O.E. MEINZER AWARD

Presented to
Charles F. Harvey

Charles F. Harvey
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Citation by Roger Daniel Beckie

It is my pleasure to present Charles (Charlie) Harvey as the recipient of the 2014 O.E. Meinzer Award. Through his career Charlie has identified important problems, attacked them with a remarkable range of original tools and approaches, and achieved many profound insights. His investigations of arsenic in South Asian groundwater are particularly noteworthy and the basis of this Meinzer Award.

Charlie's early contributions with his collaborators were directed at understanding solute transport in heterogeneous aquifers and are all notable for their ingenuity and novelty. He developed temporal moment equations which provide a simpler and analytically advantageous description of solute transport. These equations have subsequently been applied in many contexts, particularly inverse modeling, rate-limited mass transfer, mixing, groundwater age and effects of heterogeneity. At a time when the dominant model was macrodispersive, Charlie showed that simple mass-transfer well explained solute transport at the MADE site and is a useful alternative conceptualization for strongly heterogeneous systems. When it was thought that pulsed pumping may provide for a more efficient remediation of mass-transfer-limited solutes, he showed that it made no difference. He showed a fundamental weakness of second-order geostatistical descriptions, which are the basis of many stochastic approaches. These contributions shared some common threads: the elegant application and clear exposition of analytical methods to gain insights into the problem. At the end of the nineties he did not appear to have a strong background in groundwater geochemistry, let alone using field and laboratory methods of investigations.

At that time, few of us in the hydrogeology community were aware of the tragedy of arsenic in groundwater that was unfolding in South Asia. In a well - intended attempt to reduce sickness and disease caused by the consumption of surface water, villagers were installing millions of "tube wells" that regrettably produced drinking water containing dangerous concentrations of arsenic. The work of local authorities in Bangladesh and India, and the British Geological Survey, revealed what to this day remains as probably the most extensive groundwater contamination problem in the world.

In 2000 it was clear that fundamental empirical science – gathering field and laboratory data – was necessary to make progress on the arsenic problem. It was understood through superb antecedent studies that the arsenic was naturally occurring, but there was no agreement on the mechanism by which arsenic was released from sediments into solution. One hypothesis assumed oxidation of arsenical sulfides was responsible, another that phosphate from fertilizer released sorbed arsenic, and a third that arsenic was released when iron oxides were reduced by bacteria during the anaerobic respiration of organic carbon.

I don't know exactly how Charlie became aware of the arsenic problem and decided as a young assistant professor to abandon the comfortable world of Cambridge and Laplace transforms and plunge into geochemistry. It was certainly a bold move.

Charlie proceeded to lead and implement a stunning set of field and laboratory investigations that are the basis of his ground-breaking contributions including his 2002 Science paper, his 2004 Geochimica paper and the 2006 Chemical Geology paper. It is hard to understate the organizational skill and acumen, as well as the risk that he undertook to abandon his familiar research areas and establish a field program on the other side of the globe, in an underdeveloped country, essentially on his own while still an assistant professor.

Typical of Charlie, he took a novel approach to his investigations. In particular, he established a single heavily instrumented field site where he characterized the hydrology and geochemistry in great detail. This was a key innovation, distinct from a regional survey approach, and provided the basis for profound insights into arsenic dynamics.

The 2002 Science paper established unequivocally for the first time that reduction hypothesis is a viable mechanism for arsenic release. In a so-called "push-pull" experiment he injected molasses and tracer into the aquifer at his field site and showed that arsenic concentrations increased as iron oxides were reduced to soluble ferrous iron and the sorbed arsenic was released into solution.

In many ways to me the most remarkable publication is the 2004 Geochimica paper. It is a tour – de – force of geochemical analysis and established Charlie as a bonafide geochemist. In a painstaking field and laboratory program, including sequential extraction analyses, he and his team quantified the arsenic solid and aqueous concentrations and general groundwater geochemistry with depth. They characterized the distribution of arsenic with depth and showed that there existed a "hump" or peak in arsenic concentration at approximately 30 m depth, something suggested by the mass surveys of villager wells. This paper is still to my mind one of the most comprehensive, thorough and informative geochemistry papers on the arsenic problem.

The 2006 Chemical Geology paper is an integrated assessment of the hydrology and geochemistry of arsenic dynamics. It employed a simple zero-dimensional conceptualization of the aquifer system to quantify the fluxes of water and mass through the system. The paper's brilliance is the clarity of the model: the system is distilled to the essential components allowing for a transparent examination of cause and effect. This was one of the first papers to interrogate two absolutely fundamental issues: 1) the role of irrigation pumping on arsenic dynamics and 2) the possible sources of the organic carbon that is driving the reduction of iron oxides. The paper quantified the water cycle, established that natural and dug-out ponds could be sources of the organic matter and that irrigation pumping severely disrupted the natural hydrologic cycle.

In the four years between 2002 and 2006, Charlie had established himself as a world leader in arsenic research. The influence he has had on the field is evident not only in publication metrics, but also in the numerous colleagues who have sought out Charlie for collaborations and advice since that time. Indeed, almost every session on arsenic in groundwater at an international conference will have at least one Charlie collaborator. And he has made us all better for it. I certainly count my sabbatical year with Charlie at MIT in 2000 – 2001 as one of the most enjoyable and fruitful of my career. I know many of you in the audience today will agree that we have all been enriched by our encounters with Charlie.

Indeed, Charlie is not only a brilliant and creative scientist, but also wonderful person. He is generous with his ideas, patient, open to new approaches and opinions and with his impish humor and easy – going nature, extremely fun to be around. One of the simplest ways to find Charlie is to listen for peals of laughter erupting from a corridor scrum.

Charlie and his collaborators' work on arsenic is remarkable for attacking so many dimensions of the problem, with such an astonishing array of scientific tools, achieving so many significant results. The impact of his work is irrefutable, and his esteem well deserved. I take great joy in being here in my hometown to recognize Charlie with the O.E. Meinzer Award. Please join me in congratulating the 2014 O.E. Meinzer Award recipient, Charles Harvey.

Response by Charles Harvey

Thank you Roger. It's particular nice to hear the citation from you because you have been a model for me of intellectual depth and broad scientific curiosity. I thank the GSA and the hydrogeology division. I am truly grateful for this award, but also suffer a bit from the imposter syndrome that undergrads at prestigious universities supposedly feel. Perhaps there was a mistake. Twenty years ago Roy Haggerty, Alicia Wilson, Carl Renshaw, David Hyndman, Fred Day-Lewis, Claire Tiediman and I were all Steve Gorelick's students. When looking for a job I was once interviewed by someone who conflated at least three of us, those with names starting with H, as one person -- the prolific young hydrologist named something like Harvaggerman. Of course, I let the misunderstanding stand, and here I am. Working with Steve Gorelick and the group at Stanford and Menlo Park was a tremendous opportunity to learn to be a successful scientist and hydrogeologist. Steve's mentoring developed the skills I needed for what came after Stanford. Before Stanford, I had an entry-level job at the Richmond USGS office, where I was inspired by the work of USGS hydrologists to pursue a career in hydrogeology.

I am obviously very lucky to be at MIT with exceptional colleagues such as Harry Hemond, who knows more about the environment than I ever will. But, any of you who know the details of my research also know that my graduate students and post-docs really did it. It's an open secret. What you might not realize is that I haven't had that many – they've just all been really good.

Let me first mention several current members of my group who just might be available for employment. Alex Cobb is the research scientist living in Borneo who did the work I talked about at 8:00 Sunday morning, which a couple of you showed up for. The scope of Alex's work is hard to believe – he designed and built our eddy flux systems, constructing the towers by helicopter deep in the inaccessible Bornean tropical peat swamp forests. He speaks Iban, Malay and Mandarin. He wrote the code that simulates the hydrology and ecological dynamics of the forest over millennia and is now conducting the analysis of gene flow through the forest. Mason Stahl, a PhD student, has led our work in Bangladesh for the last years. To test hypotheses about the cause of arsenic contamination, he directed construction of a lake above an extensive network of wells and sampling devises. I only hear about this from Mason, but I know it must not be easy. Mason has found geochemical and hydrological surprises: terrestrial crabs control the flow through the lakebed and mobilization of old labile organic carbon from beneath the lake. Mason is driving the research to answer questions we have been seeking for a decade.

Our work in Bangladesh began with the interests of Winston Yu back in 1996, who first analyzed the severity of the public health project. It's worth emphasizing that the problem remains bad – very recent epidemiology shows that in parts of Bangladesh twenty percent of mortality can be attributed to arsenic in groundwater. To launch the project in Bangladesh, I first visited Dhaka with Shafiq Islam, now at Tufts, who introduced me to Borhan Badruzzman at the Bangladesh University of Engineering and Technology (BUET). Borhan has guided our project from the beginning and remains, fifteen years later, a most trusted collaborator and colleague. The initial science was directed by Chris Swartz, a recent PhD from MIT. Chris had the broad geochemical insights to understand the system and the field acumen to choose the right measurements. Again, it was really Chris who did the work. Two excellent students followed Chris. Ashfaque Khadakar developed the first numerical models of groundwater flow at the 10-m scale of arsenic variations that we still use to guide our work. Becca Neumann mustered a stunningly broad range of data and models to characterize the reactive flow system that controls arsenic concentrations. At her faculty position at University of Washington, Becca has continued to expand her work to include detailed understanding of root dynamics and redox processes in the subsurface.

That leaves just seven other former student and post-docs. Kaeo Duarte, Holly Michael, Brendan Zinn, Kurt House, Hanan Karam, Elena Abarca and Pete Oates. Pete was the student too smart to take an academic job. Although Pete will never tell you this, he did the most theoretically deep work I have been involved in. Pete has seen his work to fruition, if not in the groundwater literature, then in his remarkable stochastic models of the stock markets and better beer brewing through reactive transport. Kaeo Duarte is an inspiration in the field of environmental management. He combined mathematical aptitude and thoughtful analysis of how people and cultures value present and future water quantity and quality. I am pleased that he is stewarding the future of Native Hawaiian lands. Brendan Zinn produced a piece of work that changed my thinking about whether simple stochastic models are useful in the real world. Kurt House has been an education for me. Through Kurt I learned everything I know about two apparently desperate subjects: thermodynamics and business. It has been a thrill to work with Kurt as he successfully navigated the world of venture capital and land rights to build the first successful carbon sequestration company. Hanan Karam and Elena Abarca have done groundbreaking empirical work on coastal groundwater and achieved new theoretical insights – let's publish it and share it with the world! That leaves Holly Michael. Holly, first, thank you for the nomination. At a young age, Holly has produced a remarkable number of important contributions to the field. I remember Holly as the new graduate student who I suggested might run out to buy fifty 55-gallon steel barrels to manufacture a fleet of seepage meters. She did it, not realizing that I had no idea what I was talking about. Now, I worry that, as I learn more and more from my students, I might start to give future students real guidance, and thereby diminish their development as independent scientists. And, incredibly, I now have the best group of new graduate students I have ever had: Alison Hoyt, Brittany Huhman and Neha Mehta. You will be hearing from them.

Whatever the set of anomalous circumstances that got me here, I'm now on a platform to say something about the field of hydrogeology. Mary Anderson recently published a fantastic paper describing how Meinzer winners have build the foundations of groundwater hydrology. Where can I go from there? I'll be brief. I'd like to suggest that the future of hydrogeology is in interdisciplinary field-based research. I don't mean the collaboration of a hydrologist with a microbiologist, geochemist or economist. Rather, I mean that the P.I., and hence the students, need to grasp the problem in its entirety. It's not about combining a hydrologic study with a geochemical or ecological study. It's about finding well-posed questions about the complete system from the get go, the system of water and chemistry and biology. Yes, this approach requires a daunting quantity of background knowledge. It's about knowing the limits of ecological understanding, targeting the hydrologic interactions themselves, and designing new field measurements and experimental methods that directly test these interactions. And, ultimately it must be done in the field. After all we aren't studying the equations themselves, or idealized lab models, rather we are only employing them to understand the natural world.