view. The insolubility of the particles limits the tracer dispersion in the environment, thus also minimizing the required amount of material to be deployed. Further, particle fluorescence enhances the tracer visibility against the background, thus partially mitigating the detrimental effect of direct sunlight and water surface reflections. The sensing system is determinately minimal and lightweight to allow for its transportation and implementation in diverse and complex natural settings.

Preliminary studies in laboratory and outdoor environments and dark to illuminated settings have assessed the feasibility of using fluorescent off-the-shelf beads as tracers. To minimize the impact of the methodology on the natural ecosystem, environmentally-friendly particle tracers have been synthesized by encapsulating minimal quantities of nontoxic fluorophore nanoparticles in a beeswax matrix through an inexpensive thermal procedure [16,17]. Further, the fluorescence excitation spectrum is broad, thus allowing for fluorescence emission under a wide range of wavelengths, see Figure 1. High radiation tests have demonstrated that the complete inactivation of the fluorophore is attained in less than a month upon continuous exposure to UV light. This feature could be



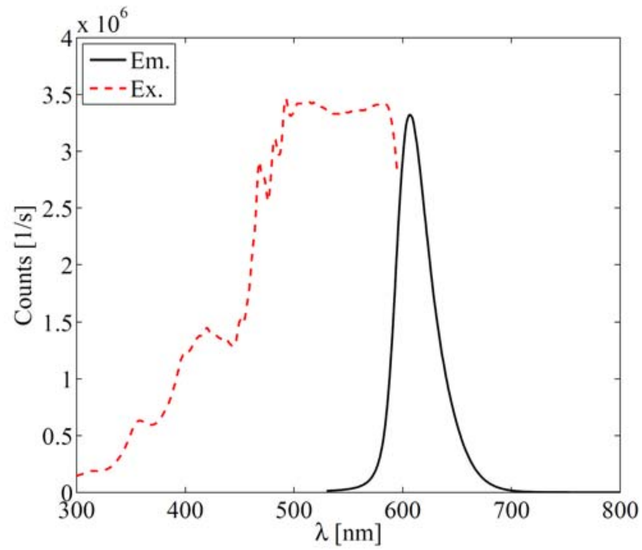


Figure 1: Top, SEM picture of environmentally friendly particle tracer and bottom, emission and excitation fluorescence spectra of the fluorophore (images are taken from [16--17]).

particularly useful for applications in pristine natural environments where the extended introduction of alien substances may be forbidden. Moreover, the biodegradability rate of the tracer matrix is compatible with large scale hydrological studies where lasting tracer persistence may hinder future experiments. Analyses through fluorescence spectroscopy and weathering tests have also highlighted emission spectra shifts due to fluorophore dilution and photobleaching effects. Interestingly, this feature may be regarded as an aging index of the particles for watershed scale environmental applications.

The particle identification and tracking is based on the rapid analysis of camera video feed through computationally-efficient procedures. Specifically, in [18] an aggregated index is defined to quantify the bead visibility against image background. The index corresponds to a weighted difference between intensity histograms corresponding to images depicting the particles and images of the sole background. Applying this methodology allows for identifying the brightest frames in recorded videos, thus detecting the beads' transits in the absence of severe light reflections. The automatic detection of the particle in natural conditions is conducted through a custom-built procedure, see [19]. This procedure is based on the known oblate shape of the particle as it appears in frames acquired through commercially available camcorders and implicitly assumes that the particle follows a rectilinear trajectory as it crosses the camera field of view. The algorithm is based on the correlation between a template image and frames extracted from the videos where the particle location is assimilated to the maximum of the correlation coefficient. The correlation analysis is sharpened by preprocessing the images from experiments by a background subtraction. Further, the procedure integrates a conditional updating scheme which allows for enhanced detecting performances. The velocity of the potential particle in the plane is estimated by collecting the locations where correlation peaks are attained. Conditional tests on maximum particle acceleration and motion transverse to the flow direction are also used to avoid false readings.

Proof-of-concept outdoor experiments in a natural stream and a semi-natural hillslope assess the feasibility of transitioning the methodology to hydrological studies, [20,21]. Specifically, flow measurements and travel times acquired at the Rio Cordon natural mountainous stream in the Italian Alps demonstrate that, despite the minute size of the spheres, the limited capabilities of commercial cameras, and the high flow regime of the stream, individual fluorescent beads can be detected and their trajectories tracked when they pass underneath the sensing apparatus, see Figure 2. Comparison to experimental analyses with an array of traditional tracers illustrate that the fluorescent particles' size and good visibility allow for optimal tracking in adverse flow and illumination conditions, whereas bulky objects remain trapped in stream pools or require the deployment of massive quantities to be detected over long stream reaches. An additional overland flow feasibility study studies the particle detectability under high turbidity loads and soil and rain drops interaction, see [21]. In spite of such severe environmental conditions, experimental findings support the use of fluorescent particles for surface flow monitoring. In particular, our studies demonstrate that particles as small as 75 μm can be detected through image analysis automated procedures. Further, estimated velocities for particles' diameter in the range 1000 -- 1180 μm are comparable to values obtained through alternative methodologies.

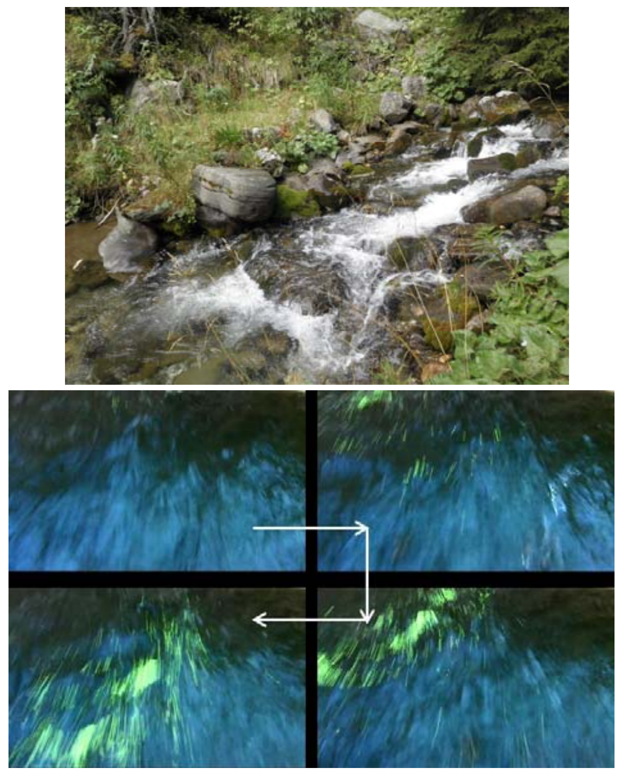


Figure 2 – Top, view of the Rio Cordon step and pool river bed (image taken from [20]), and bottom, snapshots captured by the sensing station depicting the fluorescent particle transit.

Future developments of the methodology encompass the integration of aerial vehicle technology into a smart sensing platform for environmental surface flow observations. This project, partially supported by the Horton (Hydrology) Research Grant will be designed for distributed monitoring in selected geographical areas. The platform will host video acquisition and image calibration units for detecting flow motion. The development of a smart mobile platform for remote surface flow monitoring is expected to advance the identification and quantitative characterization of hydrological surface processes from an unprecedented perspective.

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The Fellow Speaks: How Satellite Interferometry Changed Glaciology

Eric Rignot (Professor Earth System Science, University of California, Irvine; and Jet Propulsion Laboratory's Senior Research Scientist)

I have been fortunate to join glaciology at the eve of the satellite age, at the right place at the right time, when climate started to hit the ice sheets hard.

Back in the 1990s, we did not know the state of ice mass balance of Greenland and Antarctica, we had no measurement, no satellite, no airplane, a few field camps and computer models that projected ice growth in Antarctica and near balance in Greenland. That was until NASA's Bob Thomas decided in 1993 to focus on Greenland and embark on a survey of the giant icy island armed with a team of specialists with an airborne laser system as its masterpiece. A few years prior, the European Space Agency had launched the Earth Remote Sensing satellite-1 ERS-1 that included a synthetic-aperture radar instrument. I was learning how to use the data to generate radar interferograms (InSAR) of ice motion, following the footsteps of Dick Goldstein at JPL. Soon, the laser program established that important changes in ice volume were taking place in Greenland, especially in the south, and the ice sheet was not just melting on the sides while in balance in the interior, something big was happening to the outlet glaciers. I joined the airplane surveys many times and enjoyed the inspiring and unmatched view of the glaciers. With satellite radar interferometry, we measured their ice motion at an amazing level of spatial detail, every 5 m with a vertical precision of millimeters, over vast areas. Most glaciers had only few prior point measurements of ice velocity, or none at all. With InSAR, we were observing strain rates. We could also image grounding lines, the narrow transition region where a glacier detaches from its bed and becomes afloat, with a precision of 50m. This elusive boundary is difficult to observe by any other means (in situ, tiltmeter, GPS, topography), hence leaving huge uncertainties on its position (1 to 100 km), with ramification on ice sheet mass balance, ice shelf melting, and ice sheet numerical modeling.

In 1996, ESA changed the entire ERS-1 mission to place it in tandem with ERS-2, 1-day apart, to provide world wide topographic coverage –which was a failure – but incidentally provide tremendous data for glaciology. I could explore the ice sheets' glaciers for the first time, in the company of very few, one of which was working only one floor down from me at JPL, Ian Joughin. My initial work focused on north Greenland where data analysis was easy and data were plenty. With Prasad Gogineni and Kenneth Jezek, we stumbled on surprising radio echo sounding results of Petermann Glacier, in north Greenland, which suggested that enormous rates of bottom melting were melting away its floating ice shelf. The floating ice tongue was cut in half after only ten years in the ocean. With InSAR, I established a way to measure the outflow of glaciers, the melt rate of ice shelves, changes in grounding line position, and estimate the entire Greenland ice sheet mass balance, none of which had been possible before.

Pine Island Glacier, in West Antarctica was next. PIG was the most majestic glacier in Charles Swithinbanks' U.S.G.S. Landsat Atlas. Terry Hughes had identified PIG as the weak underbelly of Antarctica, to be later dismissed by the absence of data. In 1996, Stanley Jacobs and Adrian Jenkins reported that the floating ice shelf of PIG was bathing in warm circumpolar deep water, an unusual circumstance. With interferometry, I detected the highest rate of grounding line retreat: 1 km/yr between 1992 and 1996, and the highest rate of melting: 58 m/yr (most publications quoted melt rates in cm/yr on large, cold-based ice shelves). The glacier was changing fast. This was so exciting I put my slides upside down at the 1997 West Antarctic Ice Sheet meeting. But only Charlie Raymond got interested, as the entire WAIS program was focused on Siple Coast at the time. Meanwhile, Duncan Wingham published his ERS-1 altimetry results that showed a blob of thinning in that region, however dismissed as not significant due to the short mission duration. Motivated by our results, however, Duncan showed in 2001 that the glacier was indeed thinning dynamically. By then, I could show that PIG was accelerating, and the signal also included Thwaites Glacier and all the smaller glaciers in the region. This suggested a common forcing over an entire sector of West Antarctica, which had to be the ocean because the melt rates were so high.

In 2002, NASA found an unlikely partner with the Centro Estudios de Cientificos in Chile to fly a Chilean Navy P3 to Antarctica to survey PIG, something NSF deemed impossible at the time. This was my first trip to Antarctica, the first time I saw PIG. Midway into the air, the pilots estimated we will have to turn back before reaching PIG. Things got better, and upon descent to PIG, we encountered the coastline with favorable skies, blue seas, white infinity, with 23 silent people in the cockpit. I will never forget that moment.

Meanwhile, the demise of PIG resurrected the marine ice sheet instability issue, and the dilemma of ice shelf buttressing, i.e. the dilemma that collapsing ice shelves will collapse ice sheets, something that was strongly believed in the US but disputed in Europe. PIG was not the right place for this because the ice shelf was healthy. I looked at the Antarctic Peninsula where ice shelves were collapsing, on Wordie Ice Shelf, but disappointedly found nothing significant. On the east coast, however, Wolfgang Rack and Helmut Rott detected a doubling in speed of Drygalski glacier following the collapse of Larsen A Ice Shelf in 1995, and the change affected the entire drainage basin, a spectacular result. In 2002, we eventually witnessed a speed up by a factor 8 of the glaciers upstream of Larsen B: the ice shelf buttressing theory of Weertman, Thomas and Hughes is proven right. If the Antarctic ice sheet were to lose its floating ice shelves now, its glaciers could flow 8 times faster, sea level rise could rise at 4 cm/yr.

In 2004, I circumnavigated Greenland following the demise of its largest glacier, Jakobshavn Isbrae in 2002. I had already observed the vast speed up of all southeast Greenland glaciers in 1996-2000, confirming the 1994-

1999 airborne laser altimetry results of Bill Krabill. In 2005, Helheim Glacier sped up, and Ian Howat and I stumbled on the speed up of Kangerdlugssuaq Glacier, another enormous glacier in South Greenland, all happening at the same time. This was not an isolated event. At a workshop in Cambridge, Julian Dowdeswell rightfully entitled our observations a change in flow structure of the entire Greenland Ice Sheet.

Many more advances occurred in this age of discovery, mostly due to the advent of satellites but also due to advances in regional atmospheric climate modeling, e.g. by Michiel van den Broeke's group in the Netherlands, and many others. We now have a very good idea about ice sheet mass balance, their 30-year trends, the processes that control them, and the critical role of the flow of their glaciers. Satellite data have changed glaciology forever. We are now in an era where multi-disciplinary work is in order, involving glaciologists, climate modelers, physical oceanographers, ocean numerical modelers and ice sheet numerical modelers who analyze more vast and complex data together from satellites, airborne platforms, ships and floats. Our next challenge is to explore and model the submerged parts of Greenland glaciers and Antarctica' ice shelves to peer how the ocean helps melt ice from beneath. This is the strongest and fiercest forcing on ice sheet evolution – and the least well known. It will be a while before more reliable projections of ice sheet evolution are produced, and the clock is ticking, but the community is moving forward. In the meantime, we must reflect on the last 20-30 years of satellite observations. They have shown us changes in ice sheet mass balance happening sooner, stronger and on a larger scale than anyone had anticipated. And we have seen nothing yet. While I would not run to the hills, many now think that we should walk.

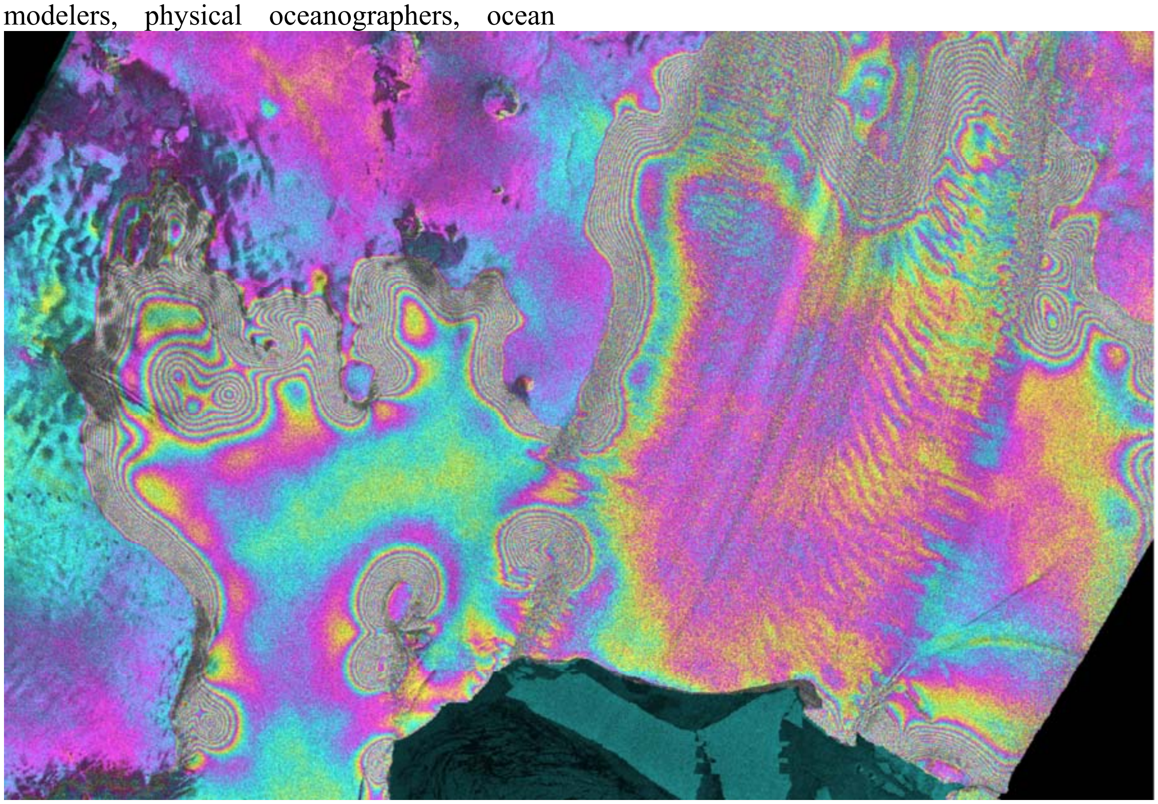

Figure 1. ERS-1/2 quadruple difference interferogram of Pine Island Glacier, West Antarctica showing the differential glacier motion due to forcing by oceanic tides only, overlaid on a radar backscatter image following a calving event. The transition boundary – or grounding line - from grounded to floating ice occurs over a series of tight deformation fringes, where each color cycle is an additional 28 mm of motion toward the radar satellite. Pine Island flows from top to bottom in an area of strong flowlines, and is pinned down along the sides by a variety of ice rises, some of which only touch the sea floor at low tide. This type of measurement provides detailed and unique information about a most critical boundary for ice sheet evolution.

The Fellows Speak: Reducing (or creating) uncertainty in subsurface hydrology using geophysics

Andrew Binley (Lancaster University, UK)

It is a great honour to be elected as an AGU Fellow, and to receive such support from esteemed colleagues. I am also grateful to be given the opportunity here to comment on some perspectives of my own field, and, at the same time, make some recognition to a few colleagues who have inspired and supported me over the years. I apologise in advance for a somewhat autobiographic account, but I feel it may help explain what I see as some key challenges and opportunities.

A central core of my research over the past 20 or more years has been the development and application of near surface geophysical techniques for improved understanding of subsurface flow and transport processes. I believe that we, as a community, have made great progress in this field of hydrogeophysics, which is amply demonstrated by the now common inclusion of geophysical studies within hydrological characterisation programs.

My PhD work in the early 1980s focussed on the investigation of hillslope scale rainfall-runoff processes, specifically exploring the validity of representing a heterogeneous hillslope using single effective parameters. This was a synthetic study, using a 3D saturated-unsaturated flow model that took days of real time on one of the few UK regional supercomputers just to simulate a few hundred realisations of a single event (realising that I may sound like one of the 'Four Yorkshiremen' in the Monty Python sketch, this could be done today on a desktop PC). This work helped demonstrate that, under certain conditions, some knowledge of the structure of hydraulic properties or states within the hillslope is necessary in order to simulate the runoff to a stream. This triggered an early realisation (to me) that knowledge of some internal structure of the system could add value to a model representation.

I was fortunate to be able to build on this after my PhD in 1986 with a move to Lancaster to join Keith Beven, who had just taken up post in Lancaster. I worked with Keith on a project aimed at developing techniques for predicting the response of ungauged watersheds. Early on we explored the value of using a distributed array of water table elevations to constrain a model in an ungauged catchment, however, the key development of the project was some means of estimating predictive uncertainty in a model along with an assessment of the value of additional information in constraining the model. The resulting GLUE (Generalised Likelihood Uncertainty Estimation) approach, or concept, was well received in some areas (less so in others). Keith's unconstrained approach to problem solving was highly influential to me and I'm extremely grateful for his mentoring during the early stages of my career.

One aspect of this early GLUE work was the exploration of the value of information in constraining a subsurface flow model. We concluded early on that in an ungauged watershed (at least the one we studied, and when considering just the rainfall-runoff response), streamflow records have significant data worth. However, there should also be some value of information about spatial patterns of subsurface properties and/or processes. At this time, many modelling studies argued for the need for more data and new data types in order to help support, for example, new stochastic modelling approaches. I was convinced that there should be some way of gaining, at least qualitatively, information about the subsurface that could feed into a modelling framework in some way, and go beyond a traditional array of piezometers or tensiometers, used in numerous hillslope runoff studies.

Geophysics appeared to offer some potential. Geophysical techniques had been used for many years in groundwater studies but often for delineating lithological boundaries. Furthermore, most of the data processing (inversion) techniques were crude or lacked robustness. A chance visit to UMIST (now part of Manchester University) around 1990 to meet Maurice Beck and see his demonstration of new techniques in Process Tomography was inspirational to me. I soon saw the potential value of electrical imaging techniques in monitoring dynamic subsurface hydrological processes. The instrumentation at that time was limited and the data inversion tools non-existent. And so my hydrological modelling trajectory changed course and I found myself moving to the (initially unfamiliar) environment of working in laboratories and field sites, and writing geophysical inverse codes. A key goal, however, has always been to try and utilise this source of spatial data in order to constrain models of subsurface hydrology. Over the past 20+ years I have been pursuing this goal and feel privileged to have worked with many colleagues, who have provided me with a wealth of knowledge and ideas. The list is long but I must take this opportunity to acknowledge the insight I have gained from Giorgio Cassiani, Bill Daily, Andreas Kemna, David Lesmes, Abe Ramirez and Lee

Slater. I also wish to acknowledge the immense practical contributions from one of my former students, Peter Winship, who tragically died before completing his PhD.

Many of our early attempts at utilising geophysics focussed on relatively small plot experiments in which we monitored the subsurface response to natural and artificial (tracer) loading. From these early experiments we were able to map in 3D the evolution of wetting fronts or tracer paths. Figure 1 shows example results from one such experiment; here using 3D electrical resistivity imaging we track the evolution of a mildly saline plume as it migrates vertically in the unsaturated zone of a sandstone aquifer, spreading laterally as a

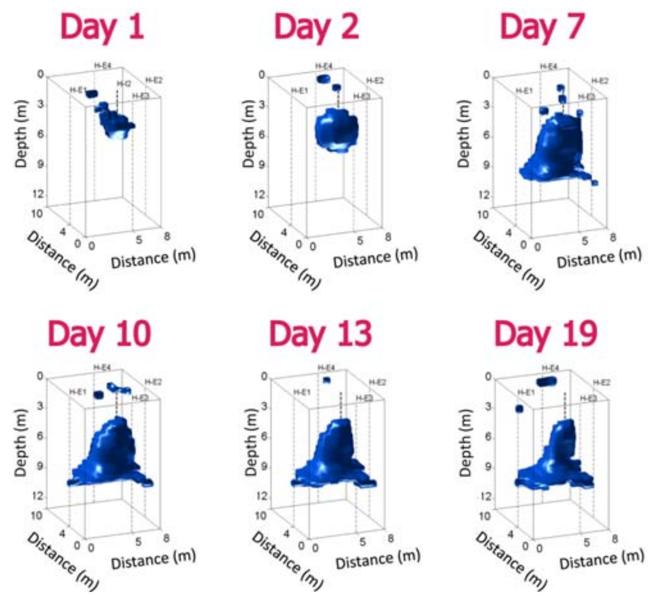

Figure 1. Changes in resistivity (from electrical resistivity tomography) during an unsaturated zone tracer test. Results are shown as isosurfaces of 7.5% reduction in resistivity relative to pre-tracer (Day 0) conditions. The tracer was injected at a depth of 3m in well H-I2. All of the tracer was injected by Day 2. Figure modified from Winship et al.(2005).

lower permeability fine sandstone is encountered. I highlight this particular example because it was the first type of experiment where we attempted to 'calibrate' a hydrological model in order to match the geophysical response, in this case using the evolution of low order moments of the plume in an objective function.

The above example was driven by the need to understand solute residence times in the unsaturated zone of a vulnerable UK aquifer. Our approach may be seen as rather crude. Some attempts have been made using synthetic datasets to use geophysics to capture complex subsurface structures or processes but I believe that there are too few examples in the literature of field-based integration of geophysical data and hydrological model.

We can utilise geophysical data, as illustrated above, in a sequential manner where the geophysical model informs the hydrological model. For many of our geophysical approaches this inevitably results in some interference (artefacts, smoothing, etc.) from the inversion process necessary for transforming geophysical data to maps of geophysical properties (resistivity, permittivity, etc). Alternatively, we can solve the problem in parallel so that the hydrological model informs the geophysical model and vice versa, thus providing a coupled hydrogeophysical inversion (e.g. Ferré et al., 2009). Such an approach can have the advantage of removing the geophysical inversion step (thus limiting associated artefacts) and enforces prior hydrological knowledge (implicit in the formulation of the hydrological model). However, there must be some mechanism for re-evaluating the hydrological model in the process, since geophysical data can, in some cases, provide evidence that the initial conceptualisation is incorrect. One is reminded of the quote attributed to the Scottish Poet, Andrew Lang: "*He uses statistics as a drunken man uses lamp posts - for support rather than illumination*". Geophysical data can have the potential to illuminate and provide new insight into the complex subsurface environment, rather than just supporting our preconceived belief.

Key to the utilisation of geophysical data in any hydrological framework is a good understanding of the link between geophysical properties and the hydrological property, or state, of interest. Whilst some of these 'petrophysical' relationships are reasonably solid (empirically, or theoretically), it is tempting to adopt 'typical' relationships in translating the geophysical model(s) to the hydrological model. In some cases greater investigation into the appropriateness of the adopted relationships is warranted, or, at the very least, some sensitivity analysis of petrophysical model parameters. In fact, one aspect of hydrogeophysics that I believe has been largely ignored is some account of the uncertainty in the derived geophysical model, or, more importantly, the resulting hydrological interpretation. Geophysical models can be subject to high aleatoric and epistemic uncertainties and yet they are often not recognised.

Although many useful petrophysical relationships have been established, thanks in the main to the oil exploration industry, there has been heightened interest over the past decade or so, in the link between certain geophysical properties and one particular property -

hydraulic conductivity. Such interest is inevitable given the control of hydraulic conductivity on so many subsurface processes. One such geophysical approach is complex electrical resistivity (or induced polarisation), which provides a measure of electrical polarisation, which can be dominated by processes occurring along the grain-pore interface. The potential link to hydraulic conductivity is thus intuitive. However, whereas this as a field method was developed for mineral exploration and contrasts between specific mineralise zones and host rock were relatively easy targets, when used in a hydrological setting the contrasts can be very subtle and easily masked by other factors. This has, in part, led to the development of more sophisticated instrumentation, field procedures and data analysis. Nevertheless, the link between geophysical and hydrological property remains challenging. Figure 2 shows an example of the relationship observed between an inferred electrical relaxation time and hydraulic conductivity of a particular UK sandstone formation. The link is clear, however: (1) this is far from universal, as demonstrated by other similar empirical studies in different soil/rock types; (2) the predictive potential of the relationship is weak given the inherent uncertainties in these type of geophysical data; (3) despite many attempts, we still do not have a solid theoretical framework that links these properties in a reliable and universal manner. We, therefore, must be careful in using such relationships in a field setting, particularly if we do not attempt to assess any uncertainty in the resultant hydrological model. We, perhaps, have been a little obsessed with attempting to map a complex field of hydraulic conductivity, for example. A more appropriate approach may be to use this type of data to define 'formation' (or lithological) classes, following the more traditional oil exploration framework. This would still provide valuable insight into the hydrological structure of the subsurface.

I explained earlier what drove me into the exploration of using geophysical techniques in a hydrological setting and have already commented about the lack of recognition of uncertainty in geophysical characterisation. In some of our recent work we have been examining the value of additional geophysical data in constraining our geophysical model uncertainty, which goes some way to addressing our initial aims. Figure 3 shows an example of some of this work. Here we use Shannon Entropy (c.f. our earlier GLUE work) as a means of assessing the value of adding new geophysical measurements in order to constrain our model of the subsurface. Clearly each measurement has a cost associated with it (the resource used to acquire and process data). This is not considered here but could be quite easily factored into a cost function. I believe that, in some applications, such an approach may be warranted and will allow us to assess the additional value of deploying geophysical techniques over, say more traditional approaches, in characterising the subsurface environment.

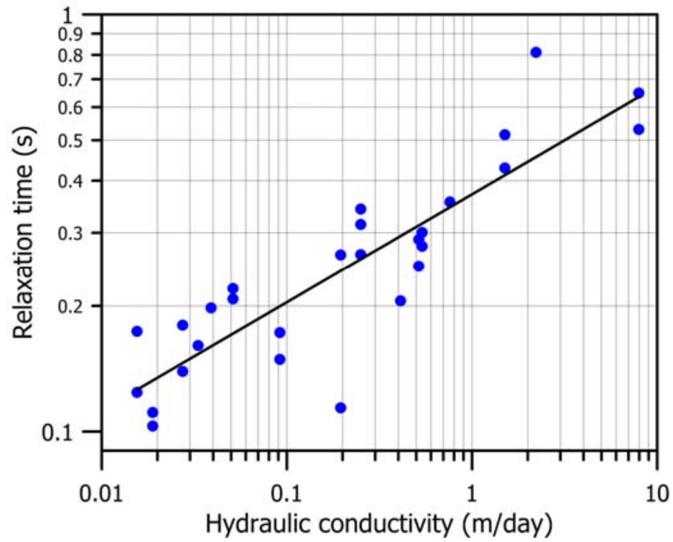

Figure 2. Observed relationship between a measure of relaxation of electrical polarisation and the saturated hydraulic conductivity for a series of Sherwood Sandstone samples. Figure modified from Binley et al.(2005).

Finally, I should remark on another aspect of hydrogeophysics which is starting to gain much needed attention – that of large scale characterisation. I am acutely aware that many of our hydrogeophysical studies have focussed on relatively small plot experiments (e.g. Figure 1). These serve well for the development and demonstration of techniques. However, if the challenge is to tackle problems at a larger (e.g. watershed, entire aquifer, etc.) scale then these plot experiments have limited value, unless they are used to target critical processes (or 'hinge points') in the hydrological system being investigated (e.g. at the groundwater-surface water interface). Some groups are exploring larger scale mapping approaches: there is renewed interest (and development) of land based and airborne EM mapping techniques for watershed scale studies. I can see some exciting opportunities here.

Challenges related to the fusion of multiple data types (soft and hard), with different measurement support scales will need to be addressed, but the potential exists for making a major leap forward in our ability to characterise the structural and dynamic complexities of the subsurface environment, and, as a result, constrain our uncertainty in models of hydrological processes at the watershed or regional scale.

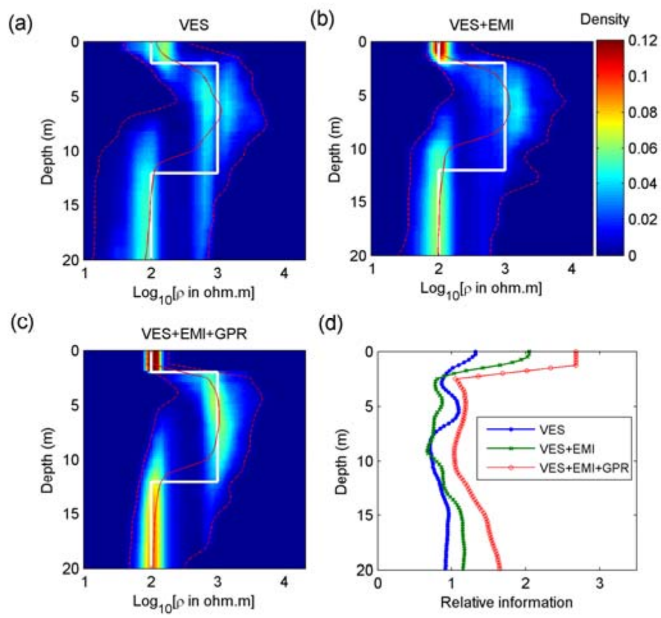

Figure 3. Geophysical inversion of a 1D electrical model using different data, VES (vertical electrical sounding), EMI (electromagnetic conductivity), GPR (ground penetrating radar) . (a) Posterior distribution of individual McMC inversion of VES. The colour scale indicates density of the estimated models, which are calculated by discretizing the estimated models with 10 cm depth-intervals and calculating the normalized histogram at each depth. (b) Posterior distributions of the joint inversion of VES and EMI data. (c) Posterior distributions of the joint inversion of VES and EMI data constrained with information from interpretation of the GPR data. Dashed lines indicate 98% confidence interval of the posterior distributions and solid line shows the posterior median. (d) Depth-dependent variation of relative information estimated from posterior distributions of individual and joint inversion of the synthetic VES, EMI and GPR data. Figure modified from JafarGandomi and Binley (2013).

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The Fellow Speaks: My Academic Progeny

Donald Siegel (Syracuse University)

What constitutes my merit to receive this recognition as an AGU Fellow? Upon reflection, I think the intellectual impact I have to offer has more to do with my intellectual progeny than any solitary achievement. Few scientists produce papers cited more than a decade; but the effects of mentorship transmit across generations. How much colleagues influence their students and their students' students becomes clear to me once I know the intellectual lineage is apparent.My intellectual family tree (Figure 1) is rooted at the University of Minnesota, where Olaf Pfannkuch taught me not only to think conceptually; but also the joys of rigorous mathematical analysis, and how to treat graduate students as junior colleagues--not indentured servants. There, I also experienced the necessary rigor that led to my doctoral studies coupling geochemical mass balance and kinetics at the watershed scale [*Siegel and Pfannkuch*, 1984]. After my doctorate, colleagues in the U.S. Geologic Survey's National Research Program taught me the synthesis of the physical and geochemical parts of hydrogeology, including isotopic systematics and modeling -all within an intellectual environment of remarkable congeniality. During the early 1980s, my USGS colleagues and I discovered that deep Pleistocene-age meltwater recharged deep aquifers sub-glacially under conditions of natural hydraulic fracturing under high pore pressures [*Siegel and Mandel*, 1984]. I began studying peatland hydrology at the USGS too, and at the advice of Marc Hult, explored heuristic modeling of remote peatland groundwater flow systems using the new numerical approaches pioneered by Alan Freeze and John Witherspoon [*Siegel, 1983*].

The notions that glaciers could force water thousands of meters deep through confining beds, and pore water could move through highly humified peat then seemed counterintuitive to hydrogeologists, soil scientists and ecologists; so I learned how to deal with rejections of

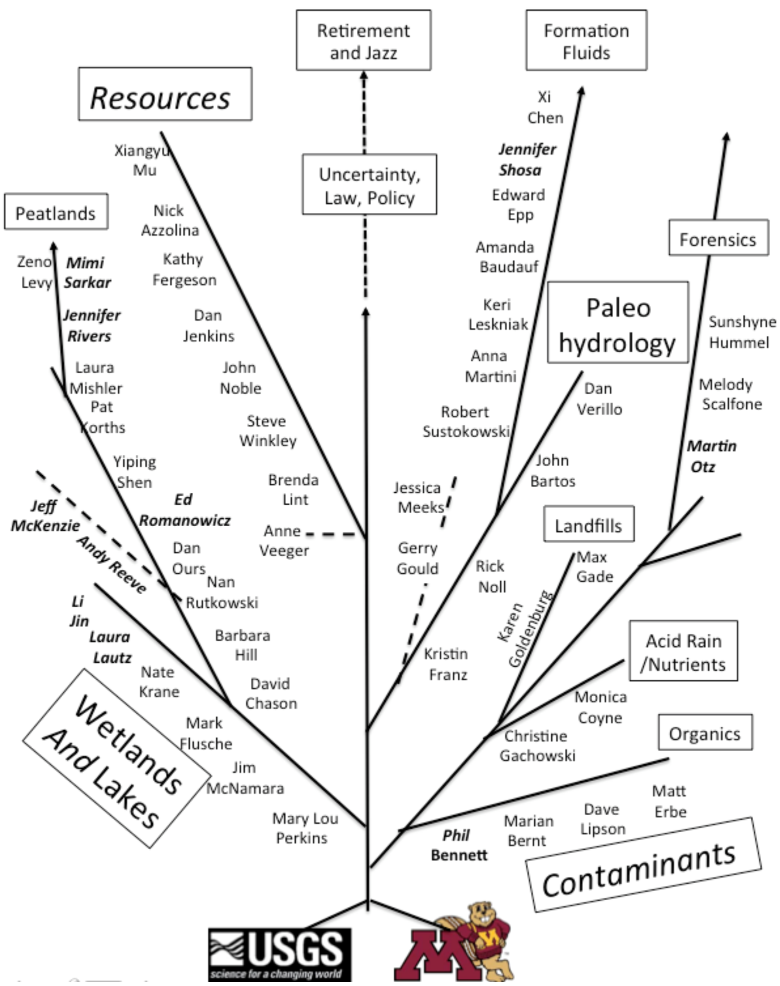

Figure 1. Donald Siegel's Intellectual Family Tree. Bold-faced names consist of his Doctoral Students; dotted lines refer to mathematical modeling lineages.

my publications for a while. These research thrusts and a third USGS effort on an oil-contaminated aquifer forged the intellectual branches that I have continued after I left the USGS in 1982: paleo-hydrology and deep formation fluids, wetland and lake hydrology, and contaminant transport. .

Phil Bennett, my first doctoral student at Syracuse University, discovered at the USGS oil-contaminated site that bacterial processes dissolve quartz at circum-neutral pH [*Bennett and Siegel, 1987*] which also challenged some traditional paradigm. My thirty-five year continuous collaboration with Paul Glaser at the University of Minnesota led to a string of doctoral students who pushed both of us into numerical modeling and studies of peatland hydrodynamics that, among many things, explored hydrodynamic dispersion [*Reeve et al., 2001*], heat transport [*McKenzie et al, 2009*] and physical mechanisms leading to the formation of unexpectedly large reservoirs of biogenic methane within peat profiles [*Romanowicz et al.*, 1995]. In collaboration with Jeff Chanton's geochemistry group at Florida State, our group's peatland work continued with doctoral students working on the biogeochemistry and fluid transport processes leading to methanogenesis in the deep peat [*Rivers et al,* 1998*; Levy et al.*, 2013].

My understanding of contaminant hydrology advanced through a series of doctoral students working on how to directly trace fluids using salts, dyes and natural isotopes [*Otz et al.*, 2003; *Lautz et al.* 2006; *Jin et al.*, 2009]. Jennifer Shosa [a Cornell graduate whom I consider "an honorary Siegel" PhD student] showed me weaknesses in my thermodynamics and fluid mechanics. My many master's level students, too many to cite individually, also pushed me intellectually. Many chose applied science topics that collectively led me to reflect deeply on "real world" policy and legal issues affecting unconventional gas exploitation, landfill contamination and water resources.

Research thrusts recycle over time. When I first arrived at Syracuse University, I mentored students to work on the geochemistry and transport of sedimentary basin brines containing natural gas. I've recently returned to brines, looking at their fate after induced hydraulic fracturing, not by natural processes, done to gain access to natural gas. My earliest USGS work with Tom Winter on lakes resurrected itself last year disguised as prairie pothole research with Yu-Ping Chin at Ohio State and Don Rosenberry and others at USGS and other Federal agencies.

After doing so many projects that cross sub-disciplines, hydraulics, ecology, limnology, surface water hydrology, contaminants etc., I now wonder whether the sophisticated tools I have sometimes used actually advanced hydrogeology as much as I thought they did. Hydrogeologic problems at small scale are often the ones we mostly need to address for society, and these notably incorporate unknown aspects of the subsurface affecting our desired results.

Can we really remediate contaminated ground water at solvent and radionuclide waste sites to low concentration levels for the long term without contaminant rebound after remediation stops—the dual porosity problem?

Have the results of very detailed studies at small spatial scales been transferred successfully to other places - or to larger spatial scales, or do they mostly have conceptual value?

Do the applications of sophisticated statistical tools that incorporate assumptions on hydrologic parameters, unsupported by much data, really do much better than expert judgments?

I have no answers to these questions; but lately, I have tended to become more "reductionist" in what I use as scientific tools as I get older [e.g. *Siegel*, 2008] and explore scientific uncertainty. I ask what approaches can be plausibly used to get the best results, in the context of the weakest links in hydrologic understanding and what can be explained to a public that conspicuously understands less science now than in the past [*Siegel et al*. 2013].

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The Fellow Speaks: The Great Drying: Hydrologic Consequences of Historical Reduction of Channel Complexity

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Hydrologists and other physical scientists increasingly conceptualize rivers as ecosystems, rather than solely as physical conduits for water and sediment. Viewing rivers as ecosystems implies that feedbacks occur between physical and chemical processes and biota, so that plants and animals actively influence channel form and function, rather than simply responding to physical habitat and disturbance regimes. Ecosystems can exhibit alternate stable states, each of which is capable of persisting in the absence of a substantial perturbation (Holling, 1973). My recent research focuses on how human manipulation of river corridors – specifically removal of instream wood and beavers – has reduced physical channel complexity and created alternate stable states in channel-floodplain systems. Instream wood and beavers share at least two important characteristics: individual pieces of wood, logjams, and beaver dams each contribute to increasing hydraulic resistance and obstructing flow; and people have been removing wood and beavers from river networks for centuries.

People have removed instream wood both directly by pulling wood out of channels and indirectly by cutting the forests that supply wood to channels. Wood removal has been so ubiquitous, sustained and intensive that today it is difficult to even imagine the quantities of wood once present in rivers throughout the forested regions of the temperate zones. The most detailed historical records come from North America, where 19th century accounts describe enormous log rafts 200 km long on rivers as diverse as the Red River of Louisiana, the Willamette River of western Oregon, and northern Ohio's Maumee River (Wohl, 2013). Individual logs and large accumulations of wood were common from the largest rivers to the smallest headwater creeks (Figure 1). This wood created many physical and ecological effects, substantially increasing the hydraulic resistance of channels and facilitating overbank flows, lateral channel movements, and channel-floodplain connectivity. Wood-rich channels helped to sustain floodplain lakes and other wetlands (Triska, 1984), as well as complex channel planforms with secondary channels that branched and rejoined (Brummer et al., 2006; Sear et al., 2010; Wohl, 2011; Collins et al., 2012), providing diverse aquatic and riparian habitat.

Beavers were primarily removed from rivers through trapping because of the value of beaver fur. Eurasian beavers (*Castor fiber*) once occupied streams from Siberia and China to England, Scotland and Spain. North American beavers (*C. canadensis*) were historically present from Alaska to Newfoundland and northern Florida to California and northern Mexico (Pollock et al., 2003). Ecologists estimate that 60 to 400 million beavers inhabited North America prior to European contact, compared to an estimated 6 to 12 million at present (Naiman et al., 1988). Even on mainstem rivers too large to be spanned by beaver dams, numerous dams built across the floodplain influenced overbank flows and secondary channels. As with logjams, beaver dams substantially enhance the magnitude and duration of overbank flows (Westbrook et al., 2006), leading to formation of secondary channels and floodplain wetlands (Polvi and Wohl, 2013) (Figure 2). Numerous studies document increased habitat and biodiversity of organisms from plants (Wright et al., 2002; Bartel et al., 2010) to insects (Rolauffs et al., 2001) and fish (Snodgrass and Meffe, 1998) where beaver are present.

Figure 1. This channel-spanning logjam along the Big Thompson River in Rocky Mountain National Park, Colorado ponds water upstream, allowing sand and pebbles to settle onto the streambed, which is composed of cobbles and boulders farther upstream and downstream from the logjam. Organic matter also settles in the ponded water. The three yellow arrows indicate three separate channels that branch downstream from the jam before rejoining to form a single channel more than a hundred meters downstream. Numerous endangered greenback cutthroat trout (*Oncorhynchus clarki stomias*) were observed in the pool when this photograph was taken in summer 2011. The adjacent riparian forest is old-growth spruce and fir.

Figure 2. A beaver meadow along North St. Vrain Creek in Rocky Mountain National Park, Colorado. Numerous small beaver dams result in areas of ponded water, complex channel planforms that branch and rejoin, and a high riparian water table. The yellow arrow points down-valley.

Flow separation and retention of organic matter that lasts even minutes to hours can create opportunities for stream biota to ingest and process nutrients (Battin et al., 2008). Consequently, logjams and beaver dams increase instream retention and processing of nutrients (Naiman and Melillo, 1984; Correll et al., 2000) and floodplain storage of sediment and organic matter (Wohl et al., 2012). Because the physical complexity of river networks influences the degree to which they retain nutrients, this complexity also influences global carbon (Aufdenkampe et al., 2011) and nitrogen (Hall et al., 2009) dynamics.

Other mechanisms can create physically complex, stable river ecosystems. The Everglades come to mind as an extensive channel-wetland system with limited woody vegetation. In forested regions, however, logjams and beaver dams are likely to have been a primary source of physical complexity under historical conditions.

Sustained removal of instream wood and beavers has had at least two consequences of enormous importance for hydrological understanding of river ecosystems. The first involves the actual hydrological changes in river corridors, and the second involves contemporary perceptions of river ecosystems by both scientists and the broader community.

When instream wood and beavers are removed, river corridors exhibit alternate stable states, transitioning rapidly from multi-thread channels with abundant floodplain wetlands to single-thread channels surrounded by drier valley bottoms (Polvi and Wohl, 2013). The hydrological changes in river ecosystems associated with reduction of hydraulic resistance and removal of in-channel obstructions are part of the 'great drying' – a progressive lowering of local and regional water tables, loss of wetlands, and loss of flood attenuation as floodplains become disconnected from river channels. The great drying reflects other human manipulations of landscapes and water, including altered land cover and topography, drainage of lowlands, pumping of ground water, and channelization of runoff in storm drains and sewers, as well as construction of levees and dams, and channelization of rivers. The cumulative effect of these activities is to decrease the hydrologic retention of river corridors and thus make rivers more flashy, with shorter duration peak flows. Associated with loss of hydrologic retention is loss of ability to retain sediment and nutrients. Rivers become 'leaky' (Wohl and Beckman, in press), rapidly transmitting materials downstream, with consequences for river metabolism, ecosystem productivity, and downstream water quality.

In a phenomenon described as the shifting baseline of perception, conditions that are familiar to us constitute our norm, even though these conditions may be of relatively recent origin (Pauly, 1995). Centuries of removal of instream wood and beavers has conditioned us to regard rivers bare of wood and beavers as normal and healthy. This is strikingly reflected in a survey conducted among undergraduate students across the United States and in several countries. Shown photographs of rivers and asked to rate each photograph on a subjective numerical scale with respect to various qualities, most students consistently rated rivers with abundant instream wood as being less esthetically pleasing, more hazardous, and in need of restoration (Chin et al 2008). This is directly at odds with the attitude toward instream wood that has developed in recent decades among river scientists and managers (Chin et al., in press), although fishery biologists and other scientists and managers formerly advocated removal of instream wood.

River scientists now acknowledge the hydrologic importance of instream wood and beaver dams in promoting physical channel complexity, hydrologic retention and channel-floodplain connectivity. Most of us, however, still do not appreciate the geographic scope, ubiquity, and magnitude of historical reductions in wood and beavers. Greater awareness of how 'riverscapes' (Fausch et al., 2002) have changed as a result of removal of wood and beavers will enhance our understanding of the broader hydrological consequences of river ecosystem alteration and help to create a historical context for contemporary river management and restoration.

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The Fellow Speaks: Reflections on my work in catchment processes

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Being elected an AGU Fellow provokes career reflection: on what has engaged your intellect; consumed your energies; and continues to maintain one's enthusiasm and motivation for hydrology. You become aware that your career has already been rather longer than you would like to think! For me, its 26 years since the start of my PhD and it is interesting to see that whilst one's interests have evolved and experience widened, many of the fundamental questions are closely related to those from 26 years ago.

My PhD was part of a large interdisciplinary research project on stream acidification in the catchment of the Llyn Brianne reservoir, Wales, UK. I soon found there were similar studies in other regions affected by industrial air pollution; in the Adirondacks (USA), Dorset Lakes (Canada) and Birkenes (Norway) – to name but a few. There were constant themes; acidic oxides (mainly SO_2) from fossil fuel burning became incorporated into atmospheric moisture, were transferred onto forest canopies in rainfall or occult deposition, washed into sensitive acid soils, acidifying them further and leaching aluminium into streams. The aluminium was toxic to invertebrates and fish resulting in reduced ecological diversity and productivity in streams.

The project was a great training context for a PhD in Hydrology; it was the local manifestation of a global problem, stressed the interconnected nature of the environment, showed the need for engagement with scientists in other fields, had strong policy relevance and produced huge quantities of multivariate environmental data. Yet strangely, at Llyn Brianne, and in many of the other acidification projects hydrology seemed a bit of a "Cinderella". The key players seemed to be atmospheric scientists, environmental chemists or stream ecologists. In some cases hydrology was limited to good quality hydrometrics for precipitation and flow estimates. There was talk about the importance of "flow paths" in routing acid waters and aluminium to streams, but hydrological process studies were usually not well linked to hydrochemical evidence, and seemed disconnected the hillslope hydrology literature and the work of the likes of Horton, Hewlett and Dunne.

Acidification research was also at the cutting edge of environmental modelling and early attempts to integrate understanding of catchment biogeochemical processes and projecting likely changes in stream acidity from altered pollutant emission scenarios or land use change. Again, to my mind, the incorporation of hydrology into models such as MAGIC and ILWAS was relatively primitive, did not reflect concurrent developments in hydrological modelling such as TOPMODEL and were only loosely connected to empirical data or the complex heterogeneity of real catchments. I was lucky to meet Colin Neal from the Centre for Ecology and Hydrology in Wallingford; Colin was an outstanding role model and mentor; he has an excellent scientific mind that takes nothing for granted and was an enthusiastic iconoclast when it came to testing models to as burgeoning data streams became available.

Soon after the start of my PhD he published a seminal paper that showed that whilst the BIRKENES acidification model could simulate stream flow, acidity and aluminium concentrations quite well, it was hopeless at simulating chloride as a conservative tracer. A classic case of a model giving the "right answer" in terms of acidification for the "wrong reasons" hydrologically. That meant the model conceptualised flows paths incorrectly and underestimated the large stores of soil- and groundwater water in headwater catchments. This corroborated benchmark studies in tracer hydrology by Sklash and Pearce showing "old water" dominated the storm hydrograph and the stores of water in a catchment were orders of magnitude larger than the event-based fluxes. For a biogeochemical model, these short-comings are misleading if one links such models to predictions of natural "clean up" times of pollutants or likely biological recovery resulting from policy change.

This crystallized the challenge: if one wants to understand the acidification of surface waters and the transport of aluminium to streams in storm events, hydrology was central. It requires thorough understanding of catchment hydrological flow paths relative to the main water stores, the associated biogeochemical interactions and the likely ecological consequences in streams. It was also clear that this needed to be understood through empirical data used to test hypotheses in integrated models. To do this long term monitoring sites with excellent data at different scales are essential. A major focus of my group's work has used a variety of tracers to understand the geographical sources of runoff, their temporal dynamics and the inter-relationships that link water fluxes to storage changes. To this end, we have made significant progress and now have models which can capture these processes reasonably well (Fig. 1) showing how the catchment landscape is intrinsically linked to the riverscape.

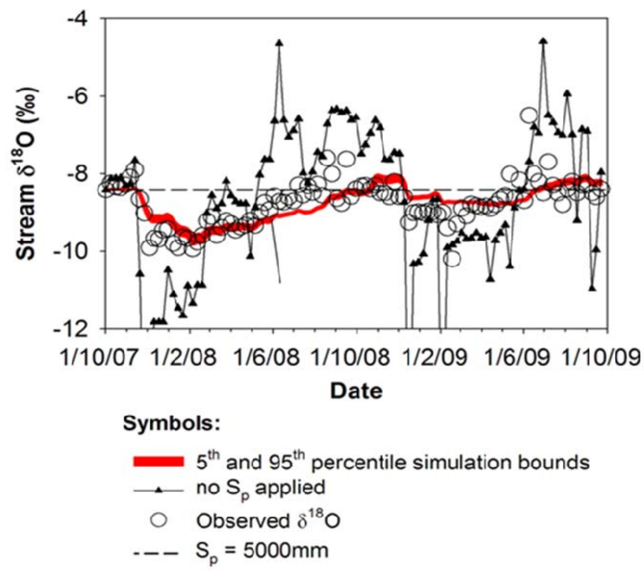

Figure 1: Simulation of stream isotopes using tracer-aided rainfall runoff model. Black triangles show simulation without soil and groundwater storage and red line shows model with storage modules.

As my research developed, these insights have continued to provide guidance. I have worked closely with fish biologists studying Atlantic salmon populations in mountain rivers. At the start, the biologists had limited understanding of how hydrology influenced fish populations. After 30 years of monitoring at the Girnock experimental site in the Cairngorm Mountains, Scotland, they understood a great deal of how biological processes affect the salmon life cycle. It has been very satisfying to establish how much of the river's ecology is influenced by hydrology. Initially we focused where salmon spawned and lay their eggs in the river bed describing the in-stream hydraulic and sedimentary characteristics of spawning locations. But we soon realised that the timing of spawning was flow dependent, and moreover, spawning distributions were strongly influenced by flow variability and catchment wetness in autumn. Wet years allowed distribution of fish throughout the river network, but lower flows restricted connectivity along the channel due to physical barriers and limited spawning to the lower river (and a consequently sub-optimal use of habitat for juveniles).

This encouraged us to look at other salmon life stages and hydrology's influence. We identified areas where survival of fish eggs in the river gravels can be poor. To our surprise this was explained by regions of discharge of de-oxygenated groundwater water through the hyporheic zone, where the egg are deposited but need a supply of well-oxygenated water (Fig. 2).

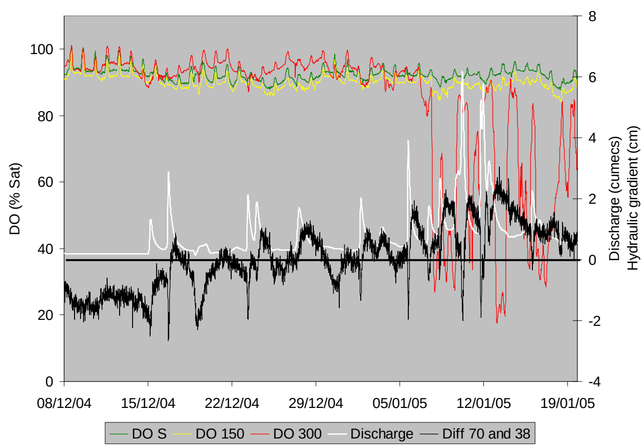

Figure 2. Dissolved oxygen in the stream and at 15 and 30cm depths of the hyporheic zone at a salmon spawning site plotted against stream flow and the hydraulic gradient in the stream bed. As flows increase after spawning the hydraulic gradient becomes positive and is reflected in the discharge of de-oxygenated water into the hyporheic causing mortalities to salmon eggs.

If the eggs survive and hatch, fry swim into the water column in Spring, statistically the driest period least likely to experience high flows, which could wipe out a year class. Moreover, periods of higher flows can make feeding more difficult for fish affecting growth rates. Our work has now extended to looking at hydrological influences on in-stream primary production, the fundamental driver for stream ecosystem function. Whilst this mainly depends upon hydroclimate – especially short-wave radiation – variable flows with increased water depths, colour and potential scour of plants on the stream bed can have profound effects.

In retrospect, I can see that linking empirical and modelling studies to understanding catchment hydrological pathways, their associated biogeochemical interactions and consequent ecological responses has been a dominant paradigm for my research throughout my career. Whilst, progress has been made, each question answered has posed many new ones – a science should – and the challenges seem greater than ever. With new technology and improved tools for data capture, the potential is huge. Yet, it still strikes me that in many cases hydrology still "punches below its

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