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unsaturated zone interest group
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The semi-annual Unsaturated Zone Interest Group (UZIG) newsletter highlights current topics concerning the unsaturated zone. Its purpose is to enhance communication within UZIG. It is not an official publication and should not be cited. Please contact authors or members of the newsletter committee with any questions, comments, and/or suggestions. Send desired changes in the mailing list to jtrost@usgs.gov.

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UZIG elects new Chair for 2013-14

By Katie Aurand
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Randy Bayless is the newly elected UZIG Chair for 2013 - 2014. He works as a Research Hydrologist and Groundwater Specialist with the U.S. Geological Survey in Indianapolis, IN, and has been a member of UZIG for almost 20 years.

The UZIG steering committee elected Randy Bayless as UZIG Chair for a two-year term through 2014. Randy has been involved with UZIG for almost 20 years and is a Research Hydrologist and the Indiana-Kentucky Commonwealth Groundwater Specialist with the U.S. Geological Survey in Indianapolis, IN.

Randy's goals for UZIG include strengthening and developing current membership through increased interaction and collaboration, growing non-USGS participation through targeted communications to academicians and other Federal agencies, and developing UZIG's standing with USGS by regular communication with the Office of Groundwater, other USGS interest groups, and the Regional Groundwater specialists.

He also plans to encourage non-UZIG hydrologists to include the unsaturated zone in their groundwater studies by promoting available resources such as expertise, equipment, and publications. Randy also plans to provide training, education, and web information about the unsaturated zone.

"It just seems like the unsaturated zone is something that's commonly overlooked," said Randy. "It's not convenient. With a little bit of education, people can get interested in it and know that it's not that difficult [to include]."

Randy said recent developments like the new MODFLOW (groundwater modeling software) module that includes the unsaturated zone (see page 8) should help people become more interested in adding an unsaturated zone component to their studies.

Members of the UZIG steering committee are currently organizing monthly web seminars for increased awareness and training about the unsaturated zone (see page 7), organizing an annual meeting (see page 2), and updating the website.

"I'm excited about the website," said Randy. "I think that's going to be a great way to educate people that aren't regular users of unsaturated zone methods, and I think it's going to be a great way to tighten the collaboration between the members."

UZIG-sponsored sessions and field trip proposed for the 2013 Geological Society of America meeting

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UZIG is planning to meet in cooperation with the Geological Society of America (GSA) annual meeting in Denver CO, October 27-30, 2013. We plan to begin with a field trip, collaborate through several UZIG sponsored technical sessions, and close with a business meeting/luncheon. Dave Stonestrom (USGS) and Geoff Delin (USGS) have organized a field trip to be held the Saturday before the meeting (Oct. 26), and several UZIG members have proposed unsaturated-zone related technical sessions. The following article includes descriptions of the field trip and proposed technical sessions. Details about UZIG activities at the GSA meeting will be included in the next newsletter (Sept. 2013). Meanwhile, contact Amanda Garcia (cgarcia@usgs.gov) or Dave Stonestrom (dastones@usgs.gov) with questions or suggestions regarding UZIG activities at GSA.

Rocky Mountain Unsaturated Zones—Exploring Fire-Earth-Sky Connections (field trip)

This multisegment field trip, led by subject matter experts, will highlight four different multidisciplinary research efforts aimed at crucial problems involving unsaturated zones in the Rocky Mountain area. The first segment will investigate linkages of large hot fires to short-to-long term changes in the partitioning of rainfall and snowmelt into infiltration and runoff, with attendant flood generation and sediment transport. These linkages will be examined within the context of enhanced potential for extreme flooding and debris flows caused by hyperarid conditions following the September 2010 Fourmile Canyon fire--at the time the most costly in Colorado history. The second segment will investigate a site in the Boulder Creek member of the NSF-sponsored Critical Zone Observatory (CZO) network, where data-driven studies are exploring interactions among water, soil, and boundary-layer ecosystems across landscapes that include little-explored thick unsaturated zones on deeply sculpted erosional terrain. The third segment will investigate seasonal systematics of elemental exchanges across the land-atmosphere interface along transitions from undisturbed to urbanized land (comprising one investigational axis) and from prairie grassland to montane forests (comprising another). This portion will include a visit to an instrumented short-grass prairie site at the Rocky Flat National Wildlife Refuge, where land surface fluxes of CO2, CH4, N2O, and water vapor are being correlated to soil-carbon dynamics. The final segment will investigate the legacy of nuclear weapons production, environmental contamination, and remediation at the Rocky Flats industrial site. The field trip will end with an optional dinner in an informal setting.

Field Trip Leaders: Brian Ebel (CIRES Fellow, U. Colorado); Dean Anderson and Katherine Powell (USGS, Lakewood); Suzanne Prestrud Anderson (PI, Boulder Creek CZO); Bruce Honeyman (tentative; Colo. School Mines)

Unsaturated Zone Geophysics

In this session we focus on the application of geophysical methods to provide quantitative estimates of unsaturated zone hydrologic properties and unique insights about vadose zone hydrologic processes. We welcome laboratory- to field-scales examples of new and novel methods to acquire, analyze and interpret vadose zone geophysics. Although examples of geophysical methods coupled with traditional hydrologic testing procedures are particularly encouraged, all approaches and aspects of surface, borehole, and cross-hole geophysical surveys, from data acquisition, through inversion, visualization and coupling of geophysical results to groundwater flow and transport models are of interest.

Conveners: John W. Lane, USGS Office of Groundwater; Kamini Singha, Colorado School of Mines

Vadose zone flow and transport in natural or engineer systems under extreme conditions

Engineered system such as a surface flow barrier or cover often creates an environment drier than the same soil under the natural condition. The surface flow barriers often contain a capillary break that is made of a fine (e.g., silt) layer over a coarse (e.g., gravel) layer. Sub-surface remediation using the desiccation technology immobilizes soil water with dissolved contaminants creates a very dry condition. Many other environment remediation technologies also create extreme flow conditions. Flow under these extreme conditions is generally not well understood. This session seeks theoretical or experimental study, measuring techniques, computer simulations, real-world problems, remediation technologies on flow and solute transport at low water content, in very coarse materials, low-permeability media, fractured systems, soil-gravel mixtures, and across the texture interface. The flow type may be capillary flow, film flow, stable or unstable flow, preferential or funnel flow, Darcy or non-Darcy flow, temperature induced flow, and other flow types.

Conveners: Z. Fred Zhang, Pacific Northwest National Laboratory; H. Liu, Lawrence Berkley National Laboratory; and J. Zhu, Desert Research Institute, Las Vegas, NV

Impacts of Land-Use Change on Unsaturated-Zone Biohydrogeology

Land-use change profoundly impacts unsaturated-zone biotic and hydrologic processes such as subsurface moisture dynamics, infiltration and runoff, sedimentary erosion and deposition, biodiversity, and ecological function. This session will explore recent work in assessing these process changes and related effects.

Rationale: Land use directly affects biodiversity and hydrogeology. Human alteration of landscapes such as deforestation, introduction of invasive species, agriculture, and urban development have significantly altered landscapes all over the world. These disturbances typically result in habitat loss, degradation, fragmentation, and even extinction. There are fundamental interrelationships between biologic, hydrologic, and geologic processes and a change in one of these can cause functional or structural change in both of the other two. Specifically, there are changes in the unsaturated zone including alteration of soil hydraulic properties and processes, water quality and availability, rainfall/runoff partitioning, erosion, habitat suitability, biodiversity, and ecological health.

This session aims to present an exciting and diverse range of studies focused on the unsaturated zone using a variety of field and modeling techniques to explore the environmental implications of land-use changes such as the introduction of native species, deforestation, urbanization, and agriculture. This will also include studies examining restoration effects on species reestablishment and diversity, restoration of soil function, and changes in hydrology.

Conveners: Kim Perkins, USGS; David Bedford, USGS; and Darren Sandquist, CSU Fullerton

Bottoms Up! - Shallow Water Table Influences on Vadose Zone Biogeochemistry

Topics will focus on the influence of shallow water table conditions on hydrologic and biologic processes that control the unsaturated zone's biogeochemistry, contaminant fate and transport, and ecological community structure and composition.

Rationale: Many hydrologic and biogeochemical processes in the vadose zone are influenced by variations in the water table near the surface. The importance of the vadose zone is often discounted in shallow water table environments because seasonal fluctuations in water tables result in periods of time where the vadose zone is significantly reduced or is absent completely. However, the dynamic nature of the shallow water table influences soil moisture conditions, oxidation reactions, biogeochemistry, and biogeochemical gradients, highlighting the importance of research in this area. The proposed session will help disseminate new research in the near-surface vadose zone, providing an opportunity for the broader GSA scientific community to learn about the role of vadose zone processes in terrestrial and wetland ecology, biogeochemistry, and emerging subdiciplines, such as ecohydrology.

Conveners: Wesley R. Henson and David Kaplan, University of Florida

Anomalies, surprises, irregularities, and contradictions in variably-saturated subsurface flow

Detailed monitoring of subsurface hydrologic-response dynamics and solute concentrations in complex, natural systems often reveals surprising observations, anomalous data, and apparent irregularities or contradictions between measured subsurface state variables and traditional flow theory. Critical evaluation of these deviations between observed and expected results can lead to important breakthroughs in our conceptual understanding of complex subsurface hydrological processes. This session welcomes submissions that present unexpected or surprising data that cannot be easily explained, analysis of unusual flow phenomena, and novel modeling approaches, with an overall aim of stimulating discussions and improving quantitative characterization of subsurface flow and transport processes.

Conveners: Benjamin Mirus, USGS; Brian Ebel, University of Colorado at Boulder; John Nimmo, USGS

Recent advances in the theory, characterization, and modeling of unsaturated zone processes

This session focuses on advances in understanding unsaturated zone processes that control gas and water transport using field and laboratory measurements, and theoretical and numerical models. Topics considering the groundwater-atmosphere continuum are of particular interest.

Rationale: From arid to humid environments, unsaturated-zone processes control gas and water movement from the water table to the atmosphere. Groundwater quality and availability predictions, land-use assessments, and climate change adaptations can all benefit from knowledge of unsaturated-zone dynamics. In particular, these processes include infiltration from the earth-surface through soils and fractured rock, fluid-soil and fluid-rock chemical interactions, and movement of water and energy. In combination, these processes often control partitioning and redistribution of natural and anthropogenically-derived liquid and gas-phase chemical constituents within the hydrogeologic system. Estimating fluxes of fluid, energy and chemical constituents through innovative sampling techniques, field and laboratory measurements, and modeling can help guide current and future decisions about land management. This session solicits contributions highlighting recent advancements in field and laboratory measurements, theoretical and numerical models, and other characterization techniques that improve the understanding of gas and water transport across the groundwater to atmosphere continuum.

Conveners: C. Amanda Garcia, USGS Carson City; Michael H. Young, University of Texas at Austin; David A. Stonestrom, USGS Menlo Park

Water repellency of soil at the Bemidji oil spill site

By John Nieber
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In August 1979 over 1.7 million liters of crude oil spilled from a broken oil pipeline in the vicinity of Bemidji, Minnesota. The broken pipeline sprayed oil over a large area of land surrounding the break. Oil infiltrated the soil over much of the area, but where the oil pooled on the surface it ran off the higher areas and deposited into the low-lying areas and percolated to the underlying surficial aquifer. Quick efforts by the pipeline company and state and federal emergency crews facilitated the capture and recovery of almost 80% of the oil. The oil that remained exists as either residual in the unsaturated zone, or as free product pooled on the water table of the shallow surficial aquifer. An aerial view of the oil contaminated area surrounding the broken pipeline is presented in Figure 1.

Following the cleanup of the areas with pooled free product, the vegetation on the spray area was burned. The area has remained largely devoid of vegetation for much of the last three decades (Figure 2) because the surface soil became water repellent due to the oil contamination and possibly the burning.

Much effort has been expended since the time of the spill to study the fate of the oil that resides as free product pooled on the water table, but other than some initial studies in the early 1990's little attention has been

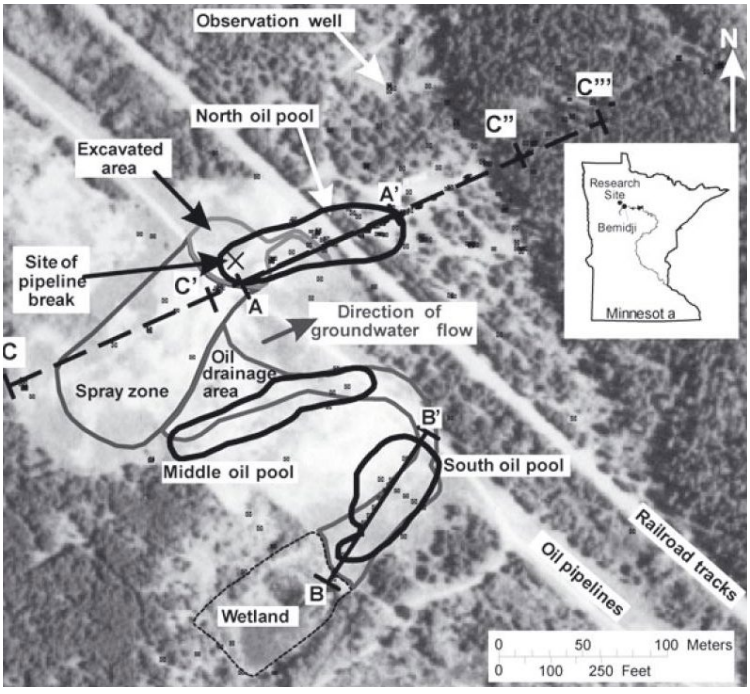

Figure 1. Distribution of oil contamination at the Bemidji oil spill site. Oil pooled in depressional areas and infiltrated to the water table. Oil sprayed onto the soil in the spray zone, infiltrated into the soil, and remains as residual product. Image from Delin and others (1998).

Figure 2. Illustration of the vegetation distribution on the high elevation areas of the spray zone. The stoniness of the surface results because the original sand layer has eroded and the sand transported to the depression downslope (to the upper right) from this location. The bottle next to the shovel contains the distilled water used in the WDPT test survey.

paid to the spray zone area. In the summer of 2011 a project was conducted to map the water repellency of the soil within the spray zone. The project was headed by myself with the assistance of two undergraduate students, Leigh Severson and Nick Grewe.

Using a grid mapped onto the spray area, measurements of water repellency were obtained at each grid point with the Water Drop Penetration Time (WDPT) test. With this method, which is a common test used to assess the water repellency of a soil, the time required for a drop of water placed on the soil surface to infiltrate the surface is measured. An index of water repellency is derived from this measurement from which the soil is classified as one of the following: wettable, slightly water repellent; strongly water repellent; severely water repellent; or extremely water repellent. As an example of this test, Figure 3 shows water drops on a water repellent surface which is extremely repellent. At this site the soil was extremely water repellent and the drops evaporated before they could be absorbed into the soil.

A map of the distribution of water repellency over the spray area is presented in Figure 4. The degree of water repellency within the spray area ranges from slightly repellent to extremely water repellent, whereas outside the area the soil is water wettable. Measurements were also made with depth, and it was found that the repellency persisted to as deep as 40 cm in some places within the spray zone.

Infiltration tests were also conducted with the Modified Philip-Dunne infiltrometer (a tube infiltrometer) at selected locations in the spray zone area. As an example of results, at site B79 that manifested extreme water

Figure 3. Water drops on water repellent soil shown at the top and to the left of the penny.

repellency, water would not infiltrate even with a depth of 38 cm of water in the tube.

In the summer of 2012 there was a second season of investigations on the spray zone and the associated water repellency. Four undergraduate students assisted with the investigations, Nick Grewe, Thu Tran, Bryan Wendt, and Nick Kanazawa. Investigations included three surveys within the spray zone: a replicated survey of the spatial distribution of water repellency, a survey of soil erosion, and a survey of plant species present. Samples were also returned to the laboratory to test water repellency with the molarity of ethanol droplet (MED) test, a test that uses different concentrations of ethyl alcohol to determine water repellency of soil. Tests were also conducted on samples to determine the ameliorating effect of adding dispersible clay to the samples.

The replicated water repellency survey with the WDPT test confirmed the results found in 2011. Water repellency results for samples tested in the laboratory with the WDPT were also in agreement with tests conducted on the same samples with the MED test method.

The soil erosion survey showed that the 25 to 35 cm thick layer of sand that originally existed on the higher elevations of the spray area had eroded, with the eroded sand producing thick deposits of sand in the adjacent depressions. The soil surface is now very stony as the sand had been preferentially eroded from the surface (Figure 2).

The vegetation survey resulted in the identification of over 40 species of plants and their locations within the spray zone. The vegetation is relatively dense in the depressional areas, locations where runoff focuses and wets the soil sufficiently to promote growth. Vegetative cover on the higher elevations is very sparse as seen in Figure 2. Non-woody plants have been able to get established in isolated spots. It might be that the places where plants are established are locations where the water repellency is sufficiently low to allow runoff water to collect and infiltrate. So landscape position (topography and microtopography) as well as degree of water repellency are both important for plant establishment. It might be interesting to determine how surface topography, water repellency distribution, and biological processes affect the locations of plant establishment.

The laboratory tests with the incorporation of dispersible clay showed that the addition of clay does reduce the degree of water repellency. As expected, the amount of clay required to reduce repellency was found to be related to the degree of contamination. However, to acquire the amount of clay needed (about 1.6% by weight) would require significant expenditure. Our estimate is over $60,000 per hectare. Other methods of amelioration of water repellency are probably needed.

One potential method of amelioration is biological degradation of the oil compounds. Dr. Randy Adams, an expert in restoration of petroleum contaminated soils and Research Professor at the Juarez Autonomous University of Tabasco, Mexico, visited the Bemidji site with me in September 2012. Randy collected samples from the site and returned with them to his lab at the University of Tabasco. Analysis of the samples showed that the oil compounds present are not as degraded as might be expected considering the time (32 years) since the contamination event. He attributed the very slow degradation to the colder climate prevalent at the Bemidji site, and to the low nutrition condition of the soils present at the site. It is hoped that identification of an effective biological remediation procedure will result through future collaboration with Randy.

Reference: Delin, G.N., Essaid, H.I., Cozzarelli, I.M., Lahvis, M.H., and Bekins, B.A., 1998, Ground water contamination by crude oil near Bemidji, Minnesota: U.S. Geological Survey Fact Sheet FS-084-98, 4 p.

Note: Many UZIG members have worked with the Bemidji oil spill site. For more information on publications and projects related to the site, visit http://toxics.usgs.gov/sites/bemidji_page.html or http://mn.water.usgs.gov/projects/bemidji/.

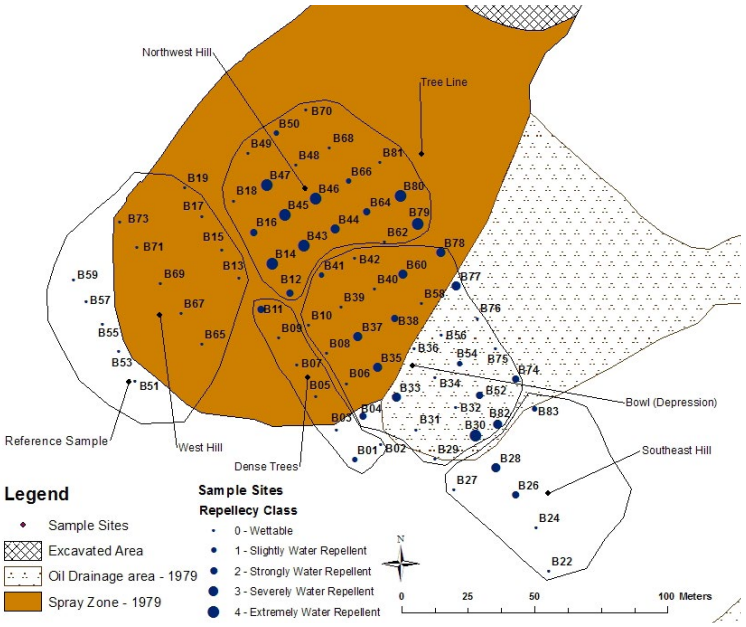

Figure 4. Map of the distribution of the index of water repellency of the soil surface within the spray area as determined with the WDPT test. An infiltrometer test at location B79 showed that infiltration did not occur even with a water head of 38 cm.

A brief history of the Unsaturated Zone Interest Group

By John Nimmo
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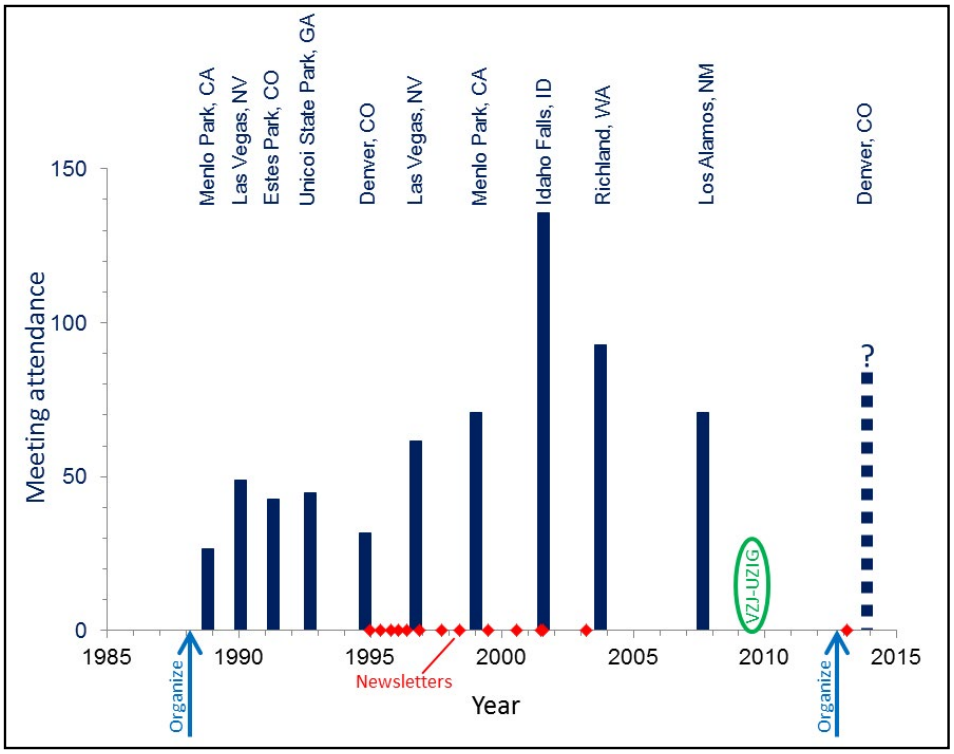
Organization of UZIG began on an afternoon in early May of 1988 in a conference room at the Holiday Inn in Golden, CO. The first meeting was a breakout session from the USGS joint-research Groundwater Meeting. A group of about 21 scientists agreed to support an informal organization whose purpose was (and is) to encourage and support interdisciplinary collaboration in vadose- or unsaturated-zone hydrologic research across organizational boundaries.

The movement of water and other substances through the unsaturated zone is physically complex and inherently interdisciplinary, yet it is often a secondary focus of studies that encompass it in some significant respect. Thus it's essential for information, expertise, instrumentation, and problems to be exchanged from diverse and administratively-disconnected groups. From the start, UZIG included participation from non-USGS organizations like USDA's Agricultural Research Service, and DOE and its contractors. Such diversity came about quite naturally, given the theme of interdisciplinary research across organizational boundaries.



Notable events in UZIG history. Ten UZIG-wide meetings appear as dark blue bars with length proportional to number of attendees. One dashed bar marks the currently-planned meeting. Fourteen red diamonds indicate issues of UZIG News. The green ellipse marks the UZIG special section of Vadose Zone Journal. Blue arrows mark organizing meetings of UZIG-interested people to initiate and reinitiate the program of UZIG activities.

The figure above charts some chronological, geographical, and statistical details of UZIG's history. Ten membership-wide meetings have been held at various locations in the United States. Most meetings were sponsored jointly by USGS and one or more other institutions. Meetings were initially held at intervals of less than two years, though the frequency has declined, especially since 2003. Attendance, however, has generally increased from the early years, peaking with 134 at Idaho Falls in 2001. The meetings included field trips that enlightened and amazed the participants. Highlights include visits to the USGS Amargosa Desert Research Site, Yucca Mountain with an excursion into the famous exploratory tunnel, and the Panola Mountain Research Watershed in Georgia.

Several additional undertakings have been important to UZIG. The newsletter UZIG News was first produced in 1995. Like the meetings, it has declined in frequency. The UZIG website (http://mn.water.usgs.gov/uzig/) has been available for many years, and is currently being updated. Besides providing general information about UZIG, the website contains newsletter archives and meeting summaries. Sharable equipment and topics of expertise also have been assembled and disseminated over time. At present the email distribution list, with about 500 names, serves as the list of UZIG members. Additional names are added on request (to jtrost@usgs.gov).

In May 2009 *Vadose Zone Journal* published a special section on UZIG and USGS research (http://vzj.geoscienceworld.org/content/8/2/411.full). Its eleven papers came from presentations given at the 2007 UZIG meeting in Los Alamos. These cover highly diverse subject matter in the broad categories of Soil-Water-Plant-Atmosphere Interactions and Unsaturated-Zone Properties and Processes.

In 2013 the need for an organization like UZIG is as compelling as ever. To reinitiate UZIG undertakings that had been flagging in recent years, 23 UZIG-interested scientists met last August in a breakout session from the USGS National Groundwater Meeting, much as they did in May 1988, to share interests and enthusiasms and coordinate activities that would promote the goals of UZIG. This issue of UZIG News tells much of what has happened since.

Thank you to John Nimmo for service as UZIG Chair

By Katie Aurand
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John Nimmo assumed leadership of the Unsaturated Zone Interest Group at the 1999 UZIG meeting and has been involved with UZIG since its inception in 1988. A Research Physicist with the USGS in Menlo Park, CA, John has authored many reports on unsaturated zone flow processes, and he has been a main driving force behind the recent upswing in UZIG activity.

"John's collegial spirit and organizational skills have factored prominently into the longevity of UZIG and the many fruitful interactions among colleagues that have resulted," said Andy O'Reilly, USGS Hydrologist. "With his motivation in 2012, UZIG has moved to more effective organization of its activities."

John has orchestrated the formation of UZIG committees to effectively accomplish tasks such as publishing newsletters, organizing meetings, and developing a webinar series. Another example of John's work to increase the visibility of UZIG is the special section on UZIG and USGS research he wrote for the *Vadose Zone Journal* in 2009 with Brian Andraski (USGS) and Rafael Munoz-Carpena (Univ. of Florida).

"It's quite an honor to follow in John Nimmo's footsteps," said newly elected UZIG Chair Randy Bayless.

John had a vision of building a broader and stronger community of unsaturated-zone scientists and implemented that vision by organizing subsequent meetings at DOE national laboratories. In addition to DOE scientists, John also actively recruited participation from academic and other research groups.

John Nimmo ends his term as UZIG Chair. A Research Physicist with the USGS in Menlo Park, CA, John has been essential to UZIG due to his expertise with unsaturated zone flow processes and his ability to mobilize UZIG members to effectively plan meetings and accomplish tasks.

"All of the national UZIG meetings over the past 14 years were due principally to John's leadership and ability to build effective teams that guaranteed meetings where ideas cross-fertilized and new working relations formed," said Dave Stonestrom, USGS Hydrologist.

UZIG thanks John Nimmo for his service as UZIG Chair and looks forward to his continued involvement.

Introducing the UZIG web seminar series

By Mindy Erickson
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Beginning in April, the USGS will host a monthly UZIG web-based seminar series (webinar). We want to provide an easily-accessible (and virtually free) forum for UZIG members to introduce themselves to one another and to share their research results. Ever-changing government travel restrictions and increasing travel costs are making conference attendance more challenging than in the past. But we all know that keeping in touch and keeping up with current research is critical – and that personal connections and knowledge of current work is crucial for building collaborations.

We would like to develop a speaker schedule for the next 6 to 12 months, and a critical element to the success of the webinar series is finding willing speakers. Please consider volunteering to present your work at an upcoming webinar. Your presentation can be 20 to 45 minutes and can cover completed work or work in progress. We would like to post an abstract and a brief biography and contact information for each presenter on the UZIG website (mn.water.usgs.gov/uzig). The presentation slides could be posted on the website depending on the speaker's preference. We urge you to consider volunteering, even if you have a talk that feels 'stale' to you. UZIG now has many new members, who would benefit from hearing about your research in unsaturated zone processes.

We plan to schedule the webinars for a time that would be convenient across all of the U.S. time zones on a 'standing day and time' once per month – for example, the second Tuesday of each month, 12 to 1 p.m. Central time. The day and time are not yet established, though.

The UZIG webinar series is being coordinated by USGS Minnesota Water Science Center hydrologist and groundwater specialist Mindy Erickson (merickso@usgs.gov). If you would like to present your work at an upcoming webinar – or to suggest someone else as a possible webinar presenter – please contact Mindy. A webinar schedule, with presenter and topic information, will be announced via email and posted on the UZIG website in late March.

We look forward to 'seeing' you at the kick-off webinar in April.

Modeling large scale variably-saturated transport with MODFLOW's UZF1 package

By Eric Morway
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The Unsaturated Zone Flow (UZF1) Package (Niswonger et al., 2006) for MODFLOW simulates flow through the unsaturated zone using a kinematic wave approximation for unsaturated flow. The kinematic-wave equation provides an approximate and efficient approach for simulating unsaturated zone flow in large model domains, including regional model domains, provided the underlying assumptions hold (i.e., diffusive gradients can be neglected, flow is downward vertical, and hydraulic properties are vertically homogeneous). UZF1 is a key component in the GSFLOW (Markstrom et al., 2008) modeling environment, which couples PRMS (Leavesley et al., 1983) and MODFLOW (Harbaugh, 2005).

Recent efforts have focused on developing reactive and nonreactive solute capabilities for UZF1 by mapping simulated fluxes and moisture contents onto fixed grids that can then be used with popular transport models, such as MT3DMS (Morway et al., in press). Bailey et al. (Bailey et al., in press) and Prommer (Personal commun.) have extended this approach for reactive transport with RT3D (Clement, 1997) and PHT3D (Prommer et al., 1998), respectively.

Among the benefits of coupling UZF1 with these transport codes, is that the larger number of MODFLOW, MT3DMS, RT3D, and PHT3D users can more easily extend existing regional-scale flow and transport models to include the unsaturated zone. Because the unsaturated zone is inextricably tied to the fate of contaminants as they are transmitted between land surface and the water table (Nielsen et al., 1986), as well as to streams (Kirchner et al., 2000), a more complete picture of the timing of solute loading can be obtained through simulation of unsaturated-zone transport modeling.

Due to MODFLOW's computationally efficient flow solution across regional-scales, a number of anticipated benefits of the recently enhanced MT3DMS, RT3D, PHT3D codes follow. First, the new codes enable evaluation of the extent and severity of human impacts across large scales, and are particularly well-suited for evaluating non-point source pollution. In addition, as climate variability could potentially alter recharge patterns, and subsequently the fate of contaminants and their impact on the quality of groundwater resources, tools like MT3DMS, RT3D, and PHT3D that incorporate unsaturated-zone flow and reactive transport should provide the needed platform for a robust investigation.

The enhanced MT3DMS, RT3D, and PHT3D codes were and are still further benchmarked against other established transport codes for 1, 2, and 3-dimensional simulations under a variety of conditions, including steady, unsteady, nonreactive, and reactive conditions (Morway et al., in press; Baily et al., in press). Under reactive conditions, a host of options are available depending upon the selected code. Significant time savings was demonstrated for both the enhanced MT3DMS and RT3D codes relative to other transport codes. For example, compared to HYDRUS 3D (Šimůnek et al., 2008) and CATHY/TRAN3D (Bixio et al., 2000), there was nearly a 10-fold speed up in the MODFLOW/MT3DMS/RT3D solutions producing nearly identical results.

In addition to expanding transport capabilities to the unsaturated-zone, efforts to further enhance MT3DMS to also simulate surface water transport are underway. In particular, MODFLOW's SFR2 (Niswonger and Prudic, 2005), SWR (Hughes et al., 2012), and LAK (Merritt and Konikow, 2000) packages will serve as the basis by which mass-conservative solute transport can be simulated in stream features and lakes. With a few modifications, the surface-water transport code could be broadened to simulate heat transport, thereby benefiting habitat suitability investigations and allowing the use of heat-as-a-tracer for model calibration. Together with variably-saturated transport using the UZF1 flow solution, these additional capabilities move the MODFLOW MT3DMS modeling community a few steps closer to fully coupled groundwater and surface-water flow and transport.

See page 9, **References**

Acronyms:

CATHY/TRAN3D: Coupled flow and transport modeling
GSFLOW: Groundwater and Surface-water FLOW
HYDRUS 3D: simulates two-dimensional movement of water, heat, and multiple solutes in variably saturated media
LAK: Lake Package for MODFLOW
MODFLOW: MODular three-dimensional finite-difference ground-water FLOW model
MT3DMS: modular three-dimensional transport model
PHT3D: Multicomponent transport model for saturated porous media
PRMS: Precipitation-Runoff Modeling System
RT3D: Reactive Transport in 3 Dimensions
SFR2: Streamflow-Routing Package for MODFLOW
SWR: Surface-Water Routing Process for MODFLOW
UZF1: Unsaturated-Zone Flow Package for MODFLOW

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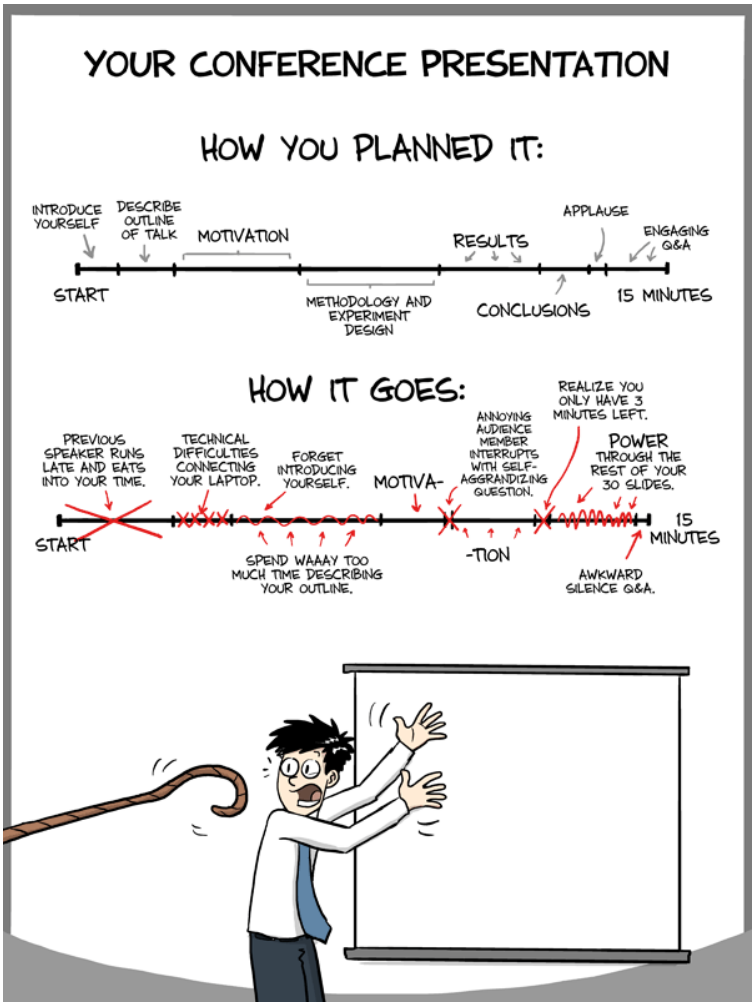
Humor corner



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