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UCOWR is not responsible for the statements and opinions expressed by authors published herein.

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## Plenary Sessions

**Challenges for the Next Generation of Colorado River Water Managers**
**Eric Kuhn, General Manager, Colorado River District**

BIO: Eric Kuhn is the General Manager of the Colorado River District, a position he has held since 1996. He earned his Bachelor's Degree in Engineering from the University of New Mexico and a Master's Degree in Business Administration from Pepperdine University in California. Prior to working for the Colorado River District, he served as an engineer officer aboard nuclear submarines in the U.S. Navy and worked as start-up engineer for Bechtel Power Corp. Eric started employment with the Colorado River District in 1981 as Assistant Secretary-Engineer. He has served on the Engineering Advisory Committee of the Upper Colorado River Compact Commission since 1981. From 1994-2001, he served on the Colorado Water Conservation Board representing the Colorado River mainstem. In 2006, Eric was appointed by Governor Owens as an at-large representative on the Colorado Interbasin Compact Committee, a position he continues to hold.

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**A Nudge in the Right Direction - Connecting Science to Water Policy**
**Anne Castle, Senior Fellow, Getches-Wilkinson Center for Natural Resources, Energy, and the Environment, University of Colorado**

BIO: Anne Castle is a senior fellow at the Getches-Wilkinson Center for Natural Resources, Energy, and the Environment at the University of Colorado, focusing on western water issues. From 2009 to 2014, she was Assistant Secretary for Water and Science at the U.S. Department of the Interior where she oversaw water and science policy for the Department and had responsibility for the U.S. Bureau of Reclamation and the U.S. Geological Survey.

While at Interior, Castle spearheaded the Department's WaterSMART program, which although not an entirely original name despite best intentions and multiple trademark searches, provides federal leadership on the path toward sustainable water supplies. She was the driving force behind the 2010 federal MOU addressing sustainable hydropower, the largest, least respected, and most vilified form of renewable energy in the country. Castle also instituted the federal Open Water Data Initiative in an attempt to make the fragmented world of water data more integrated and accessible.

As a counterbalance to the somewhat old school and traditional culture of water management, she entered the arena of space policy and was a champion for the USGS Landsat Program, the nation's longest sequential moderate-resolution satellite imaging system. She joined the cadre of victims of Landsat love, populated by earth scientists, western water managers, and Google Earth aficionados. Castle also provided hands-on leadership on Colorado River issues and was the Chair of the Glen Canyon Dam Adaptive Management Work Group and a champion of Minute 319 between the U.S. and Mexico. The fact that the Colorado River descended further and further into drought during her tenure is generally believed not to be her fault.

Castle is a recovering lawyer, having practiced water law for 28 years with the Rocky Mountain law firm of Holland & Hart. She was the Landreth Visiting Fellow at the Stanford Woods Institute for the Environment for the Spring 2015 quarter, and is now working with the Getches-Wilkinson Center on projects relating to implementation of the State of Colorado's Water Plan and Colorado River management policy. She received a Bachelor of Science degree in applied mathematics, with honors, from the University of Colorado, College of Engineering, in 1973, primarily to demonstrate to her father that girls could be good at math. Her J.D. in 1981 was also from the University of Colorado, qualifying her as a Double Buff.

## Plenary Sessions

**Water Sustainability for the Nation: What Will it Take?**

Deborah L. Swackhamer, UCOWR Warren A. Hall Medal Award Recipient

Professor Emerita at the University of Minnesota of Science, Technology, and Public Policy in the Humphrey School of Public Affairs and Environmental Health Sciences in the School of Public Health

BIO: Deborah L. Swackhamer is Professor Emerita at the University of Minnesota of Science, Technology, and Public Policy in the Humphrey School of Public Affairs and Environmental Health Sciences in the School of Public Health. She also directed the Water Resources Center from 2002 until 2014. She received a BA in Chemistry from Grinnell College, IA and an MS and Ph.D. from the University of Wisconsin-Madison in Water Chemistry and Limnology & Oceanography, respectively. After two years post-doctoral research in Chemistry and Public & Environmental Affairs at Indiana University, she joined the Minnesota faculty in 1987. She officially retired from the University in 2015, and continues to work informally with researchers and decision makers on water resource policy. In 2012 Dr. Swackhamer completed a 4 year term as Chair of the Science Advisory Board of the US Environmental Protection Agency, and served as a member of the Science Advisory Board of the International Joint Commission of the US and Canada from 2000-2013. She currently serves as Chair of the US EPA Board of Scientific Counselors. She is a member of the National Academy of Sciences Board of Environmental Science and Toxicology. She was President of the National Institutes of Water Resources in 2011-2012. Dr. Swackhamer received the prestigious Founders Award from the Society of Environmental Toxicology and Chemistry for lifetime achievement in environmental sciences in 2009. She is a lifetime Fellow in the Royal Society of Chemistry in the UK. In November, 2014 she was named an Inaugural Fellow of the international Society of EnvironmentalToxicology and Chemistry.

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**Update to "Optimal Operation of Multi-purpose Reservoir Systems: State-of-the-art Review"**

John W. Labadie, UCOWR Warren A. Hall Medal Award Recipient

Professor of Civil and Environmental Engineering at Colorado State University

In the summer of 1997, Issue 108 of what was then called UCOWR Water Resources Update focused on the topic: "Reservoir System Management," with Ralph Wurbs serving as the Issue Editor. Included in this Issue was a contribution by the speaker entitled "Reservoir System Optimization Models." In 2004, this UCOWR article was updated and expanded in the paper: "Optimal Operation of Multi Reservoir Systems: State of the Art Review," which was published in the Journal of Water Resources Planning and Management. In 2015, the speaker received a personal communication on behalf of Steve Starrett, President of the EWRI of ASCE, stating that "your review on the Optimal Operation of Multireservoir Systems published in 2004 by the Journal of Water Resources Planning and Management is one of the top five most cited articles published by any (of the seven) EWRI journals to date." After more than 12 years, it is surprising that this state-of-the-art review paper, with its origins in a UCOWR Update edition, continues to be heavily cited in the water resources scientific literature. An attempt will be made to explain the reasons for this, and to explore the advances in the state-of-the-art of optimization of multipurpose, multireservoir systems since publication of the 2004 paper, including future research directions.

BIO: John W. Labadie, Ph.D., P.E., F.ASCE, D.WRE, is Professor of Civil and Environmental Engineering at Colorado State University, serving as Coordinator of the Water Resources Planning and Management Program. He received his B.S. and M.S. degrees in Engineering at the University of California, Los Angeles, and Ph.D. in Industrial Engineering and Operations Research from the University of California, Berkeley. Dr. Labadie specializes in application of decision support systems, artificial intelligence, machine learning, and knowledge-based systems to complex problems in water resources and environmental systems management. He is developer and instructor of the graduate courses: GIS in Civil and Environmental Engineering, Computer-aided Water Management and Control, Engineering Optimization, and Engineering Decision Support Systems, with all courses offered through CSU Online. He has served as Principal and Co-Principal investigator for over 50 research projects totaling over $8 million in funding from sponsors at the federal, state, local, and international levels. He served as Senior Editor of the Journal of Water Resources Planning and Management, with his 2004 review on optimal operation of multireservoir systems one of the top five most cited articles published by any of the EWRI journals to date. He is a Fulbright Research Scholar, won two annual Best Paper awards from scholarly journals, and was the 2015 CSU Online Innovative Educator.

**William M. Alley and Rosemarie Alley, Invited Authors**

BIO: Dr. William M. Alley and Rosemarie Alley are a scientist/nonscientist team writing for the general public on environmental and Earth Science issues confronting society. Dr. Alley was Chief, Office of Groundwater for the U.S. Geological Survey for almost two decades and is currently Director of Science and Technology for the National Ground Water Association. Rosemarie Alley is a freelance writer. Their latest book is High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater. They previously published Too Hot to Touch on the science, history and politics of nuclear waste.

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**John Fleck, Invited Author**

BIO: John Fleck is Professor of Practice in Water Policy and Governance in the University of New Mexico Department of Economics and director of the university's Water Resources Program, where he co-teaches classes in contemporary water policy issues, modeling, and technical communication for water managers. A science journalist with 30 years of newspaper experience, he first wrote about water in the 1980s as a beat reporter covering the Metropolitan Water District of Southern California. He is the author of the book Water is for Fighting Over and Other Myths About Water in the West, an exploration of solutions to the Colorado River Basin's water problems, published by Island Press.

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**Peter Colohan, Director of Service Innovation and Partnership, Office of Water Prediction, National Oceanic and Atmospheric Administration**

BIO: Peter Colohan is the Director of Service Innovation and Partnership for the Office of Water Prediction at the National Oceanic and Atmospheric Administration (NOAA). From 2010 to 2016, Peter served as a senior advisor to Obama Administration officials on environmental data, climate, water, and drought, first as a member of the White House staff in the Office of Science and Technology Policy (OSTP), then as OSTP's Assistant Director for Environmental Information, then as senior advisor to the NOAA Chief Scientist. From 2002 to 2010, Peter served NOAA as a consultant and program manager in strategic planning and international coordination of Earth observations and environmental monitoring. During this time, he facilitated the establishment of the Group on Earth Observations (GEO), an intergovernmental body involving over 90 governments, five United Nations agencies, and more than 50 international organizations. Peter holds degrees from the College of William and Mary in Virginia and American University's School of International Service.

Peter will provide remarks on the integrated challenge of managing water risks in a changing climate. He will describe the interconnected challenges of flood, drought, and water quality, and need to focus on community needs and questions in response to those challenges. He will discuss the NOAA Water Initiative efforts to promote holistic delivery of integrated decision support tools based on the latest science and technology. He will demonstrate one of NOAA's new prediction capabilities, the National Water Model, a prototype operational continental scale hydrology model of the river and stream network of the United States, launched by the National Weather Service in August 2016.

## Plenary Sessions

**Ted Kowalski, Senior Program Officer, leading the Walton Family Foundation's Colorado River Initiative**

BIO: Ted Kowalski is a Senior Program Officer, leading the Walton Family Foundation's Colorado River Initiative. In this role, Ted supports work that promotes sustainable management of the Colorado River in order to benefit rivers. Prior to joining the Foundation, Ted was the Chief of the Interstate, Federal and Water Information Section, for the Colorado Water Conservation Board. In this role, Ted represented the State of Colorado in State, Federal, inter-State, and international negotiations. Ted is recognized for his deep expertise in Colorado River water management issues. He has testified before the U.S. Congress and before the Colorado General Assembly, and he has spoken at dozens of conferences. Ted started his career in the Colorado Attorney General's office working on water law issues. Ted has a law degree from the University of Colorado and an undergraduate degree from Cornell University.

## Session 1, Unnamed Events: A Look at the 2015-2016 Floods in Louisiana

### Rainfall variability and its impacts on irrigation in Louisiana

Maureen Thiessen, Graduate Student, LSU
(co-author: S. Davis)

Climate variability, especially rainfall, is inherent to the humid southeast region and Louisiana is no exception. However, many factors influence management within the state such as soil types, land uses, land management, infrastructure, and politics. Though water management is critical to health and safety, there is little consideration for master planning and few regulations that support it. In recent years, Louisiana experienced more variability than normal, resulting in multiple intense rainfall events that created significant flooding followed by short term drought periods. Unlike tropical storms and hurricanes that have advance notice, these intense events are unexpected and cause significant damage to a budget-challenged state. Two specific rainfall events led to state of emergency declarations, receiving up to 43 cm in 36 hours in Bossier City in March 2016 and 76.2 cm in 24 hours in the Baton Rouge area in August 2016. Due to a third of the 2016 annual rainfall and 38-55% of average annual rainfall occurring in just a few days of the year, there were distinct periods of unseasonable short term drought that sometimes occurred during critical growth periods of agricultural crops. Traditional management practices such as land leveling, tillage, and lack of cover crops have exacerbated the issue by failing to store any of the excess surface waters for future use. Agriculture relies on limited groundwater supplies for irrigation, creating a disconnect between the perception of a water-rich state and water availability. Recent research indicated a need for irrigation to maximize yield, though producers reported that irrigation wasn't required in the "wet years." This presentation explores the weather patterns from 2015 and 2016, discusses the impact of the weather to the state, and focuses on the effect of climate variability on the irrigation industry as a whole.

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### Flooding impacts to row crop agriculture in Northeast Louisiana

Bruce Garner, County Agent - Agriculture and Natural Resources, LSU AgCenter
(co-author: *S. Davis)
*Presenter - Stacia Davis, Assistant Professor, LSU AgCenter

Northeast Louisiana experienced widespread and prolonged flooding during the spring of 2016 as a result of unseasonable and excessive rainfall. West Carroll Parish, located in northeast Louisiana and considered a part of the Mississippi Delta, was no exception. Despite the short-term drought occurring after the flood events, adverse impacts to row crop production were far-reaching and long-lasting over the entire growing season. The objective of this project was to evaluate the impact of multiple flooding events during the planting season and its impact on irrigation planning and implementation. From information gathered during implementation of irrigation demonstrations and irrigation studies, issues were identified that led investigators to begin looking at the negative impact of the spring floods with reference to irrigation initiation. The repeated and prolonged cropland flooding caused delayed planting and repeated replanting, thus pushing crop development out of optimal growing periods. The planting delays influenced crop yield and crop quality across three major cropping systems (hybrid corn, soybeans and sweet potatoes) in the parish. Investigators concluded that solutions cannot always be found to be climate variability, but taking advantage of conservation practices provide the best opportunity for recovering from unpredictable and extreme weather conditions.

### Drainage and water quality of Upper Ward Creek in Baton Rouge, Louisiana

Jeff Kuehny, Professor and Director of the LSU AgCenter Botanic Gardens, LSU AgCenter
(co-authors: R. Keim, W. Kron, B. Breaux, *J. Beasley)
*Presenter - Jeffrey Beasley, Associate Professor, LSU AgCenter

The City of Baton Rouge is 76.8 square miles with a 2010 census population of 229,493. The hydrology of the parish naturally divides into three main watersheds, which are further subdivided into a total of 704 micro-watersheds or subsegments. The watersheds consist of approximately 446 sq. mi. of mixed residential, commercial, and industrial land use. The eastern part of the parish drains into the Amite River and the southern part of the parish drains into Bayou Manchac. The northwest portion of the parish drains into the Mississippi River. Over time urban sprawl and flood protection channelization of this watershed has reduced, segmented, or eliminated natural ecological and beneficial functions of the watershed. Most of the rivers, streams, and bayous in the parish are listed as impaired and found to be "not supporting" for any of its designated recreational uses or fish and wildlife propagation. The water quality and flow data collected in watersheds of EBRP suggest that most are impaired by nonpoint source pollution. However, the data was collected at only a few sites along the watershed and does not provide the necessary background information for determining which Best Management Practices (BMPs) practices are critical to improving the health of the watershed. Thus the watersheds will continue to degrade until consistent quantitative data is obtained to justify implementation of BMPs by the city, parish and neighboring parishes and their stakeholders. Historical and current watershed data was combined with data currently being collected during storm events to establish a baseline for water quality and flow, and watershed function of Upper Ward Creek so that a sustainable watershed plan can be implemented to prevent future degradation and improve watershed health.

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### Correcting HAZUS general building stock structural replacement cost data for single-family residences to improve flood mitigation analyses

Steven Shultz, Professor of Real Estate and Land Use Economics, University of Nebraska

Alternative approaches are evaluated to correct 2015 FEMA HAZUS General Building Stock (HGBS) replacement cost values for single-family residential structures in Sarpy County, NE. HAZUS is one of the most common data sets of structural replacement values used by FEMA and others to evaluate flood mitigation efforts. First, HGBS values were reduced across the board by 59% which is the overall difference between HGBS replacement costs and inventory derived depreciated structural replacement values (DSRVs). The resulting 'corrected' HGBS values which overall (across the entire study area) equal inventory DSRVs, but the mean value of differences between HGBS replacement costs and DSRVs observed across 2,414 census blocks is 39% with a standard deviation of 490%. DSRVs were then regressed against available HGBS data at the block level of analysis via six alternative model specifications resulting in $R^2$ values ranging from 0.59 to 0.69. The most promising model was based on HGBS square footage and related housing data which on average on average across blocks had predicted HGBS based DSRVs values that under-estimated actual DSRVs by 29%. Finally, regressing DSRVs against building square footage data from the County tax assessor (similar to a 'Level II' type of HAZUS-MH analysis) resulted in a $R^2$ value of 0.96 and the resulting predicted DSRVs across blocks were on average only 12% lower than actual DSRVs. This is considered the optimal model to predict DSRVs across census blocks for use in HAZUS-MH analyses despite that it does not rely on any HGBS data.

## Session 2, Modeling I

### Estimation of the changing land surface environment in the Rocky Mountains with a spatiotemporally enhanced land cover product

Nicolas Rodriguez-Jeangros, Ph.D. Candidate, Colorado School of Mines
(co-authors: A. Hering, T. Kaiser, J. McCray)

The study of water in a changing environment requires first a detailed characterization of this environment in space and time. Land cover (LC) is a critical variable driving many hydrological processes, so its assessment, monitoring, and characterization are essential inputs to study these processes. However, existing LC products, derived primarily from satellite spectral imagery, each have different temporal and spatial resolutions and different LC classes. Previous efforts have focused on either fusing a pair of LC products over a small space-time region or on interpolating missing values in an individual LC product. We developed a method for fusing multiple existing LC products to produce a single LC record for a large spatial-temporal grid. We first reconcile the LC classes of different LC products, and then we present a probabilistic nearest neighbor estimator of LC class. This estimator depends on three unknown parameters, which are estimated using numerical optimization to maximize an agreement criterion that we define. Each pixel in the grid has an independent estimator, and therefore, the methodology is highly suitable for a parallel implementation. We implemented the methodology in C++ using MPI libraries for the parallelism in supercomputers. We illustrate the method using six LC products over the Rocky Mountains, producing an enhanced high-resolution LC product with yearly maps over a period of 30 years. This unprecedented high frequency/resolution LC product aims to inform and support small and large scale hydrological and climatological studies in the Rocky Mountain region.

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### Space-based monitoring of land-use/land-cover in the Upper Rio Grande Basin: An opportunity for understanding urbanization trends in a water-scarce transboundary river basin

Stanley Mubako, Research Assistant Professor, University of Texas at El Paso
(co-authors: W. Hargrove, J. Heyman, C. Reyes)

Urbanization is an area of growing interest in assessing the impact of human activities on water resources in arid regions. Geographic Information Systems (GIS) and Remote Sensing technologies provide an opportunity to analyze land use and land cover change over time, and monitoring areas undergoing rapid urban growth. This case study for the water-scarce Upper Rio Grande River Basin uses a supervised classification algorithm to quantify the rate and evaluate the pattern of urban sprawl. A focus is made on the fast growing El-Paso-Juarez metropolitan area on the US-Mexico border and the City of Las Cruces in New Mexico, areas where major concerns include environmental challenges and loss of agricultural and native land to urban development. Agriculture and native land cover classes are the major providers of land for urban development. The proportion of native land cover in the study region fluctuated between 76 and 83 percent between 1990 and 2015, depending on the amount of land under crops each analysis year. Urban development expanded from just under 3 percent in 1990, to more than 11 percent in 2015, mainly around the major urban areas of El Paso, Ciudad Juarez, Las Cruces, and smaller urban settlements scattered along the Rio Grande River valley. Agricultural land use decreased from around 19 percent in 1990 to 12 percent in 2015, with fluctuations between some years. The decreasing trend is mainly attributed to land lost to urban development. Change for the water land class was below 1 percent for all years considered. This is consistent with an arid region that does not have significant surface water bodies. This analysis can be useful in planning to protect the environment, preparing for growth in infrastructure such as schools, increased traffic demands, and monitoring availability of resources such as groundwater as the urban population grows.

## Session 2, Modeling I

### Streamflow response to potential land use and climate changes in the James River watershed, Upper Midwest United States

Laurent Ahiablame, Research Assistant Professor, South Dakota State University
(co-authors: T. Sinha, M. Paul, J. Ji, A. Rajib)

Changes in watershed hydrology are mainly driven by changes in land use and climate. The Soil and Water Assessment Tool (SWAT) was used to quantify the influence of future climate and land use changes on surface hydrology in an agricultural catchment in the Upper Midwest. Various scenarios of projected climate change were developed under three emission scenarios (A1B, A2 and B1) to represent mid (2046-2065) and end (2080-2099) of the 21st century for three general circulation models (CGCM3.1, GFDL-CM2.1, and HADCM3). Corresponding land use maps (for years 2055 and 2090) were derived from the FOREcasting SCEnarios (FORE-SCE) model. The scenarios were designed in a way that land use was changed while climate conditions remain constant, land use was then held constant under a changing climate, and finally both land use and climate were changed simultaneously to reflect possible future land use and climate conditions. Results indicated that future climate change will likely have more influence on hydrology compared to future land use change. The combined effects of land use and climate changes would intensify changes in hydrological processes of the region in the near future.

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### America's water: Frequency of low flow violations: Spatio-temporal variability of stream dry days across the conterminous United States

Maryam Pournasiri, Ph.D. Candidate, University of Colorado Denver
(co-authors: I. Pal, U. Lall)

This research investigated spatial-temporal variability of the stream dry days, an important streamflow drought indicator, across the conterminous U.S. PAM algorithm with F-madogram, a non-parametric method, was applied to cluster the data. Driest years in the history of the stream dry days index data (CDO henceforth) displayed concurrent and perpetual droughts at different regions (clusters), reflecting the extreme drought events in the U.S. history since 1963. CDO has a strong correlation with other known drought indices. The results indicated that CDO dry years have mostly occurred when conditions were both dry and warm. Composite analyses with the large scale climate variables over the driest years indicated that CDO mainly associates with the coincidence of warm SSTA in the northern Pacific and Atlantic Oceans over many regions.

## Session 3, Irrigation Aquifer Depletion and Challenges to Sustainability: Opening Session

### Some results of a 50-state groundwater survey and groundwater utilization trends by Central Arizona agriculture

Sharon Megdal, Director, University of Arizona Water Resources Research Center

This presentation will provide an overview of groundwater issues identified through a survey of the US states. The results, coupled with the latest USGS water census, show that states that face a potential critical condition in their groundwater resources—more than 30 percent of human needs are met by groundwater and declining aquifer levels – are located in the western US and southern portion of the mid-west. The presentation will also explain how Arizona has made significant progress in addressing groundwater overdraft in Central Arizona through the substitution of surface water supplies for groundwater. This has been accomplished through Arizona's advanced and innovative framework for storage and recovery. However, progress in addressing groundwater overdraft may be reversed due to long-term Colorado River drought.

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### Ogallala Aquifer depletion: Sustaining the resource

Daniel Devlin, Director, Kansas Center for Agricultural Resources and the Environment, Kansas State University

The Ogallala Aquifer is a vast underground aquifer located in the Great Plains and underlies 450,660 square kilometers in parts of eight states and accounts for about 30% of the irrigated land in the United States. The regions overlying the Ogallala Aquifer are some of the most productive regions in the United States for growing alfalfa, cotton, corn, wheat, sorghum and soybeans. These crops provide cattle operations with feed for 40% of the feedlot cattle output in the United States. Farmers and ranchers in this region began intensive use of ground water for irrigation in the 1930s and 1940s. Estimated irrigated acreage in the area overlying the aquifer increased from 5.0 million ha in 1949 to 36.1 million ha by 2005. Irrigation use accounts for nearly 90% of the groundwater withdrawals from the Ogallala Aquifer. In many areas of the aquifer, especially the southern portion of the Texas High Plains and in northwestern Kansas, the saturated thickness has been reduced by as much as 40% of pre-development levels. It is conservatively estimated that current use is ten times the rate of natural recharge. Withdrawals greatly exceeding recharge rates have resulted in deeper water tables, reduced saturated thickness and lower well yields. In Kansas, by 2010, 30% of the groundwater stored in the aquifer had been used and it is estimated at current use rates, 69% of the groundwater resources will be depleted by 2050. Depletion is greatest in the central and southern portions of the aquifer with average water level changes in the Ogallala Aquifer from predevelopment to 2007 decreasing by state: Colorado -3.8 m feet; Kansas -6.8 m; New Mexico -4.7 m; Oklahoma -3.9 m; and Texas -11.1 m. Potential climate change impacts on the central and southern Great Plains managed ecosystems and society are profound. These changes may include increasing temperatures, larger daily rainfall amounts in extreme events, longer and more frequent heat waves, and related impacts on plant production, water supply, and human health. Annual precipitation is predicted to decline slightly while annual temperatures will likely increase by 1 to 3 C. This will have significant impacts on the regional economy and rural communities as crop and livestock production will be adversely impacted. Higher temperatures will increase crop water demand and possibly increase irrigation demand from the Ogallala Aquifer. When one combines the projections of climate change with the certain reduction of irrigation availability, there is the potential for irreparable economic, environmental, and community impacts. As the nation's and, in many ways, the world's breadbasket, agricultural disruptions in this region have the potential to severely disrupt national and global food supply. Thus long-term strategies are needed to cope with the impacts of climate change and variability on water use and availability, crop production and the economic sustainability of this region. The region is currently studying the future of irrigated agriculture and how to sustain irrigation for as long as possible. This may include increased regulatory measures, new technology developments and voluntary reductions in water use.

## Session 3, Irrigation Aquifer Depletion and Challenges to Sustainability: Opening Session

### Ogallala Aquifer Program: A catalysis for research and education to sustain the Ogallala Aquifer on the Southern High Plains (2003-2017)

David Brauer, Manager of the Ogallala Aquifer Program, CPRL-ARS-USDA
(co-authors: D. Devlin, K. Wagner, M. Ballou, D. Hawkins, R. Lascano)

The Ogallala Aquifer Program (OAP) was created in 2003 with support from Congressmen from Kansas and Texas. OAP is a research-education consortium seeking solutions from problems arising from declining water availability from the Ogallala Aquifer in western Kansas and the Texas High Plains. The consortium is led by the ARS laboratories in Bushland and Lubbock TX, and the university partners are Kansas State University, Texas A&M AgriLife Research and Extension Service, Texas Tech University and West Texas A&M University. The OAP has provided over $40 million to support research and education activities. About half of these funds were used to support permanent ARS scientists and ARS hired post-docs. The other half were used by university scientists to supplement on-going projects by providing support for supplies, sample analyses, temporary employees, etc. Initially OAP activities were focused on seven priorities. In 2013, the four objectives replaced the seven priorities. An additional priority was added in 2017. The current objectives are: 1) Develop and evaluate water management strategies and technologies that could reduce water withdrawals for irrigation by 20% in 2020 compared to 2012; 2) Develop and evaluate management strategies and technologies that would increase the productivity and profitability of dryland cropping systems; 3) Improve the understanding of hydrological and climatic factors that affects water use and agricultural profitability; 4) Determine the impacts of alternative water withdrawal/use policies on the economic viability of the agriculture industry of the Southern Ogallala Aquifer Region; 5) Develop best management practices for production of high value and alternative crops for both dryland and irrigated systems. The objectives of the program and distribution of resources are decided by an executive committee with a member from the four universities and two from ARS, one from Bushland and the other from Lubbock. Proposed projects that utilize resources from more than one participating institution, leverage existing resources and address the stated objectives are more likely to be provided support. The impact of the OAP on research directed at agriculture on the High Plains has been recognized by three prestigious awards.

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### USDA-NIFA's Water for Food Production Systems: A mechanism to fund a broader portfolio in the sustainability of groundwater derived irrigation

James Dobrowolski, National Program Leader for Water, USDA National Institute of Food and Agriculture

NIFA launched a new challenge area, Water for Food Production Systems (WFPS), to tackle critical water issues—availability (quality + quantity) for irrigation and processing, drought preparedness, excess soil moisture, flooding, nutrient loss and contamination in rural and urbanizing areas focused on food across the U.S. Continued significant variations from the historical rate of water supply, demand and quality are projected to impact agricultural production systems making this new challenge area particularly timely. Of particular interest is the improvement of NIFA's portfolio of groundwater-focused projects in water stressed regions like the High Plains. Supporting nearly 20% of total U.S. production of wheat, corn, cotton, and cattle produced, the High Plains, watered by the Ogallala Aquifer system is key to sustaining U.S. food production today and securing food for 9.5 billion by 2050. Population growth and a changing climate are taxing the future reliability of supplies—the Ogallala is over-appropriated, with agriculture the greatest consumer at 94%, growing urban areas second, expected to increase dramatically by 2025. NASA's GRACE mission showed the Ogallala pumped at 10 times the rate of replenishment. Concomitantly, the timing of spring snowmelt has shifted to earlier in the year affecting recharge. If innovative strategies are not forthcoming, water shortage will inevitably result in reduced agriculture to feed urban water demands. Both the problems and solutions to Ogallala water scarcity lie within agriculture, and because of the complexities involved, an integrated, multi-state, and multi-disciplinary Coordinated Agricultural Project (CAP) funded in 2015 offers hope for groundwater sustainability, though complicated by multiple water governance organizations, changing urban-rural landscapes, significance of federal lands and reclamation projects. NIFA's presentation will suggest how development of innovative management practices, technologies and tools for a wide set of stakeholders through CAP projects that link behavioral with biophysical sciences and engineering promote science based decisions.

## Session 4, Feasible Alternatives to Permanent Fallowing in the Colorado River Basin

### Deficit irrigation, crop switching, rotational fallowing, irrigation efficiency and water conservation: Can they save water?

Brad Udall, Senior Scientist, Colorado Water Institute, Colorado State University
(co-author: G. Peterson)

Deficit irrigation, crop switching, rotational fallowing and, two related but different concepts, irrigation efficiency and water conservation, have been proposed as ways to save water from agriculture for use by municipalities or the environment. There are many studies from around the West on split-season irrigation, a form of deficit irrigation, of alfalfa. These studies show that alfalfa can be successfully deficit irrigated even in the hottest climes, provided proper practices are followed. Soil types are especially critical. Crop switching is appealing in theory as a way to save water. However, numerous studies and publications have shown that crop switching is difficult to implement because there are many complicated and potentially expensive issues to resolve. Calls for crop switching often ignore the larger economic and market forces that encourage farmers to produce many traditional, water intensive crops. Existing crops have an entire production and risk management system built around them that must be replicated with a new crop. Only one successful example of crop switching to save water was found in the West. Rotational fallowing, also known as lease-fallowing, is the act of temporarily fallowing farm land to save water for other purposes. Rotational fallowing has been used for over twenty-five years in the both the Upper and Lower Colorado River Basins. A number of lessons can be drawn from these examples. Irrigation efficiency and water conservation involve distinctly different kinds of reductions in water use. improving irrigation efficiency refers to the act of saving non-consumptive use water, sometimes called 'saved water'. Conversely, water conservation is the act of saving consumptive use water. Each concept has different physical and legal ramifications, especially how they affect other uses and users. In general, greater quantities of saved water can be created than water saved from reducing consumptive use, but reducing consumptive use affects fewer water users. Many examples of irrigation efficiency improvements exist. Irrigation efficiency can paradoxically lead to increased water use. There are far fewer examples of successful water conservation projects.

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### *"Conservation for whom and for what?" Multi-stakeholder collaboration around agricultural water in the Colorado River Basin

Peter Leigh Taylor, Professor and Department Chair, Colorado State University
(co-author: *K. MacIlroy)
*Presenter - Kelsea MacIlroy, Research Assistant, Colorado Water Institute

In the face of current and expected reductions in Colorado River Basin (CRB) water flows related to drought, demographic growth, and climate change, the region's agricultural sector finds itself with a target on its back with its majority share of the CRB's surface water. Many voices now call for agriculture to "conserve" its water to generate supplies to help address growing demand from other water users. These calls, however, are often made with insufficient appreciation of formidable technical, legal, economic, and socio-cultural factors that make it difficult for agricultural producers to conserve and share water without undermining the viability of their operations and ways of life. Through in-depth interviews and field visits, this study explored six cases in Colorado, Arizona, and California in which multi-sector collaboration around agricultural water conservation for multiple uses has managed to surmount obstacles to produce significant successes. In these cases, irrigators have collaborated with municipal suppliers, federal agencies, and environmental organizations to conserve agricultural water through fallowing, water leasing, shared infrastructure development and other mechanisms that also benefit agricultural producers. Though these collaborative efforts confront significant continuing challenges, successful collaboration has been associated with: hydrological conditions that facilitate non-zero-sum use arrangements; existing and new opportunities in water law for innovative collaboration around conservation; sharing arrangements that are perceived as fair by participants; and creative efforts to organize common ground around varying, often conflicting ways of defining and implementing notions of conservation and efficiency. While the complexity of water across the CRB precludes one-size-fits all solutions, this study points to ways in which successful agricultural water conservation collaboration can be encouraged by targeting favorable hydrological contexts, creating and widening legal spaces for mutually beneficial collaboration, and promoting organizational approaches that directly confront the reality that "conservation" is a multifaceted, often conflictual concept.

## Session 4, Feasible Alternatives to Permanent Fallowing in the Colorado River Basin

### A farmer-led initiative to quantify and demonstrate irrigation efficiencies at farm-scales in the Lower Gunnison Basin

Perry Cabot, Research and Extension Leader, Colorado State University
(co-authors: C. Denison, D. Kanzer, A. Derwingson, J. Harold)

Phosphorus is often a limited nutrient in coastal settings and identifying all sources, both natural and anthropogenic, is important for assessing the overall water quality and ecosystem health of coastal areas. This paper summarizes the results of both laboratory experiments and field investigations of phosphorus concentrations in coastal carbonate aquifers affected by seawater intrusion. As seawater intrudes into a coastal carbonate aquifer and mixes with the fresh groundwater, phosphorus has been found to be released into the resulting mixing zone groundwater. At low to moderate salinities (30 psu) phosphate desorption occurs as bicarbonate ions in the intruding seawater compete for adsorption sites. Concentrations of phosphorus in mixing zone groundwater has been found to range from 1 to 8 µmol/L compared to values of less than 1 µmol/L in either the fresh groundwater or the intruding seawater. The high concentrations of phosphorus in the brackish groundwater has been found to associate with the extent and biomass of coastal mangroves as well as phosphorus concentrations of seagrasses. Furthermore, phosphorus concentrations as well as ecosystem metabolism were observed to spike in the surface water during times of groundwater discharge. In summary, seawater intrusion into coastal carbonate aquifers and its associated brackish groundwater discharge can affect both groundwater and surface water chemistry as well as ecosystem function in the coastal zone. As global sea levels continue to rise, seawater intrusion is expected to further intrude into coastal aquifers, further releasing phosphorus as the freshwater portion of the aquifer becomes brackish.

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### Farmer perspectives on agricultural water conservation in the Upper Colorado River Basin

Paul Kehmeier, Vice-President, Orchard Ranch Ditch Company

On July 1, 2015, the states of Wyoming, Colorado, Utah, and New Mexico initiated a unique test program to deal with declining reservoir levels stemming from the 15-year drought that has plagued the Colorado River. The System Conservation Program Pilot (SCPP) for the Upper Colorado River Basin committed $2.75 million in the Upper Colorado River Basin to fund farmers, municipalities and other water users to voluntary and temporary forego the use of their water in exchange for compensation. The program is designed to develop and test tools that could potentially be used as part of a drought contingency plan to help protect storage within the Colorado River basin. The desired outcome of the SCPP is for a conserved consumptive use fraction to arise from the foregone diversion, consequently adding additional "system water" to the Colorado River. As a participating producer in the SCPP, I volunteered to reduce the amount of water delivered some of my alfalfa fields as an alternative to fallowing. In doing so, I reduced my consumptive use to benefit the SCPP while trying to maintain ground cover, improve soil health, and access an additional revenue stream. One of the unexpected challenges I faced as a participating producer in this program arose as I confronted the reality that my seeking to release and transmit water for the purpose of conservation is not currently consistent with Colorado water law. I will also convey some of the general perceptions by agricultural producers, particularly those in the Upper Colorado River basin, of the SCPP and its overall precedence to developing our role in the water challenges faced by the system as a whole.

## Session 5, Drought Early Warning and Drought Monitoring: Planning for Scarcity I

### The Evaporative Demand Drought Index (EDDI): A new drought monitoring and early warning tool

Mike Hobbins, Research Scientist, NOAA - Physical Sciences Division
(co-authors: D. McEvoy, A. Wood, J. Huntington)

NOAA's Physical Sciences Division and the Desert Research Institute have developed a new, multi-scalar drought index—the Evaporative Demand Drought Index (EDDI)—to improve the treatment of evaporative dynamics in drought monitoring and to provide drought early warning. Existing popular drought indices—such as the Palmer Drought Severity Index that informs much of the US Drought Monitor—primarily rely on precipitation and temperature to represent hydroclimatic anomalies. When evaporative demand (Eo) has been considered—for example, to derive actual evapotranspiration (ET) from land surface models—it has often been estimated from poorly performing, temperature-based parameterizations. Instead, EDDI uses the Penman-Monteith reference ET equation to estimate Eo, and leverages the interrelations of this fully physical Eo and ET, measuring Eo's physical response to surface drying anomalies due to land surface/atmosphere interactions in both sustained and "flash" droughts. EDDI shows significant promise as a leading indicator of drought as measured by US Drought Monitor, providing a valuable planning window for land and water resource managers and agricultural producers.

Uniquely, EDDI relies solely on readily available meteorological data while obviating the need for both precipitation and surface moisture data. Therefore, EDDI provides a perspective of drought from the atmospheric demand side previously missing from the "convergence of evidence" approach to drought monitoring. EDDI has demonstrated the most predictive skill in retrospective analyses for the onset of agricultural drought (low soil moisture) and hydrologic drought (low streamflow). Future research will examine the potential of EDDI in predicting wildfire weather risk. Further, the reference ET that EDDI uses as an Eo-estimator can be forecast at weekly and seasonal timescales (the latter forecasts being more skillful than those of precipitation) and it can be decomposed to attribute drought explicitly to its demand-side meteorological drivers.

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### Assessment of historical and projected drought variability in the Great Plains

Zach Zambreski, Kansas State University
(co-author: X. Lin)

Drought variability is projected to increase under climate change, which will increase the vulnerability of agricultural systems in the Great Plains. Identification of regions that share similar drought variability is important for resource consolidation and drought emergency management. This study examined historical and projected changes in seasonal drought variability in the Great Plains from 1900 to 2100 using observational data from Prism and projected data from 12 General Circulation Models. The technique implemented to facilitate this analysis was rotated Empirical Orthogonal Functions (EOFs). Drought indices utilized were the Palmer Drought Severity Index (PDSI) and Standardized Precipitation-Evapotranspiration Index (SPEI) on multiple timescales from three to twenty-four months. Regions were classified into homogeneous zones based on EOF analysis, which ranged from three to nine depending on the index and season for the historical period (1900-2015). Comparison among indices and seasons showed consistency in drought structures among zones identified in the southern plains, and more complex drought structures in the central and northern plains. Agricultural drought frequency during the spring and summer has increased during the last century for the zone including the High Plains of Texas and New Mexico. Zones in the eastern portion of the study area have seen an overall decrease in frequency of multiple types of drought. Ensemble mean of GCM data from 2016-2100 showed an increase in the complexity of drought structures for hydrologic drought during the fall, winter, and summer but a decrease during the spring. Springtime agricultural drought frequency is expected to decrease in several zones in the northern plains. Overall most zones show a peak wetness by the mid-2030s and drying thereafter across indices and seasons.

## Session 5, Drought Early Warning and Drought Monitoring: Planning for Scarcity I

### Using state and transition models as a drought adaptation tool on southwestern rangelands

Amber Wyndham, Soil Scientist, USDA-NRCS
(co-authors: A. Rango, E. Elias, C. Steele, J. Brown)

Increased climate variability, including more frequent and intense drought is projected for the southwestern United States. Increased temperatures and reduced precipitation lower soil water availability resulting in decreased plant productivity and altering species composition which may affect forage quality and quantity. Reduced forage quality and increased heat stress attributable to warmer temperatures could lead to decreased livestock performance. Mitigating the effects of increasing drought is critical to social and ecological stability in the region. Reduced stocking rates, change in livestock breeds and/or grazing practices are general recommendations that could be implemented. Ecological Sites (ESs) and their associated state and transition models (STMs) are tools to help land managers implement and evaluate responses. ESs are landscape subdivisions of soil-vegetation combinations that behave similarly. STMs are graphical depictions that demonstrate how a site can change under different management practices. The USDA Southwest Climate Hub and Natural Resources Conservation Service (NRCS) are working together to produce a drought vulnerability assessment at the Major Land Resource Area (MLRA) level based on ESs/STMs that will help landowners and government agencies identify and develop adaptation options for drought on rangelands. The assessment will evaluate how site-specific information can mitigate the effects of drought on rangelands and improve decision making for selecting management adaptations at the local level. The objective is to develop a matrix showing how responses to climate variability differ across two MLRAs and identify vulnerability levels to drought.

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### Insights on drought and long-term climatic trends: Retrospective analyses of RMA cause of loss data

Julian Reyes, Research Hydrologist, Climate Hub Fellow, USDA SW Climate Hub
(co-authors: A. Eischens, M. Shilts, E. Elias, R. Steele)

A modern trend among federal agencies, funding streams, and research projects involves the synthesis of existing data to increase the overall collective value and meaning of such knowledge. The creation of the U.S. Department of Agriculture (USDA) Climate Hubs follows this line of thought with information synthesis and tool development as tangible outputs of this new federal coordination network. The Hubs' mission is to develop and deliver science-based information and technologies to agricultural and natural resource managers to enable climate-informed decision-making. As part of this, Hubs work across USDA agencies to synthesize existing information to meet the needs of our stakeholders.

The USDA Risk Management Agency (RMA) is responsible for overseeing the Federal crop insurance program and works with private insurance companies. The USDA also administers other programs for commodities not insured under the federal program such as for livestock and honey bees. RMA has collected annual cause of loss data since the mid-1900s with monthly data beginning in 1989. These data describe the reason for loss (e.g. drought, wind, irrigation failure), indemnity amount (i.e. total cost of loss), insurance plan code, as well as relevant spatio-temporal information (i.e. state, county, year, month).

The objective of this paper is to link climate information with cause of loss data to potentially shape the development of future RMA programs and provide regionally-relevant information to our stakeholders to effectively manage their lands. We describe an initial retrospective analysis at various spatial scales by land use/land cover, ecoregions, climate zones, and geopolitical boundaries. In addition, we link historical weather data (precipitation and temperature) with causes of loss at multiple time steps: monthly, annual, and decadal. Ultimately this analysis will convey county-level trends to support informed land management decisions and ecosystem resilience.

## Session 6, Advanced Analytical Technology: Avoiding Water Treatment Problems

### Development of natural resources in environmentally sensitive areas; public perceptions, public acceptance

David Burnett, Director of Technology, Texas A&M University-GPRI, and Marian Higgins, CMGC Foundation
(co-authors: U. Kreuter, R. Haut)

Historically, the lack of broad-scale stakeholder input has led to public resistance and divisive confrontations that have slowed or terminated the development of many unconventional energy production projects. The source of many of the objections has come from the potential impact of water resources usage. Our group has studied previous natural resource development projects and proposed projects in environmentally sensitive areas to understand community views of newly proposed technology and the public's perceptions of such technology. Surveys and interviews showed a clear message from the community that they need to receive knowledgeable (and credible) information about events and developments that will impact them. (2) Factual knowledge about events or developments that would impact a community is welcomed but must be available in an open unbiased manner. (3) Environmental "capital," or the environmental resources of the community, is a term the community believes in, even if the concept isn't actually couched in that manner. We suggest that these results can be used as guidelines for projects considering projects in such new areas. We have labeled efforts to provide a dialog with the community as "pre-development research". Our findings show clearly that to reduce the probability of such resistance and divisive actions, such pre-development research is beneficial and serves as an effective tool to address societal issues and attitudes regarding water resources and energy development, assuming the development of the resource was determined to be technically, economically, and environmentally feasible. The economic, social and environment benefits are enormous and should be a factor in almost every Company's' evaluation of new development.

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### Total organic carbon (TOC) a key water quality analysis

Gary Erickson, Senior Applications Specialist, GE Analytical Instruments

Water quality directly affects the health of people, animals and plants, determines when water is fit for supporting industrial purposes and impacts the environment when the quality is low. One of the most important screening parameters in water quality analysis is total organic carbon (TOC). The ubiquitous nature of carbon make monitoring for it in the evaluation of water quality a must.

We will evaluate:

1) The capabilities of the analysis
2) Fractional components of carbon (soluble, purageable and particulate) that can be identified and approach to measuring them
3) The relationship of TOC to oxygen demand measurement tools
   a. biological oxygen demand (BOD)
   b. chemical oxygen demand (COD)
4) Relationship of TOC measurements to Oil and Grease in specific applications.

A short discussion on the application of the data from these measurements related to reuse and treatment will summarize the discussion.

## Session 6, Advanced Analytical Technology: Avoiding Water Treatment Problems

### Confirming water quality and improving environmental monitoring: Appraisal and utilization of an enhanced portable instrument for wet-chemistry analysis

L. Keith McLeroy, Senior Technical Consultant, Global Petroleum Research Institute, Texas A&M University, and Leslie Merrill, President, RETEGO Labs

The Global Petroleum Research Institute (GPRI) at Texas A&M University is distinguished for its high-level assessments of innovative analytical instrumentation and laboratory testing protocols for the chemistry and microbiological examination on various matrices of waters. A Phase 1 laboratory appraisal was performed on the RETEGO TTR-1© Detector portable spectrometer and on the RETEGO© test assay vial sets categorized as "wet-chemistry". GPRI evaluated the complete TTR-1 unit, each analyte's detection ranges, the straightforwardness of written protocols and the quality control/assurance robustness of the software generated data. The test vial sets for hardness/alkalinity, scaling salts, chlorides and iron, and barium were investigated. Laboratory assessments were conducted employing high quality known standards for all analytes. The RETEGO platform utilizes advanced detection and chemical processes that were originally established for complex industrial wastewaters. The detection chemistries are accomplished by simply adding liquid samples to a single designated assay testing vial; each vial contains a stable matrix of all the chemicals required to conduct the colorimetric, turbidimetric or fluorescence test for the analyte. The analytical result for each vial is measured using the TTR-1 spectrometer; this advanced spectrometer quantifies by conducting a multivariate analysis of a data set obtained through frequency-modulated colorimetric and fluorescence measurements utilizing multiple laser and other light emitting diodes having distinctive wavelengths. This presentation will describe the assessments conducted, provide noted outcomes of the protocols, exhibit the assaying results, and detail the QA/QC statistics. Additional discussions will exhibit how the RETEGO can provide inexpensive, accurate and timely feedback for water analysis and how it can be a critical means to managing overall costs of treatment. For example, water that is out of balance may become either intolerably corrosive or create a heavy scale. RETEGO provides the ability to incorporate existing indices (in this case the Langlier Saturation Index (LSI), Pukorius Saturation Index (PSI) and Ryzner Saturation Index (RSI)) that utilize the results obtained through the testing to concurrently create a detailed report for operations. The talk will conclude with a brief demonstration of the RETEGO testing methods.

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### Microbial control in oil field waters: Modeling economics of prevention

Alan Shepstone, Texas A&M Petroleum Engineering
(co-author: L. Keith McLeroy)

The oil and gas industry constantly seeks ways to improve operational efficiency and reduce costs of drilling activities. In efforts to reduce the risk of formation damage and corrosion downhole, the industry uses biocides to try to control bacteria levels that can contribute to these damages. Biocides as they are used today are woefully inadequate, and should be supplemented with pH based treatment using proprietary acid blends. With acid blends, concentration does not matter as a change in pH is the driving factor in killing bacteria. Ineffective use of biocides leads to increased operating expenditures that can be avoided. In addition, the kill duration of acid blends is longer than that of biocides. Common industry bacteria testing methods are ineffective for biocide efficacy evaluations, requiring a "wait and see" approach that can take up to a month to obtain results. This study uses a rapid microbial monitoring technology (analysis in less than 20 minutes) to determine the effectiveness of biocides over time. In all phases of the study, an effective kill was predetermined to be at least a 90% reduction in bacteria levels. In the first phase of the study, two biocides and four proprietary acid blends were tested on oilfield produced water separately, each at a different pH. In the second phase of the study, the acid blend with the fastest kill of bacteria was used to lower the pH of the water sample, while the best performing biocide was used to continuously dose the sample at various concentrations and instances in time. This data enabled determination of whether a specific combination of biocide and acid blend is better than either one independently. The industry would do well to add these acid blends in the efforts to treat produced water. Additional work is being performed to develop a model for predicting the required biocide loading for a given set of produced water characteristics. The model will take input parameters such as bacteria amount (derived from rapid monitoring technology), fluid volumes, compatibility, and others. Field data will be required for validation of the model.

## Session 7, Tribal Perspectives on Water Management Topics and Collaborative Engagement Approaches

### Engaging southwestern tribes in sustainable water resources topics

Karletta Chief, Assistant Professor, University of Arizona
(co-author: A. Meadow, K. Whyte)

Indigenous peoples in North America have a long history of understanding their societies as having an intimate relationship with their physical environments. Their respect for their ancestors and 'Mother Earth' speaks of unique value and knowledge systems different than the value and knowledge systems of the dominant United States settler society. The value and knowledge systems of each indigenous and non-indigenous community are different but collide when water resources are endangered. One of the challenges that face indigenous people regarding the management of water relates to their opposition to the commodification of water for availability to select individuals. External researchers seeking to work with indigenous peoples on water research or management must learn how to design research or water management projects that respect indigenous cultural contexts, histories of interactions with settler governments and researchers, and the current socio-economic and political situations in which indigenous peoples are embedded. They should pay particular attention to the process of collaborating on water resource topics and management with and among indigenous communities while integrating Western and indigenous sciences in ways that are beneficial to both knowledge systems. The objectives are to (1) to provide an overview of the context of current indigenous water management issues, especially for the U.S. federally recognized tribes in the Southwestern United States; (2) to synthesize approaches to engage indigenous persons, communities, and governments on water resources topics and management; and (3) to compare the successes of engaging Southwestern tribes in five examples to highlight some significant activities for collaborating with tribes on water resources research and management. There is a strong recognition of the importance of engaging tribal participants in water management discussions particularly with pressing impacts of drought, climate change, and mining and defining water rights.

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### Emerging contaminants on Tribal lands

Otakuye Conroy-Ben, Assistant Professor, Arizona State University

The extent of wastewater-derived contaminants is known and well-studied in public surface water, reclaimed water, and reuse in the U.S., however little is known about the extent of emerging contaminants on Tribal lands. This is for a variety of reasons: water sampling and testing is costly, and emerging contaminants are a low priority, among others. Recent activities in the Southwest have revived discussion of water quality, pollution, and reuse in a changing climate. For example, in northern Arizona, Tribes oppose the expansion of the Snowbowl ski resort, which uses reclaimed water to artificially supplement snow when needed. The Colorado River is impacted by wastewater, which serves not only regional states, but is also the lifeline to many Tribal communities. Inclusion of tribes in wastewater pollution and reuse, the research and application benefits the conservation of water and protection of water and cultural resources. This seminar will explore the state of emerging contaminants on Tribal lands and in culturally-sensitive waters.

## Session 7, Tribal Perspectives on Water Management Topics and Collaborative Engagement Approaches

### Taking back the responsibilities to protect our water

John Doyle, Co-Principle Investigator, Little Big Horn College
(co-authors: M. Eggers, C. Martin)

Water, the "giver of life" has always been held with high respect by the Apsalooke' people and is considered a source for good health and wellbeing: still today water is a sacred resource essential to many ceremonies, prayers and other traditional practices. We have always lived along the rivers, which provided water for domestic uses and we understood the importance of clean, safe water for survival purposes. However, today our world is very different from what our ancestors experienced. In the 1960's, an increase reliance of home wells and indoor plumbing were made available to our rural families. Unfortunately, the groundwater is very high in total dissolved solids, including toxic metals that make maintaining home plumbing system expensive and the water can be unsafe to drink. Our rivers now have such high levels of *E.coli* that there are times when it is unsafe to swim, in spite of that awareness it is still used much the same way as we have always used it. Our climate is changing: less snow, milder winters, hotter summers, increasingly frequent spring floods and other changes that are stressing our water resources and our community health. Prevention measures would be so much better than dealing with multiple repercussions of water contamination and climate change. In previous years the Crow public school system incorporated science learning into their curriculum and taught it daily. Today, the Crow public school system limits what science curriculum is taught and to what ages. We need to re-build this capacity in our community, starting at the kindergarten level and going on through advanced degrees, so we have the knowledge and understanding of our water resource challenges and have the capacity to address them and put in place prevention methods because no one else is going to do this for us.

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### Land cover and climate change impacts on streamflow and implications for indigenous peoples in the southeastern U.S. Coastal Plain

Ryan Emanuel, Associate Professor, North Carolina State University
(co-authors: N. Singh, J. Painter, J. Vose, D. Wear, K. Martin, J. Sikes)

In the coming decades, the southeastern US is expected to experience substantial shifts in land cover and climate. Such changes will test the ability of the region's freshwater resources to meet needs of both natural ecosystems and human communities. The impacts of land cover and climate change on water are of particular concern to indigenous peoples of the southeastern US. For these peoples, the cultural significance of land and water, together with historical legacies of discrimination, marginalization, and other factors, create unique vulnerabilities to environmental change. Although much work has focused on hydrologic responses to climate and land cover change in the southeastern US, implications for indigenous communities are largely overlooked or unknown. With this in mind, we configured a hydrological model (SWAT) to assess impacts of projected climate and land cover change on streamflow in the Lumbee River (North Carolina, USA). This blackwater stream is a significant natural and cultural resource for the Lumbee Tribe, who have occupied the watershed for centuries. The watershed, which contains extensive riparian wetlands and agriculture-dominated uplands, is home to more than 30,000 tribal citizens. We ran SWAT with statistically downscaled climate projections for the mid-21st century and a mid-century land use scenario from the US Forest Service's Southern Forest Futures Project. We used these inputs to simulate daily streamflows on the Lumbee River for the 2040-2060 period. After comparing scenario results to historical baseline conditions, we discuss implications for natural and human systems. We focus especially on impacts of concern to the Lumbee Tribe, who have benefitted historically from abundant and well-moderated water supplies but increasingly face prospects of more frequent and severe droughts, floods, and other water challenges. We also discuss tribal engagement efforts, particularly in the wake of historic flooding following Hurricane Matthew in 2016.

## Session 8, Modeling II

### Evapotranspiration and partitioning of the hydrologic cycle in fragmented landscapes in the Western United States

William K. Blount, PhD Student, Research Assistant, Colorado School of Mines, Department of Hydrologic Science and Engineering
(co-authors: T.S. Hogue, K.J. Franz, K.R. Knipper)

Evapotranspiration is a crucial process for understanding water balances and for the management of agricultural and water resources, especially in water-stressed regions of the Western United States. Evapotranspiration accounts for approximately 60% of terrestrial precipitation globally and approaches 100% of annual rainfall in arid ecosystems, where transpiration often becomes the dominant term. Vegetation characteristics and spatial patterns of landscape fragmentation greatly impact partitioning of water within the hydrologic cycle at a local scale. Satellite remote sensing provides an inexpensive, spatially-distributed source of data to identify spatial land cover patterns and how they change through time, calculate components of the local hydrologic cycle, examine changes in the partitioning of components of the local cycle, and forecast changes due to climate change and land cover disturbance. This presentation overviews current work on the relationships between patterns of fragmentation and thresholds for changes in hydrologic systems due to fragmentation in the Western United States. More accurate and spatially distributed estimations of evapotranspiration are necessary for better decision making by resource managers but can be difficult to obtain in water-stressed regions. In semi-arid and arid regions, evapotranspiration is water-limited and can be calculated by employing a water stress function to parameterize potential evapotranspiration. In the current study, we develop two actual evapotranspiration products derived solely from remotely sensed observations by scaling potential evapotranspiration estimates, calculated using the Priestley-Taylor equation, in two ways: with downscaled soil moisture observations and with vegetation water content indices. Actual evapotranspiration estimates are validated using four ground-based flux tower sites in southern Arizona and compared to a calibrated empirical evapotranspiration model created specifically for the region. Results suggest that these methods provide an alternative to more complex surface-atmosphere models. The proposed methodology requires no ancillary ground-based data or site specific calibration, allowing it to be transferable to ungauged basins.

### Time scales of hydrologic control on agro-eco-hydrologic variability in intensively managed watersheds

Muhammad Ukasha, Graduate Student, Colorado State University
(co-author: J. Ramirez)

We use the monthly Total Water Storage Anomalies (TWSA) observed by the state of the art Gravity Recovery and Climate Experiments (GRACE) satellite mission, soil moisture and snow water storage from Variable Infiltration Capacity (VIC) hydrology model and surface water storage (i.e. lakes and reservoirs) to study the time scales of hydrologic control in relation to the monthly precipitation for the Sacramento and San Joaquin river basins in California. At the scale of combined watersheds (~154,000 $km^2$), correlation analysis of monthly precipitation with TWSA at time lags ranging from 0 to -6 months shows that TWSA has a strongest correlation of around 0.6 with precipitation at lags of -2 and -3 months. However, the individual components of water storage showed different lag time and correlation strength with soil moisture and snow water storage having a highest correlation of 0.8 at -1 month lag and surface water storage with a lag of typically -3 to -4 months. The analysis suggests the possibility of longer lag times of groundwater storage. In addition, we performed a correlation analysis of Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) with GRACE TWSA and its time derivate dTWSA/dt (i.e. monthly changes in TWSA) in order to understand the control of water storage and its changes on the agro-ecological variability in the region. Analysis shows that LAI is more strongly related to both TWSA and dTWSA/dt as compared to NDVI implying that LAI is a better indicator of agro-ecological variability. Furthermore, LAI was found to be strongly correlated with TWSA at +2 months lag and strongly correlated with dTWSA/dt at 0 month lag. This paper will present the analysis procedure and results to help increase the scientific understanding of the hydrology of the region.

### Evaluating weather generators data in hydrological modeling

Abdullah Alodah, Ph.D. Candidate, University of Ottawa
(co-author: O. Seidou)

Weather generators reproduce artificial climate time series that are commonly used for hydrological modeling and adaptation studies. To examine the realism of a stochastically generated climate time series, a novel stochastic method is suggested to be assessed in the Climate Statistics Space (CSS) and the Risk and Performance Indicators Space (RPIS). For the purpose of this study, MulGETS was used to stochastically generated climate time series based on variability observed on the historical period, namly: precipitation, maximum and minimum temperatures. Climate data from two watersheds that have different climate patterns, namely: South Nation in Onatrio (SN) (1971-2011), Canada and Selingue in Niger (SL) (1971-2001), were used for the purpose of this study. A climate state represented by a time series is summarized by a subset of climate statistics for observations as well as MulGETS's data. MulGETS was able to perform well in SN where the point representing the observations was centered inside the cloud of points representing the synthetic time series in some CSS whereas SL data was not well-reproduced. Same data were fed into a calibrated SWAT model to checking if proximity with observations in the CSS translates into proximity in the risk/performance indicators space (RPIS). Initial results indicated that the weather generator is biased toward one zone of the CSS. In addition, SWAT results suggested that some important statistical characteristics have been overlooked and were not being reproduced by the weather generator. Although the suggested application was centered in two pilot watersheds, the methodology will be of interest for deferent locations.

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### Water balance analysis for agricultural area using SWAT model in the Rincon Valley, New Mexico

So-Ra Ahn, Assistant Research Scientist, Texas A&M AgriLife Research Center
(co-authors: S. Abudu, Z. Sheng)

Understanding the hydrologic cycle of agricultural area is of critical importance in an arid region such a Rincon Valley, New Mexico. In this study the hydrologic cycle of agricultural area in Rincon Valley was investigated to understand vertical water budget and horizontal water transfer for agricultural watershed management using a watershed-scale hydrologic model, SWAT (Soil and Water Assessment Tool). To predict the reliable available water quantity of the watershed, the model was established by dividing the basin into 29 sub-basins as hydrologic unit codes (HUC12) and including 14 crops that spatial coverages derived from the crop data layer (CDL). The SWAT was calibrated for the period of 2001-2003 and validated for the period of 2004-2006 using daily observed streamflow, evapotranspiration, and groundwater level data. The SWAT simulated the present vertical water budget and horizontal water transfer considering the surface-groundwater interactions and irrigation water management practices in the Rincon Valley. Simulation results indicated the temporal and spatial variability for irrigation and non-irrigation seasons of hydrologic cycle in agricultural area in terms of surface runoff, evapotranspiration, infiltration, percolation, baseflow, soil moisture, and groundwater recharge.

## Session 9, Irrigation Aquifer Depletion and Challenges to Sustainability: GW Modeling

### Changes in agricultural-water climate extremes in the Ogallala Aquifer Region

Xiaomao Lin, Assistant Professor, Kansas State University
(co-authors: P. Gowda, J. Harrington Jr., I. Ciampitti, R. Aiken, R. Bailey, I. Kisekka, D. Brown)

Understanding regional changes in climate extremes, directly associated with agricultural water, is necessary for planning appropriate adaptation measures due to major impacts on agricultural practices and productions especially in arid and semiarid regions such as Ogallala Aquifer Region. In this study, we use long-term historical daily climate data (1961 to 2015) across the Ogallala Aquifer Region to identify changes in extremes, focusing on relative thresholds that describe the tails of distributions in precipitation events. The analysis was conducted using non-parametric statistical tests on monthly and crop growing season scales. The results indicate that most of agricultural-water climate extremes showed a significant increase, but that the rate of increase varied significantly among specific sub-regions in the Ogallala Aquifer Region spanning the period of 1961 to 2015.

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### Assessment of changes in terrestrial water storage using land surface modeling data in the U.S. Great Plains

Yongjun Zhang, PostDoc, Kansas State University
(co-authors: X. Lin, P. Gowda, Z. Zambreski, S. Kutikoff)

Terrestrial water storage (TWS), a sum of groundwater, soil moisture, surface water, snow, and ice, is critical to human activity and ecosystem functioning. This study employed model-simulated data to examine TWS changes in the U.S. Great Plains during the past 37 years. The model we used was the Noah Version 3.3 land surface model (LSM) at 0.125 degree resolution. The model simulations were driven by the North American Land Data Assimilation System (NLDAS) atmospheric forcing. Results showed that the TWS deficit had increased since 1980s. However, variations in TWS between the northern and southern Great Plains are significantly different. Large parts of South Dakota, Nebraska, and Kansas show slightly drying trends, however, an obvious drying trend is found in Oklahoma and Texas. The influence of sea surface temperature (SST) on TWS for this region is also analyzed in this study. We found that SST anomalies in the tropical Pacific is significantly correlated with TWS in the Great Plains, with a phase lead of 6 months. The possible mechanism between TWS and SST anomaly is also discussed in this study.

## Session 9, Irrigation Aquifer Depletion and Challenges to Sustainability: GW Modeling

### Considerations on the estimates of groundwater actually available in the Ogallala Aquifer as opposed to predictions using current (2016) methodology

Robert DeOtte, Professor of Civil and Environmental Engineering, West Texas A&M University
(co-author: G. Green)

The Ogallala is an unconfined aquifer that serves as a vital resource for the Texas High Plains providing the chief source of water for irrigated crop production. State water policy mandates establishment of desired future conditions for groundwater management areas, which requires that the current state of reserves be determined. In order to accurately estimate the water remaining in storage, water levels are measured in wells prior to the beginning of the irrigation season (Well Measurement Approach, WMA). This data is used to identify a groundwater surface profile that serves as the calibration basis for MODFLOW based Groundwater Availability Models (GAM) used to predict likely future conditions. Previous work applying an Agronomic Water Mass Balance Approach (AWMBA) indicated that for some areas of the Ogallala Aquifer in the Texas Panhandle more water was available than would be indicated by the WMA. It was hypothesized that the cones of depression developed during pumping did not fully rebound and drawdown between wells lagged measurements creating mounds of water. To test this hypothesis MODFLOW was used to evaluate drawdown cycles for several decades using a limited number of actual wells in a conceptual framework. For the model it was assumed that pumps operated continuously for 120 days then remained off for the rest of the year allowing some level of rebound. Using hydraulic parameters typically associated with the southern portion of the Texas Panhandle, MODFLOW predictions indicated that full rebound did not occur during the non-pumping portion of the year and the hypothesis of mounded water could not be rejected. Estimates in the northern region are substantially less convincing. This research effort supports the concept that there may be more water remaining in portions of the aquifer than has been previously thought.

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### Improving Regional Groundwater flow models for the Texas portion of the Ogallala Aquifer

Sreeram Singaraju, Research Associate Engineer, Texas Tech University
(co-authors: V. Uddameri, P. Gowda, R. Bailey)

The Ogallala aquifer is the largest aquifer underlying parts of eight states (Texas, New Mexico, Oklahoma, Colorado, Kansas, Nebraska, South Dakota and Wyoming) in the United States. While about 20% of the aquifer lies in Texas, the state uses over 5 Million acre-feet of water per year to be one of the major producers of winter wheat, sorghum, corn, and cotton in the nation. Several regional groundwater flow models have been developed to simulate the flow of water in the Texas portion of the Ogallala aquifer. However, most of the existing models were developed using a spatial resolution of 1 mile X 1 mile which is not suitable to study intra-section interferences between wells which is becoming a serious issue as declining water levels in the aquifer is causing farmers to use multiple wells to meet their groundwater needs. Periodic updating of groundwater flow models also allows for inclusion of new data and better model parameterizations of ET, recharge rates and other hydrological processes of significance. The primary goal of this study is to refine existing regional groundwater flow models using a spatial resolution of 1 km X 1 km. The refined model will provide us with an opportunity to incorporate new information such as data from new wells and other physical properties of the aquifer and incorporate better descriptions of hydrologic processes. To this end, the models will then be coupled with Decision Support System for Agrotechnology Transfer (DSSAT) and Soil and Water Assessment Tool (SWAT) to better characterize crop water requirements (which are supplied through groundwater pumping) and spatially variable recharge rates. The refined models will not only allow us to capture the interactions between closely spaced wells but is also likely to provide a better picture of water availability across the aquifer in Texas and as such foster scientifically-credible groundwater resources management in this groundwater dependent region.

## Session 10, Colorado's Alternative Water Transfer Mechanisms: Valuation and Problems

### Why ATMs? And why not much yet? Issues for irrigators

John Wiener, Research Associate, University of Colorado

This session will begin with a brief introduction by Dr. John Wiener of the ATMs being investigated, and some of the other stresses adversely affecting viability of small and medium scale farming. Farmers' interests disclosed in Ditch and Reservoir Company Alliance discussions and a survey by the Colorado Cattlemen's Association will be noted. One of the problems is water provider preference for "permanence", versus difficulties for agriculture in long-term planning. As climate change adds to pressure on small and medium sized agriculture, loss of productive capacity threatens future food choices. Means for the mitigation of impacts will be proposed.

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### Ironing out inefficiencies and remedies for water markets

Charles Howe, Professor Emeritus of Economics, Senior Research Staff, Institute of Behavioral Science, University of Colorado

*Presenter - John Wiener, Research Associate, University of Colorado

The second paper, from Dr. Charles Howe, will address issues of transactions costs and economic inefficiency affecting water law and markets, noting some problems which may not be much appreciated. Among the latter are the asymmetries in bargaining capacity and information, and the problems of speculation. Anti-speculation doctrine has deep roots but may be easily circumvented by undisclosed private actions, while public and visible actions which might help markets are discouraged. These conditions may promote concentration of transfers.

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### ATMs need a buyer - Municipal water sources on the Colorado Front Range

Brett Bovee, Regional Director, WestWater Research, LLC

The Colorado Front Range has had a robust water market for many decades. This water market has been dominated by permanent transfers (sales) of reliable, high value water rights from irrigators to municipal water providers. The future water acquisition decisions by municipal water providers will continue to be a primary influence on water allocation and management in Colorado. Recent transactions and analysis will be presented which indicate an increase in water leasing along the Front Range, but several important hurdles to overcome for ATMs to be more acceptable for municipalities. Research findings will be presented on the comparative costs of ATMs and more traditional permanent water supply acquisitions for municipalities. Ideas will be presented on how to increase the number of ATMs in Colorado as a starting point towards larger-scale discussions of water allocation and management.

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### What if they had a market, and nobody came: Lessor attitudes towards ATMs

Mark Smith, Professor of Economics, Colorado College

The fourth paper, from Dr. Mark Griffin Smith will address ATMs from the perspective of behavioral economics. While studies show that water can be leased at prices higher than lost profits, farmers and ranchers are reluctant to participate in leasing arrangements. Behavioral economics provides at least four possible explanations for such behavior: (1) an endowment effect where water rights holders place a higher value on water rights because they own and control them; (2) an agreement to participate in an ATM is made within the social context of a community where at least some friends and neighbors will oppose participation; (3) the leasers' loss of identify as an active farmer or rancher; (4) uncertainty associated with participating in a novel program. If such behaviors create barriers to ATMs, how can "nudges," i.e. the leasing program, be designed to promote participation?

## Session 11, Drought Early Warning and Drought Monitoring: Planning for Scarcity II

### How historical drought data can inform the future adaptive capacity of agricultural systems

Caitriana Steele, College Assistant Professor, New Mexico State University
(co-authors: E. Elias, A. Rango)

The vulnerability of a natural or social system to an extreme climate event is a function of exposure, sensitivity and adaptive capacity. Exposure defines the level of stress imposed on the system by the climate event. Sensitivity is the predisposition of the system to experience harm caused by exposure to the climate event. Exposure and sensitivity combine to give the degree of impact on the system. Adaptive capacity is the ability of a system to successfully adapt to the impacts of an adverse climate event. Drought is one of the most challenging climate events facing agricultural producers in the United States. When we consider how to improve the adaptive capacity of agricultural systems to an extreme climate event such as drought, it is essential that we understand the impacts of drought at the local scale, and within prevailing social, economic and environmental contexts. Key to improving our adaptive capacity is proactive rather than reactive planning. In the United States, there are several products from the National Weather Service (NWS) and others that give quantitative indication of the degree of severity of drought, current soil moisture conditions, and evaporative demand. These indices provide information on the exposure of agricultural systems to the climate stressor. Producing data on the sensitivity of agricultural systems to drought is much more challenging because sensitivity to drought can be highly influenced by local conditions and the socio-economic context of the system. The National Drought Mitigation Center (NDMC) collects information on drought impacts from individuals in its Drought Reporter. There are other national and state level efforts that also engage stakeholders in data collection and impact reporting (e.g., CoCoRaHs, Arizona DroughtWatch). To gain a better understanding of the sensitivity of agricultural systems to drought, we propose to analyse drought impact reports with reference to historical drought monitoring data from multiple sources. This approach is inspired by the procedures already used to produce the NDMC Drought Monitor but it will be applied within the vulnerability conceptual framework so that we may discover adaptive solutions for future drought events.

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### A dynamic statewide water budget for New Mexico

Joshua Randall, Program Specialist, New Mexico Water Resources Research Institute
(co-authors: K. Peterson, J. Roach, B. Thomson)

New Mexico Dynamic Statewide Water Budget (NMDSWB) is a multi-year effort to account for the origin and fate of New Mexico's water supply. The goal of the NMDSWB is to represent a synoptic picture of water resources and use in New Mexico, such that planners, law-makers, engineers, and the public have an easily accessible dynamic tool to aid in management, planning, and understanding of the state's water in the past and into the future. The historic portion of the model runs on a monthly time step from 1975 to 2011, and incorporates measured data such as stream flow, climatological conditions, and water consumption to estimate water quantity, location, and flows through the system. Examples include groundwater changes, evapotranspiration, and recharge. The NMDSWB is built on a system dynamics modeling framework and information from the model output is available at four spatial reference scales: river basin, county, water planning region, and state. The future portion of the NMDSWB includes projections of the state's water resources up to 2100. Building upon the framework the historic section, future projections will be made based on a set of assumptions set by the user. Initially, three specific scenarios are implemented: climate change scenarios, population scenarios, and efficiency scenarios. The climate change scenario includes downscaled GCM data that has been used to project temperature, precipitation, and water surface flows that are implemented into the model. The population scenario incorporates a future population model to estimate a per-capita relationship to water. The water efficiency scenario projects water use efficiency in different areas of the model such as agriculture and industry. Proper planning of future water resources is essential to understanding water availability. The NMDSWB is a tool that can help assess where, when, and what sectors of water in New Mexico will need consideration moving forward.

## Session 11, Drought Early Warning and Drought Monitoring: Planning for Scarcity II

### Added benefits of the Healthy Watershed Approach: Increased drought resiliency for the Upper Llano River, Texas

Tyson Broad, Watershed Coordinator, Llano River Field Station - Texas Tech University
(co-authors: T. Arsuffi, K. Wagner)

Texas Tech University Llano River Field Station and Texas A&M Water Resources Institute are working with local stakeholders to implement a Healthy Watershed Protection Plan (HWPP) for the Upper Llano River through a federal Clean Water Act 319(h) grant from the Texas State Soil and Water Conservation Board and U.S. Environmental Protection Agency. The WPP uses a stakeholder process for decision-making based on watershed science, modeling, landowner concerns, types and scale of treatment measures needed; and economics and feasibility of BMP implementation. The Llano River is a spring-fed river dependent upon recharge from precipitation on the arid karst Edwards Plateau of West Texas. Average annual precipitation is 23 inches; however, when average precipitation falls to 70 percent of normal, recharge approaches zero, resulting in zero to little flow in streams across the Plateau. Such dearth in precipitation has occurred 24 times (22 percent) during the 110-year period of record and is projected to increase with climate disruption. The general ecosystem dynamics model used to develop BMPs provides estimates of evapotranspiration and recharge and can be used to simulate water yields and water quality under a variety of land management and climatic scenarios. Although a primary goal of the HWPP is to maintain or improve water quality, the program can also provide a critical secondary benefit by increasing watershed resiliency during times of drought. Best Management Practices (BMPs) to protect water quality/quantity -brush control for water supply enhancement, upland grazing management, prescribed burning, and riparian and stream bank restoration- also improve water supply conditions during drought by decreasing evapotranspiration, increasing the moisture-holding capacity of the soil, and increasing recharge. Model output is an important outreach tool for demonstrating benefits and drought resiliency resulting from BMP implementation to stakeholders.

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### Preserving Lake Kinneret (the Sea of Galilee) as a strategic water resource for the state of Israel

Doron Markel, Lake Kinneret Monitoring and Management Director, Israel Water Authority

Lake Kinneret (the Sea of Galilee) is the only freshwater lake in Israel, supplying about 20-25% of the country's potable water. Israel also supplies 50 million cubic meters per year (MCM/y) from the Lake to the Hashemite Kingdom of Jordan. There are plans to increase the supply to 100 MCM/y by 2020, according to recent agreement between the countries. The Lake also sustains commercial fishery and serves as a touristic attraction. In order to control water quantity and quality an intensive and sophisticated monitoring system in the lake and its watershed has been developed since the 1970s. In the last 40 years, the Lake has exhibited a clear decrease in net inflows from an average of 500 MCM/y in the1970s to an average of 300 MCM/y since the 2000s. This is mainly due to regional climatic change and a long-term decrease of the precipitation in northern Israel. As a consequence, there is increased variability in water-level fluctuations and progressive deterioration of water quality. The latter is mainly due to salinity increase and the occurrence of cyanobacteria blooms. According to long term climate forecast models, net inflows into Lake Kinneret are about to decrease even more to an average of 200-250 MCM/y until 2050. Currently, the intensive desalination by the shore of the Mediterranean Sea enables flexible pumping policy from Lake Kinneret and stabilizing the lake water level. However, operation of the lake with low water exchange (low amount of water inflow and outflow) may lead to increase salinity and cyanobacteria blooms. The Israel Water Authority has executed a strategic management plan to overcome the consequences of the low water exchange in Lake Kinneret. The plan includes increased removal of saline inflows, fisheries management, intensified prevention of pollution in the watershed and increase water inflow and water exchange by various means.

### Surface water quality criteria for nitrogen and phosphorus throughout the United States: A changing status with implications

Michael Kuitu, Extension Program Specialist, Texas A&M AgriLife Extension Service
(co-authors: J. Mowrer, D. Gholson, J. Cary, W. Ling)

Nutrient pollution of surface water bodies is a growing concern of environmental regulatory agencies and the general public. In the United States (U.S.), nutrient pollution of surface waters—primarily caused by excess nitrogen and phosphorus—commonly results in eutrophication. Economic, biological, and potential human health impacts resulting from eutrophication are continually documented. As a result, environmental regulatory agencies have been under increasing pressure, in recent years, to more effectively address nutrient pollution. At present, with approval of the U.S. Environmental Protection Agency (EPA), individual states can establish their own surface water quality criteria, numeric or narrative, to fulfill requirements of the Federal Water Pollution Control Act amendments of 1972 and 1977—commonly known as the Clean Water Act. Historically, individual states have developed narrative nutrient surface water quality criteria in lieu of numeric criteria. Narrative nutrient surface water quality criteria have been argued to be a root of regulatory ambiguity, resulting in degraded surface water bodies and multiple lawsuits between government entities, environmental advocacy groups, and private industry. Therefore, the EPA has created non-mandatory guidelines to encourage and assist states to develop and implement numeric surface water quality criteria for nitrogen and phosphorus so that clear, enforceable limits on their concentrations may be established. In the changing environment of water demand, availability, and quality, the number of U.S. states and territories with either partial or complete numeric surface water quality criteria for nitrogen and phosphorus is increasing. However, 27 states still use narrative criteria for nitrogen and phosphorus. The obstacles and implications of developing, or not developing, numeric surface water quality criteria for nitrogen and phosphorus are likely to result in impacts to industry, municipalities, and the general public with mixed reception by each.

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### The Illinois River Watershed - The convergence of science, lawsuits and collaboration

Brian Haggard, Director, Arkansas Water Resources Center
(co-authors: X. Lin, P. Gowda, Z. Zambreski, S. Kutikoff)

The trans-boundary Illinois River Watershed has been the focus of scientific investigation, lawsuits and regulatory actions, and even joint collaborative efforts to improve water quality. The Illinois River Watershed drains from northwest Arkansas into northeast Oklahoma and includes three of Oklahoma's Scenic Rivers with a numeric total phosphorus (TP) criteria. In 2003, the state of Arkansas and Oklahoma signed the [first] Statement of Joint Principles and Actions stating the shared goal to reduce TP concentrations, resulting in reduced effluent TP limits and various legislation and regulations on poultry litter management. These management changes improved water quality, reducing TP concentrations and loads in the Illinois River. However, the TP concentrations in the Illinois River and select tributaries were still greater than the applicable numeric criteria in. Continuing in a collaborative fashion the states augmented the first agreement, providing a three-year extension of commitments with the Second Statement of Joint Principles and Actions in 20113. The primary concern has centered on elevated TP concentrations in Oklahoma's Scenic Rivers that results in significant shifts in the algal community and undesirable water-quality conditions. The second agreement outlined a Joint Study under the management of a Joint Study Committee with several mandatory components, and the ultimate goal was a recommendation to the Governor's Offices on the TP concentration, and sampling frequency and duration, necessary to protect the aesthetic beneficial use of the waters. This presentation will provide a history of the conservation efforts, water quality improvements, and recommendation from the Joint Study Committee based on science.

### Distribution of wastewater constituents in a heavily pumped, urban groundwater system

Madeline Gotkowitz, Hydrogeologist, Wisconsin Geological Survey

Groundwater resources in urban areas are often used for public water supply, but groundwater in these areas can be contaminated by residential and commercial wastewater streams. We evaluated the presence of wastewater constituents, including human enteric viruses, artificial sweeteners, pharmaceutical and personal care compounds, and several steroidal hormones, in a heavily-pumped urban groundwater system in Wisconsin. Seven field sites were established in urban and suburban settings at locations with sanitary sewer systems ranging from 10 to 75 years old. Twenty-two monitoring and public water supply wells were sampled 24 times over a twelve month period for enteric viruses. A subset of 15 monitoring wells was sampled once for 46 pharmaceuticals and personal care products (PPCPs), four artificial sweeteners, and a suite of steroidal hormones. Laboratory techniques for PPCPs included use of high-performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS), which provided detection limits for some organic compounds as low as 10-9 g/L.

Of the 22 wells sampled for human enteric viruses, 13 were virus-positive at least once. The over-all virus detection rate was relatively low 3.7% (17 of 455 samples positive), and detections were associated with precipitation events. The subset of 15 monitoring wells sampled once for organic compounds showed widespread presence of various wastewater constituents, with at least one PPCP or sweetener detected in each well. Steroidal hormones were present in wastewater but not in groundwater samples. Artificial sweeteners acesulfame and cyclamate were detected in 14 of the 15 samples, at depths up to 80 m below ground surface. Prescription medications sulfamethoxazole and carbamazepine were detected in over half of the wells, at depths up to 52 m. Taken together, these results demonstrate temporal and spatial variability in the transport of colloidal and dissolved wastewater contaminants in groundwater.

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### Impact of management practices on bacteria in the Upper Great Plains

Bruce Bleakley, Professor, South Dakota State University
*Presenter - Rachel McDaniel, Assistant Professor, South Dakota State University

With over 175,000 miles of streams and rivers either threatened or impaired by pathogens, they are the number one cause of impairments in the United States. *E. coli* have the ability to survive and grow in the environment, particularly environments with high carbon content. In addition, high concentrations of carbon provide “hotspots” for gene transfer and may lead to an increase in antibiotic resistance genes released into the environment. These genes have the potential to be taken up by pathogenic bacteria, which can be a threat to human health. Many management practices have been developed to reduce contaminant transport from agricultural production to the environment, including bioreactors to treat nitrogen from tile drainage water, riparian area management to limit sediment and nutrient transport, and wetlands to treat runoff. Several studies are underway to examine the impact of these management practices on bacterial transport as well as the proportion of phenotypic antibiotic resistance present in and around these practices in the Upper Great Plains. Field and lab scale assessments are being conducted on woodchip bioreactors and their impact on both *E. coli* and antibiotic resistant bacteria in tile drainage water. Preliminary results indicate that bacteria concentrations, including at times *E. coli*, can be elevated at bioreactor outlets when compared to the inlet. Work will continue to evaluate the phenotypic antibiotic resistance of bacterial isolates. A second study is underway to determine the impact of riparian area management on stream *E. coli* concentrations. Preliminary results from two years of data show a rapid decrease in bacteria concentrations in areas where cattle producers are participating in riparian area management. Finally, work is being done to evaluate the phenotypic antibiotic resistance and metal tolerance in bacteria isolated from wetland environments.

### Water scarcity and its effect on human behaviors

Bryce Hannibal, Texas A&M University
(co-author: *L. Sansom)
*Presenter - Lindsay Sansom, Project Coordinator for Texas Transboundary Groundwater Governance Project, Texas A&M University

Studies on environmental attitudes and behaviors often omit important local environmental factors. It is likely that individual behaviors are dependent on how individuals perceive local environmental issues. In this study we examine individual water conservation behaviors in relation to local water scarcity. We examine 3 distinct dependent variables that measure different aspects of water conservation behaviors and investments. We use a multilevel statistical regression to determine if a relationship exists between levels of drought and individual water conservation behavior. As expected, we find that certain categories or groupings of individuals (i.e., political liberals) are more likely to conserve water than their counterparts. The results from the county-level predictors are mixed. We find that the influence of water scarcity on individual water conservation depends on levels of scarcity, as well as measurement technique. We conclude with some policy recommendations and steps for future research on water scarcity.

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### Confirming the environmental concerns over surface water conditions within the Houston neighborhood of Manchester utilizing participatory-based research

Garett Sansom, Associate Director, Texas A&M University - Institute for Sustainable Communities
(co-authors: P. Berke, T. McDonald, E. Shipp, J. Horney)

In the last few decades, there has been an increase in community-based participatory research being conducted within the United States. Recent research has demonstrated that working with local community organizations, interest groups, and individuals can assist in the creation of and sustainability in health initiatives, adoption of emergency protocols, and potentially improve health outcomes for at-risk populations. However little research has assessed if communal concerns over environmental contaminants would be confirmed through environmental research. This cross-sectional study collected survey data and performed surface water analysis for heavy metals in a small neighborhood in Houston, TX, that is characterized by industrial sites, unimproved infrastructure, nuisance flooding, and poor air quality. Surveys were completed with 109 residents of the Manchester neighborhood. Water samples were taken from thirty zones within the neighborhood and assessed for arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), silver (Ag), and mercury (Hg). Survey results showed that the vast majority of all respondents were concerned over proximity to industry and waste facilities, as well as exposure to standing surface water. Barium was discovered in every sample and many of the zones showed alarming levels of certain metals. For example, one zone, two blocks from a public park, showed levels of arsenic at 180 (µg/L), barium at 3296 (µg/L), chromium at 363 (µg/L), lead at 1448 (µg/L), and mercury at 10 (µg/L). These findings support the hypothesis that neighborhood members are aware of the issues affecting their community and can offer researchers valuable assistance in every stage of study design and execution.

### Risk perception and trust in international transboundary groundwater sharing: Texas-Mexico case study

Lindsay Sansom, Project Coordinator for Texas Transboundary Groundwater Governance Project, Texas A&M University

Along the Texas-Mexico border, different management regimes, property rights, and uses for groundwater are overlapping or conflicting, which has led to unilateral takings on both sides of the border and severe aquifer degradation. This paper is motivated by the expectation that, in the face of surface water scarcity and increased reliance on groundwater resources, improved water security requires stakeholders and managers to behave in cooperative ways. Within this type of polycentric governance, it is difficult to obtain policy integration and cooperation, particularly given the number of conflicting water uses. A risk perception approach can help to understand constraints to collective action and effective cooperation.

This research provides insight into how trust and perception of risk impacts cooperation over shared transboundary water resources. Trust in social and political institutions has proven to be a central tenant of social capital and a necessary condition for achieving cooperative behavior. This study discerns whether trust alone is a sufficient variable to increase cooperation, and how perception of risk among different water governance stakeholder groups seems to impact their willingness to engage in formal or informal cooperative behaviors.

By measuring how risks are perceived by different stakeholder groups, this study will determine what role trust plays in bi-national cooperation, and how risk perception and trust impact willingness to cooperate formally and informally over transboundary water sharing, with a focus on groundwater. Results from this project identify points of contention and disunity between decision makers of transboundary policy in Texas and Mexico and guide interventions to promote cooperation in protecting our most vital resource.

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### Can environmental attributes influence protected area designation? A case study valuing preferences for springs in Grand Canyon National Park

Julie Mueller, Associate Professor, Northern Arizona University
(co-authors: A. Springer, R. Lima)

Springs in Grand Canyon National Park (GRCA) provide water to nearly 5 million visitors per year. In addition to use value for visitors, springs have cultural value to indigenous peoples and provide critical habitat for plants and animals. Finally, base flow to the Colorado River is dependent upon springs and they also provide an important water source for backcountry recreation. Climate change, uranium mining, and increased groundwater pumping threaten the continued viability of Grand Canyon springs. Springs protection is at the forefront of proposed national policy to protect the area of the aquifers contributing to springs of the Grand Canyon outside of the designated boundaries of the national park. To date very little research on the non-market values of springs has been conducted, and no research has estimated non-market values of springs within Grand Canyon National Park using a Choice Experiment. We conduct a nationwide online Choice Experiment (CE) to determine willingness to pay (WTP) to protect backcountry springs and attributes including; accessibility, suitability as a back country water source, suitability as habitat for species of concern, aesthetics, and significance to Indigenous Nations. We estimate a Bayesian mixed logit, and find an average willingness to pay of $32.60 per household for a spring with the presence of all five attributes. The habitat attribute produces the highest WTP of $14.80. We find WTP of $4.50 for springs with cultural significance. Results from our study could be instrumental in designation of the Grand Canyon National Heritage Monument. In addition, our results indicate that careful consideration of watershed services on public lands is essential for efficient decision-making regarding protection of public lands.

## Session 14, Modeling III

### Modification of the SWAT model for improving hydrological simulation in intensively irrigated watersheds

Xiaolu Wei, Ph.D. Candidate, Colorado State University
(co-authors: R. Bailey, A. Tasdighi)

The Soil Water and Assessment Tool (SWAT) is a popular modeling tool for simulating hydrological processes and nutrient transport in watershed systems. However, SWAT often does not perform well in highly-managed watersheds with intense irrigation, due to management practices and associated hydrological processes (e.g. canal seepage) that are not included in the original model. In this study, we present a version of SWAT that can be applied to highly-managed irrigation systems, with the following modifications: each cultivated field designated as a hydrologic response unit (HRU), so that irrigation can be applied according to water rights; the management of each HRU includes operation schedules such as crop rotation, irrigation, harvest, and tillage; total irrigation applied to the cultivated fields is limited by canal diversions from the river; and seepage from the irrigation canals to the underlying aquifer is calculated by the difference between canal diversions and irrigation amount associated with water rights. The seepage amount is assigned to the HRUs adjacent to the canals based on area fraction, and added directly to the shallow aquifer. The modified SWAT model is applied to a 950 km2 watershed in the Lower Arkansas River Valley (southeastern Colorado), a semi-arid region that has been intensively irrigated for over 100 years and is threatened by shallow water tables due to over-irrigation, lack of artificial drainage, and seepage from earthen canals. The total number of HRUs for the model is 5,298, with 2,826 HRUs representing individual fields. The model was tested against monthly stream discharge at 5 stream gages during the 1999 to 2007 period, with automated calibration performed using dynamically dimensioned search algorithms. The model will be used to assess the impacts of different best management practices on streamflow in the region. The model can be used in other irrigated regions.

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### How hydrologic allocation modeling has supported decision making in the Colorado Rio Grande Basin

Kelly DiNatale, President, DiNatale Water Consultants
(co-author: *B. Macpherson)
*Presenter - Brian Macpherson, Water Resources Engineer, DiNatale Water Consultants

Hydrologic allocation modeling in RiverWare has been used in the San Luis Valley of Colorado (Colorado Rio Grande basin) to assist in decision-making between irrigators, the State of Colorado, and environmental and recreation groups. With many competing interests and obligations for this headwaters flow, including the interstate compact between Colorado and New Mexico, the RiverWare Policy Language (RPL) and conventional hydrologic modeling has been used to test reservoir storage, river exchanges, and irrigation curtailment logic in order to maximize Colorado's beneficial use and meet its obligation to New Mexico. Additionally, Trout Unlimited has provided flow targets that have guided release schedules that maximize boating and fish habitat conservation while still meeting the irrigation and Interstate compact goals. While the Prior Appropriation Doctrine dictates priority of diversion of water rights, the State of Colorado has discretion in its curtailment policy to meet its obligation to New Mexico. The practice of "Compact Storage" during the winter months is another synergetic operation between the State, irrigation and reservoir companies, and Colorado Parks and Wildlife that offers multiple benefits, and requires RiverWare modeling to test its efficacy under the Prior Appropriation Doctrine and with varying hydrologic conditions. Many interactive features in RiverWare, including dynamic plotting and dashboard scripts, assist in usability and stakeholder involvement.

## Session 14, Modeling III

### Geo-DSS for integrated river basin management: Russian River case study

Christopher Fields, Research Assistant, Colorado State University
(co-authors: J. Labadie, L. Johnson)

GeoMODSIM is an ArcGIS data model integrating the MODSIM river basin decision support system with GIS system tools and was coupled with the NWS RDHM Hydrologic Model for evaluating river basin management strategies accommodating agricultural water demands and habitat requirements for endangered fish. GeoMODSIM tools are used for importing NHDPlus data sets, automatically constructing the georeferenced river basin network structure, and executing the model within the ArcMap interface. GeoMODSIM is applied to evaluating streamflow conditions under various management scenarios for a tributary of the Russian River in Northern California.

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### Development of the future value function for optimal reservoir operation through the application of Q-learning

Matthew Peacock, Graduate Research Assistant, Colorado State University
(co-author: J. Labadie)

The use of forecasting information in reservoir operation is increasing as the constraints placed on existing systems change due to modified priorities, increased demand, or a changing climate. Making operational decisions for a reservoir system requires some information about the value that will be realized from the state of the system at the end of the forecast horizon. In dynamic programming, the future value function provides this information by mapping a real number to each state in the system state-space, with this real number representing a value of arriving in that state based on the expected return from operating the system optimally from that point on. The process of estimating this function can be extremely complex as reservoir systems commonly have very large state-spaces, and are subject to highly stochastic inputs and non-linear, non-continuous constraints. Traditional dynamic programming methods such as implicit or explicit stochastic dynamic programming require either inference of operating rules or development of transition probabilities which are not possible in some cases. The Q-learning algorithm is an agent-based reinforcement learning approach from the field of machine learning which estimates the future value function through interaction with an environment, in this case, a simulated reservoir system. Through an iterative process of decision making followed by observation of a state transition, the agent implicitly learns the stochastic nature of the system. This method is applied to a case study of the operation of Lake Mendocino in the Russian River basin in northern California.

## Session 15, Irrigation Aquifer Depletion and Challenges to Sustainability: GW & Crop Modeling I

### Comparison of methods for estimating agricultural groundwater pumping in the Central Valley, CA

Stephen Maples, Ph.D. Candidate, Dept. of Land, Air, and Water Resources, UC Davis
(co-author: G. Fogg)

Accurate estimation of groundwater budgets and effective management of agricultural groundwater pumping in California's Central Valley is a priority for achieving new, legally-mandated groundwater management goals. Comprehensive measurements of agricultural groundwater pumpage in the Central Valley are uncommon, despite that this is typically the largest component of the groundwater budget. Without these measurements, accurate estimation of groundwater budgets remains a challenge in much of the Central Valley. CVHM and C2VSim are two regional-scale hydrologic models that couple groundwater and agricultural water budget models to provide historical and current estimates of distributed groundwater pumping, changes in groundwater storage, and evapotranspiration (ET) in the Central Valley. However, both models estimate these water budget components using conceptually different representations of soil-moisture conditions, estimations of ET requirements, and prioritizations of water allocation. The uncertainties related to these conceptual differences have not been adequately investigated. Here, we evaluate differences in distributed agricultural groundwater pumping, groundwater change-in-storage, and ET estimates for both models at regional and sub-regional scales. Results show wide-ranging, but typically large differences in the magnitude of simulated distributed agricultural groundwater pumping and in temporal groundwater storage trends, both at the regional and sub-regional scale. In general, model agreement is poor at the sub-regional scale that is important for water management. Because many of the input data are the same for both models, these findings suggest that estimates of these important water budget components are sensitive to conceptual differences between methods, especially at the sub-regional scale.

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### An integrated modeling framework for investigating water management practices in the Ogallala Aquifer Region

Ryan Bailey, Assistant Professor, Colorado State University
(co-authors: P. Gowda, I. Kisekka, S. Nozari, C. Ray, V. Uddameri, X. Lin, A. Andales, V. Prasad, M. Schipanski, R. Waskom)

With relatively low recharge rates, the Ogallala Aquifer Region (OAR) has experienced declining groundwater levels over the past half-century due to groundwater pumping for irrigated agriculture. Current rates of groundwater extraction are not sustainable to maintain adequate groundwater supply for the coming decades. In addition, climate change forecasts predict an increase in the duration and intensity of drought periods during the next 50 years. To evaluate the potential of future management and policy options to maintain rural economies in the OAR requires a coordinated effort among growers, agronomists, hydrologists and economists. This paper outlines an integrated modeling framework that will link land surface hydrology, agronomy, groundwater hydrology, and downscaled Global Climate Models (GCM) outputs to investigate alternative management practices for optimizing water use in the OAR. It is developed for use in an ongoing USDA-NIFA funded Cooperative Agricultural Project that seeks to optimize groundwater use in the OAR to sustain food production systems, rural communities, and ecosystem services. It consists of the DSSAT (Decision Support System for Agrotechnology Transfer) cropping system model, coupled with the SWAT (Soil Water Assessment Tool, for watershed hydrology) and MODFLOW (for groundwater hydrology). A case study will be presented and discussed in detail to demonstrate the application of the proposed integrated modeling framework.

## Session 15, Irrigation Aquifer Depletion and Challenges to Sustainability: GW & Crop Modeling I

### Calibration and validation of DSSAT-CSM using lysimeter data for estimating daily ET and crop yield in the Texas High Plains

Pradip Adhikari, Post Doctoral Fellow, Oklahoma State University
(co-authors: P. Gowda, G. Marek, I. Kisekka, D. Brauer, B. Northup, A.C. Rocateli)

Texas High Plains (THP) is one of the most important food and fiber producing regions in the Southern Great Plains, currently facing rapid decline of groundwater levels in the underlying Ogallala Aquifer. Predicated warm summers and high temporal variability in growing season precipitation in the future may demand growers to pump more groundwater from Ogallala Aquifer to meet high crop water demand. The Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) is a widely used tool for evaluating impacts of different water and crop management practices on crop yield and water use efficiency. In this study, CROPGRO-Cotton/Soybean, CERES-Sorghum/Maize/Wheat modules of the DSSAT-CSM were calibrated and validated using long term data (1989-2010) from irrigated and dryland lysimeter fields managed by the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX. Data were divided equally for calibration and validation purposes. Crop growth characteristics, crop yield and ET between 1989 and 2010 crop growing seasons were used for model calibration and validation.

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### Calibration of CERES-Maize against precision weighing lysimeter data under semi-arid conditions of eastern Colorado

Allan Andales, Associate Professor, Colorado State University
(co-authors: M.C. Capurro, G.E.B. Smith, P.H. Gowda, I. Kisekka)

Alternative water management strategies in the Ogallala Aquifer Region (OAR) of the U.S. need to be explored to mitigate adverse effects of groundwater decline on agriculture. There is a need to evaluate impacts of various water conservation strategies on crop yield across the OAR. For the OAR portion in eastern Colorado, alternative irrigation management strategies can be evaluated across different locations using a calibrated cropping systems model. The objective of this study was to calibrate and evaluate the performance of the CERES-Maize crop model using water balance and corn growth data from a precision weighing lysimeter in southeast Colorado. The mass of an undisturbed soil monolith with an actively-growing corn crop contained in a steel tank (3 m x 3 m area; 2.4 m deep) was continuously monitored with a calibrated load cell to determine hourly and daily corn evapotranspiration (ET) and soil profile water balance. Corn was planted on the monolith and surrounding field (4 ha) in early May for two growing seasons (2013 – 2014). Irrigations on the monolith and surrounding field were applied through furrows spaced 76 cm apart. The CERES-Maize crop model integrated in two cropping system models [Decision Support System for Agrotechnology Transfer (DSSAT) and Root Zone Water Quality Model (RZWQM2)] was calibrated against weekly measurements of soil water content and corn growth; and daily measurements of evapotranspiration (ET) in 2013. The calibrated models were validated using 2014 growing season data. Comparative performance of DSSAT and RZWQM2 in simulating ET, growth, and soil water content are reported.

### Overview and benefits of on-farm water storage systems in Mississippi watersheds

Mary Love Tagert, Assistant Extension Professor, Mississippi State University Extension Service
(co-authors: J.O. Paz, J.D. Pérez-Gutiérrez, R. Karki)

The USDA-Natural Resources Conservation Service (NRCS) began implementing the Mississippi River Basin Healthy Watersheds Initiative in fiscal year 2010 to improve water quality and wildlife habitat in the Mississippi River Watershed and address growing concerns about the hypoxic zone in the northern Gulf of Mexico. It was at this time that we began to see on-farm water storage (OFWS) systems installed in priority watersheds in the Mississippi Delta. However, farmers were interested in these systems primarily due to the continued decline of groundwater levels in the Mississippi River Valley Alluvial (MRVA) aquifer, the main source of water for irrigation of crops in the Mississippi Delta. More OFWS systems have been installed in the central Delta where groundwater declines have been most severe. Since 2010, a growing number of farmers in the Mississippi Delta have voluntarily implemented OFWS systems to provide an additional source of water for irrigation and reduce risk during the growing season, especially during times of insufficient rainfall. Farmers in this region of the state typically use surface water conjunctively with groundwater, but producers in East Mississippi have also been interested in implementing OFWS systems as a source of water for irrigation, transitioning from dryland production to irrigated acreage. The use of groundwater for irrigation in East Mississippi is not economically feasible or even possible in some areas. Farmers must instead rely solely on surface water for irrigation. OFWS systems have proven to be a good solution for providing water for irrigation in both the Mississippi Delta and in East Mississippi. This presentation will discuss the implementation of OFWS systems in different regions of Mississippi, including the multiple benefits provided by this dual-purpose best management practice (BMP) that improves water quality and provides additional water for irrigation.

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### Irrigation water supply potential of on-farm water storage systems in Mississippi agricultural watersheds

Juan D. Pérez-Gutiérrez, Ph.D. Candidate, Mississippi State University
(co-authors: J.O. Paz, M.L. Tagert)

The ability to irrigate is critical for improving agricultural profitability in Mississippi, especially in the Mississippi Delta region (MDR). In this western region of Mississippi, farmers primarily use groundwater from the Mississippi River Valley Alluvial (MRVA) aquifer to irrigate crops, and this has resulted in over pumping of the aquifer and thus declining groundwater levels. In areas experiencing more severe groundwater declines, on-farm water storage (OFWS) systems have been implemented to provide an additional source of water for irrigation and reduce the pumping pressure on the aquifer. These systems collect and store rainfall and tail water runoff so that farmers can use the stored water to meet irrigation demands. OFWS systems are typically implemented in the MDR with pads, or small berms, around fields, where water is piped to a tailwater recovery (TWR) ditch and then pumped to a storage pond. Fields are usually precision leveled when systems are installed. OFWS systems have also been established throughout northeast Mississippi to support irrigation to maintain and increase crop yields. In this part of the state, it is not economically feasible to irrigate with groundwater, so surface water is the only reasonable option. Because surface water is typically the sole source of water for irrigation in northeast Mississippi, OFWS systems here must be designed to hold enough water to irrigate a given crop through the entire growing season. In addition, sprinkler irrigation is the common method used in northeast Mississippi, and fields are not usually precision leveled. Assessment of the water supply benefits of OFWS systems have not been documented. This study quantifies the water supply potential of three OFWS systems by examining the water volume pumped from the systems to irrigate crops. The two systems located in the MDR capture and store runoff water by combining a tailwater recovery ditch and an agricultural pond. The third system, which is located in northeast Mississippi, routes runoff through a drainage ditch to an agricultural pond, where it is stored until used. Results of this study can be helpful to water resource managers for meeting sustainability goals and designing more efficient irrigation and conservation practices in Mississippi.

## Session 16, Water Conservation Strategies and Practices for Agriculture

### Assessment and mitigation of irrigation reservoir levee erosion

Daniel Wren, Research Hydraulic Engineer, USDA-ARS
(co-authors: Y. Ozeren, M. Reba)

In some areas of the United States, crop irrigation has contributed to rapid declines in groundwater level, making it necessary to use on-farm reservoirs to store surface water. These irrigation reservoirs are impounded by levees made from local soils that are often low in cohesion and susceptible to erosion. Wind-driven waves and surface runoff cause significant damage to the levees, creating a perpetual maintenance expense to producers. The fluctuating water levels that are necessary for irrigation make it difficult to use vegetation to protect the levees, and other options, such as geotextiles and stone, can be prohibitively expensive. Researchers with the Agricultural Research Service and the University of Mississippi National Center for Computational Hydroscience have been engaged in the study of irrigation reservoir levee erosion since 2005. These efforts have included the development of a wind-wave prediction model for small reservoirs, the design of floating wave barriers for reducing wave energy, direct measurements of levee erosion, laboratory study of wave erosion mechanisms, and a large-scale survey of the condition of existing irrigation reservoir levees. The presentation will contain a summary of each phase of the research.

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### Validation of smart phone apps and other best management practices to improve crop water use efficiency

Kelly Morgan, Professor, University of Florida

Shortages of fresh water supply are increasingly common in the southeast (SE) US. Growing population in this region has been suggested as a key component contributing to this water stress. Recent droughts have been more severe than would historically be expected resulting in rising water demands (population increase) and decreases in water availability. A 2010 report indicated that water demands are expected to exceed water supply in many areas of the US which will result in greater drought risks by 2050. Much of Florida is projected to be at 'high' to 'extreme' risk of water shortage while water shortage in Alabama and Georgia is projected to range from 'moderate' to 'extreme'. Simple water balance apps for urban lawn, cotton, citrus, and peanut, developed and validated for Florida and Georgia. The goal of this project was to validate water conservation under commercial production conditions as one of several model based Best Management Practices to improve crop water use efficiency by 20 to 35%, reduce water use, and improve water quality. SmartIrrigation scheduling Apps for urban lawn, cotton, citrus, tomato, strawberry were found to conserve water and neutral or positive affect crop yield in a series of two year-replicated studies at grower sites or research centers in Florida and Georgia. The apps were modified based on field findings. The stakeholder groups beta tested the apps and identify key factors that should be modified to improve the acceptability or usability of the apps. The apps can be downloaded in andriod or iphone version from app stores and information on us obtained at http://smartirrigationapps.org/.

## Understanding the emergence of adaptive water governance: A case study of the Cache River Watershed of southern Illinois

Jodie Hancock, Graduate Student, Southern Illinois University Carbondale
(co-author: K. Akamani)

In recent decades, the accelerated rate of biodiversity loss, anthropogenic global warming, and other grand conservation challenges have drawn the attention of scientists and policy makers to the view that social and ecological systems are not separate but instead must be treated as a complex whole. The sustainable management of coupled social-ecological systems, such as water resource systems, requires institutional mechanisms for managing uncertainties and building more resilient social-ecological systems. Adaptive governance is an outcome of the search for a way to manage uncertainties and complexities within social-ecological systems. The concept of adaptive governance has emerged as a product of resilience theory and theoretical insights on common pool resources management. Adaptive governance refers to flexible multi-level institutions that connect state and non-state actors to facilitate a collaborative and learning-based approach to ecosystem management. As such, it has the potential to integrate social considerations into the decision process while also dealing with uncertainties in complex water resource systems. However, little is understood on how a transformation to an adaptive governance system takes place and what criteria qualify a given institutional mechanism as an adaptive governance regime. This paper presents preliminary results on an ongoing study that is aimed at understanding the process and outcomes of transitions toward adaptive water governance by using the Cache River Joint Venture Partnership (JVP) within the Cache River Watershed in southern Illinois as a case study. Qualitative data for the study were generated through key informant interviews among members of the JVP and other knowledgeable actors, document review, and participant observation. The data are currently being analyzed through coding using the NVivo software. The results of the study promise to provide rich theoretical and policy-relevant insights into the process of institutional transformation in social-ecological systems and its implications for resilience and vulnerability in water resource systems.

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## Water governance and community sustainability: Evaluating the impact of the Joint Venture Partnership on the resilience of communities in the Cache River Watershed

Rachel Sheely, Graduate Student, Southern Illinois University Carbondale
(co-author: K. Akamani)

Resilience is a concept that is becoming heavily researched in the sustainability and resource management literature. For rural resource-dependent communities, community resilience is the ability to adapt to various drivers of change while maintaining or enhancing community well-being. Community resilience is influenced by multiple drivers of change, including the implementation of conservation policies. In recent decades, the field of water resource governance has been transitioning from a reliance on command-and-control institutional structures toward adaptive multi-level institutions, such as adaptive co-management and adaptive governance. These transitions offer potential opportunities for enhancing the resilience and sustainability of resource-dependent communities. Yet these relationships remain largely unexplored. This paper reports on the preliminary results of an ongoing study aimed at understanding the implications of ongoing transitions in water governance for the resilience of rural communities in the Cache River Watershed (CRW) of southern Illinois, a watershed that has been designated as a Ramsar Wetland of International Importance. The Joint Venture Partnership (JVP) was formed in the early 1990s to address various ecological crises in the watershed. While the JVP has made significant progress in restoring and reforesting the corridor along the Cache River, the impact of these management efforts on the resilience of communities in the watershed has not been adequately analyzed. The methods of data collection for this study consist of interviewing key informants, participant observations, and content analysis of documents. The interviews will be recorded, transcribed, and analyzed using a deductive coding approach with the aid of NVivo software. Findings from the study shall enrich current understanding of the dynamics of resilience and vulnerability in resource-dependent communities, as well as how those dynamics are influenced by water governance mechanisms and other drivers of change.

### Improving Saipan's water system operation

Shahram Khosrowpanah, Interim Dean, School of Engineering, University of Guam
(co-authors: L. Heitz, M. Iglecias)

Water hours and low delivery pressure have long been a part of the daily lives of the people in the islands of the Western Pacific. In Saipan, Commonwealth of the Northern Mariana Islands (CNMI), large investments have been made in system improvements, but delivery problems still exist. A stated goal of the Commonwealth of the Northern Mariana Islands (CNMI) government is to provide 24-hour water to all residents served by the Commonwealth Utilities Corporation (CUC) water system. However, due to inadequate inflow to some of the sub-regions, system leakage, and lack of knowledge of the system behavior as a whole, the system has been unable to provide 24-hour water service. To help reach 24-hour water service delivery, WERI researchers developed computerized models of each of the fifteen sub-regions of the CUC water system, using Geographic Information System (GIS) capability and the Saipan census data determined the number of users at each system junction node for residential and commercial customers, developed water demands and how this demand changes with both residential and commercial customers during a period of time (Diurnal Demand Pattern), and pressure changes throughout the system. In addition researchers provided training on system operation for the (CUC) operators. As the result, the CUC was able to improve the operation of the water delivery system, reduce the maintenance cost, reduce the amount of the water that was being lost through the system, and improve generally 80% (by population served). The procedure, and results will be presented at in this conference.

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### Short and long-term effects of a large-scale critical zone disturbance on hydrologic response

Fabian Nippgen, University of Wyoming

Mountaintop mining with valley fills (MTMVF) is a surface mining procedure that dramatically changes the face of entire landscapes. Mountaintops and ridges are removed with explosives to access underlying coal seams up to several hundred meters deep. The rock overburden is subsequently deposited in adjacent valleys as so-called valley fills. Approximately 10% of the Central Appalachian Coal Region are impacted by MTMVF activities, that produce landscapes much flatter than the originally steep and dissected topography. In addition to reconfigured slopes, the valley fills increase water storage potential up to 10-fold. Despite the large scale of the disturbance, questions remain about the effects on hydrologic response, especially over longer periods of time. We used a two-pronged approach to quantify the dramatic changes on hydrologic response imposed by MTMVF. In a first step, we compared two sets of paired watersheds (1st and 4th order) to immediately quantify alterations of the hydrologic system at different temporal and spatial scales. At both spatial scales, the timing and the rate of water delivery was affected by mining, with the mined watersheds exhibiting increased baseflows and muted peak flows, turning intermittent into perennial streams. At the event-scale, the reference watersheds exhibited higher dormant season runoff ratios, but similar responses to the mined watersheds during the drier growing season. In a second step, we compared the hydrologic responses of a valley fill chronosequence, ranging from active mining to ~20 years after mining operations ceased. Runoff ratios of the mined sites decreased over time, with higher-than-reference runoff ratios in the first years after mining and lower-than-reference values after 10+ years. However, even the older mined watersheds maintained perennial streamflow, despite decreases in overall water delivery.

### Water quality monitoring to identify nutrient sources and sub-watershed priorities within the Lake Wister Watershed

Bradley Austin, Post Doctoral Research Associate, Arkansas Water Resources Center
(co-authors: D. Leasure, S. Patterson, B. Haggard)

Lake Wister is the primary drinking water source for over 40,000 individuals in the Poteau River Valley of LeFlore County in Oklahoma. Other uses for the lake include agriculture, primary contact recreation, aesthetics, and aquatic communities. However, due to issues with nutrients, sediments and excessive algal growth, Lake Wister water quality is listed as non-supporting for public and private water supply, aquatic community, and aesthetics, which has resulted in the lake's placement on Oklahoma's 303(d) list of impaired waterbodies. Starting in July of 2016, water quality was examined monthly during base flow conditions at 25 stream reaches near the outlets of each of the sub-watersheds that flow into Lake Wister. Land use and cover was quantified for each of the 25 sites and a human development index (HDI) was calculated as the sum of percent agriculture and urban development for each of the sites. The geometric mean of the water quality parameters total nitrogen (TN) and phosphorus (TP), and turbidity were regressed against the HDI metric, finding positive relationships for all three parameters (TN $r^2$= 0.69, P<0.001; TP $r^2$=0.60, P<0.001; turbidity $r^2$=0.53, P<0.001). From this initial assessment the main stems of the Poteau River and Fourche Maline, along with Bandy Creek were selected for further investigation due to having higher HDI values than the other sub-watersheds and greater nutrients and turbidity than what was predicted by the linear models. These three sub-watersheds will be sampled at a finer scale to further define potential nutrient and sediment sources. Overall, the findings from this study will help in prioritizing sub-watersheds for the implementation of Best Management Practices to help reduce both nutrients and sediments entering the lake.

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### Investigation of the use of a simple model with national datasets to predict nutrient loads in urban stormwater

Tyler Dell, Research Associate, Colorado State University
(co-authors: M. Arabi, C. Olson)

As urbanization occurs, nutrient pollution from urban stormwater has become an increasing problem. Several models have been developed for predicting urban runoff, and by extension pollutant loads. Many of these models are complex, and difficult to understand by users with little modeling experience. Though these sophisticated models produce excellent results, many users feel uncomfortable using them due to the "black box" nature or as a result of the challenges in obtaining the necessary inputs for these models. Currently, with the availability of national datasets such as the National Land Cover Database (NLCD), simple models have once again entered the scene of stormwater modeling as users desire planning level estimates of urban stormwater nutrient loads. With the availability of national datasets, many simple models require very little input collection and can provide rapid order of magnitude estimations for nutrient loads which can be used for planning analysis to address the problem of nutrient pollution. This study investigated using a modified version of the Simple Method, combined with national datasets for inputs, to calculate order of magnitude nutrient loads in urban stormwater for a given area of interest. After evaluating the method at two study sites in Fort Collins, it was determined that the method was able to predict event nutrient loads for total nitrogen and total phosphorus within 100% and 125% respectively of the mean observed load. Overall it was demonstrated that the Simple Method with national datasets was successful at producing order of magnitude estimates of event nutrient loads.

## Water resources in the Tualatin River Basin: Management under increasing water demands and climate change

Kenneth Williamson, Director of Regulatory Affairs, Clean Water Services
(co-authors: *R. Kapur, T. Lu)
*Presenter - Raj Kapur, Water Resources Program Manager, Clean Water Services

The Tualatin River, located in Washington County, Oregon, ranges from a pristine coastal mountain stream to a slow-moving, highly impacted valley- floor river at it mouth. During the summer, flows mostly result from municipal wastewater discharges and augmented flows from two upland reservoirs. The river represents a classic water resources management issue resulting from balancing water flow from natural flows and storage and water use for agricultural, municipal and industrial needs. The water quality in the river is affected by municipal and industrial discharges, extensive agricultural non-point sources and instream algal growth.

Clean Water Services (CWS) is a water resource utility that manages four wastewater treatment facilities that discharge to the Tualatin River. A TMDL and its strict requirements require advanced wastewater treatment at two of these facilities and a basin water quality trading plan to comply with NPDES permit requirements. The effluent limits for many parameters including phosphorus, ammonia, CBOD, TSS, and temperature are near the technological capabilities of the treatment technology being used at these facilities.

This paper describes CWS' present scenario planning to meet water quality objectives through 2050. The scenarios incorporate changing inputs related to growth and climate change. Potential management options include industrial pretreatment, treatment facility modifications, new treatment technologies such as membrane bioreactors and reverse osmosis, increasing recycled water use, increasing stored water capacity, and expanded water quality trading. The scenarios will also address potential regulatory unknowns including applicable instream temperature standards, increasing 303d listings for a variety of pollutants, and challenges to the legality of temperature trading. The need and viability of regulatory options such as variances, and site specific criteria is also explored. The results of the scenario planning will be presented including the advantages, disadvantages, barriers and expected cost of each. CWS' goal is to select a suite of strategies to meet water quality objectives in the Tualatin River Basin through 2050.

## Governance, policy, and economics of clean water in the Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania

Gerald Kauffman, Director, Delaware Water Resources Center, University of Delaware

This research evaluates the governance, policy, and economics of improved water quality in the Delaware Basin, an interstate watershed in Delaware, New Jersey, New York, and Pennsylvania. The watershed or river basin approach is examined as a means to manage the water resources of interstate river systems. The organization and budget structure of the Delaware River Basin Commission (DRBC) is compared to other prototypical institutional models of interstate river basin management in the United States. A benefit-cost analysis is applied that employs a watershed pollutant load model to estimate market and nonmarket benefits, marginal abatement cost curves, and net benefits to determine optimal costs of water quality improvements to meet a more protective year-round fishable standard in the Delaware River. Results show that the annual benefits of improved water quality in the Delaware River range from $400 million to $1.1 billion at an annual pollutant load reduction cost of $449 million. The most cost effective DO water quality standard is 4.5 mg/l defined by the intersection of the marginal benefits (MB) and marginal cost (MC) curves or the point where willingness to pay (WTP) for improved water quality equals the marginal costs of pollution reduction. Market-based mechanisms such as user-polluter pays approaches and water quality trading are explored as alternatives to traditional Clean Water Act regulations to incentivize and fund Delaware River water quality improvements. This research concludes that the DRBC has the requisite authority under a Federal/state compact to manage the Delaware River as a single entity and has the capability to tap beneficiary-pays revenue streams to fund water quality programs in an interstate basin that supplies drinking water to 5 percent of the population of the United States.

## Session 19, All Voices Matter: How to Draw Underrepresented Voices into Water Policy Decisions

### River Sisters Initiative - Reconnecting municipal Colorado River water users from source to sea

Jorge Figueroa, Senior Water Policy Analyst, Western Resource Advocates

Since the 1960s, because of damming and diversions, the Colorado River in Mexico has been a dry river that rarely has reached the sea. In the last decade, the restoration of the Colorado River delta, spearheaded by Pronatura Noroeste, Sonoran Institute, Environmental Defense Fund, and the US and Mexican governments, represents one of the most complex and successful binational restoration projects in the world. That said, these efforts have largely overlooked the important role the river can play to the city of San Luis Rio Colorado, and the important role the city can play in supporting the broader efforts planned for the delta's restoration. The goal of the River Sisters initiative is to create a binational water leadership education and cultural exchange program between urban leaders and institutions in Mexico and the state of Colorado to connect urban water users of the Colorado River with the River from source-to-sea, strengthen Delta restoration efforts, and provide technical support in the design and creation of a River Park in Mexico that will reconnect the people of San Luis Rio Colorado to the Colorado River and ultimately help reconnect the River to the Sea.

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### Latino students learning about water for policy decision opportunities

Nancy Negrete Contreras, Colorado Water Sustainability Fellows
(co-author: M. Smith)

Eight Latino students at Colorado State University have been accepted into a Colorado Water Sustainability Fellowship Program, the purpose of which is to broaden the diversity of voices in water policy decision making throughout Colorado and the Colorado River Basin. These students are being introduced to water issues and water careers and will in the summer of 2017 work with Denver Latino high school students to organize a fall Denver Youth Water Summit. One of the eight students will share what it is like to be an undocumented student who is allowed to study at the university under the Deferred Action for Childhood Arrivals (DACA) executive action of then President Obama and now under the threat that the action will be reversed by the new president. She will tell about the opportunities the students are gaining in learning about current water issues in Colorado and the Colorado River Basin. She will share why it is important for natural resource policy decisions to take into account the voices of all affected shareholders.

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### Ten Tribes Partnership - A place at the Colorado River Basin water policy table

Daryl Vigil, Ten Tribes Partnership

The Ten Tribes Partnership was formed in 1992 by ten federally recognized tribes with reserved water rights in the Colorado River Basin, for the purpose of strengthening tribal influence among the seven Basin States over the management and utilization of Colorado River water resources. Specifically, the Partnership intended to assist member tribes to develop and protect tribal water resources and to address technical, legal, economic and practical issues related to the management and operation of the Colorado River. The Partnership formally joined the Colorado River Water Users Association in 1996 in the hopes of actively participating with the seven Basin States in negotiations relating to the Colorado River. With combined annual water rights in the Upper and Lower Basin of approximately twenty percent of the mainstream flow, the Partnership's mission is to ensure that, within the next decade: (1) each tribe has settled or otherwise resolved its reserved water rights claims; (2) each tribe has the ability to maximize its on-reservation use of water and the flexibility to explore, facilitate and implement off-reservation use and transfers; (3) each tribe benefits from water infrastructure projects promised or obtained through settlements or negotiations with state and federal governments and partners in a timely fashion; and (4) the federal government firmly asserts and exercises its trust responsibility to protect the tribes' reserved water rights in all of its management actions related to the Colorado River. The Colorado River Water Users Association was formed in 1945 to bring together "all water user and organizations" with a stake in the Colorado River, but the tribes were not invited to join the association until 1996. Daryl Vigil from Ten Tribes Partnership will tell about how the tribes were able to secure a voice in the Colorado River Water Users Association at that time, taking their place alongside the seven states with concerns in the Colorado River. He will tell about how important it has been for the tribes to have that representation.

## Session 20, Modeling IV

### Application of neural networks to development of a computationally efficient surrogate to the MODFLOW model: Application to the stream-aquifer system of the Lower Arkansas River Basin in Colorado

Faizal Rohmat, Graduate Research Assistant, Colorado State University
(co-authors: J. Labadie, T. Gates)

Colorado State University (CSU) has conducted extensive field data collection efforts in the Lower Arkansas River (LAR) Basin of Colorado in support of basin-wide planning and analysis of conservation practices for improving water quality and sustaining the valuable agriculture of the LAR Basin, while ensuring that proposed conservation practices comply with complex basin water rights and the Arkansas River Compact. Geo-spatially distributed conservation scenarios include selected combinations of various levels of irrigation efficiency improvement, canal sealing, lease-fallowing, and reduced fertilizer applications. It is evident that accurate modeling of the complex stream-aquifer system of the basin is imperative to the success of this endeavor. To this end, the extensive data collection efforts conducted over the past 17 years have resulted in two well-calibrated and tested MODFLOW-UZF regional-scale stream-aquifer numerical models and application of CSU's basin-wide Geo-MODSIM river basin management to the LAR Basin. Although Geo-MODSIM employs an internal, simplified lumped parameter stream-aquifer system model, it is desired to link Geo-MODSIM with the spatially-distributed, well-calibrated MODFLOW-UZF models to supplant the simplified model. Unfortunately, attempts to do this have been thwarted by the high computational expense of MODFLOW-UZF, since many repeated model executions are required when integrated with Geo-MODSIM for eventually finding the best management strategies. To overcome this problem, efforts have been directed to employing computationally efficient artificial neural networks (ANN) for replicating the behavior of MODFLOW-UZF. A large number of carefully selected spatial, temporal, and conservation scenario variables act as the explanatory input variables to the ANNs, with stream-aquifer interactions calculated by MODFLOW-UZF serving as the ANN outputs in a supervisory learning scheme. Methodologies implemented in the collection of the variables are described, including the use of geographic information system (GIS) extensibility technology, along with results of the ANN implementation.

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### Potential for LID practices to retrofit urban watersheds

Esther Mosase, South Dakota State University
(co-author: L. Ahiablame)

Urban development is a concern for hydrologists and water resources managers as increased urbanization generally results in flooding and water quality degradation. Over half of the world's population (54%) currently lives in urban areas with expected increase to 66% by 2050. Best management practices (BMPs) and low impact development (LID) practices can be used to restore pre-development hydrologic conditions in urban watersheds. Although the effectiveness of urban BMPs and LID practices is widely acknowledged for storm runoff management, the extent to which implementation levels of LID practices minimize the impacts of urbanization in a watershed is not well understood. This study used the Personal Computer Storm Water Management Model (PCSWMM) to determine the level to which an urban watershed can be retrofitted with LID technologies.

### Estimating potential *E. coli* loads and transport due to rainfall from domestic sources

Kyna Borel, Graduate Research Assistant, Texas A&M University
(co-authors: V. Swaminathan, R. Karthikeyan)

Almost half of Texas water bodies are considered impaired, exceeding the regulatory standard for contaminates, by the Texas Commission on Environmental Quality (TCEQ). Forty-one percent of impaired Texas water bodies are contaminated due to bacteria. In order to address this bacteria contamination, SELECT was developed to characterize *E. coli* sources based on spatial factors such as land use, population density, and soil type. SELECT was automated within Geographic Information Systems (GIS) using Visual Basics for Applications (VBA) and contained a Graphical User Interface (GUI) so a user could adjust the parameters to fit specific water bodies being studied. However, VBA is no longer supported by the current version of ArcGIS and uses input data that is not publicly available or too difficult to obtain for many watersheds. The curve number method was applied to model the transport of *E. coli* using SELECT and rainfall to estimate *E. coli* concentrations. SELECT was programmed within GIS using Python for domestic sources including, on-site sewage facilities (OSSFs) and dogs using publicly available input data. The curve number method was automated using python within the SELECT domestic sources GUI to estimate the transport of SELECT calculated potential *E. coli* loads from a rainfall event. The model outputs include spatial maps of the potential *E. coli* loads aggregated to the subwatershed area and the transported potential *E. coli* loads for both OSSF and dog sources.

## Session 21, Irrigation Aquifer Depletion and Challenges to Sustainability: GW & Crop Modeling II

### Multi-model generation of corn production functions with associated uncertainty in High Plains

Isaya Kisekka, Kansas State University
(co-authors: A. Araya, P.V.V. Prasad, P.H. Gowda, A. Andales)

As irrigation capacities continue to decline in the southern and central High Plains region, to optimize net returns producers have to strategically allocate limited water to appropriate mixture of crops. Production functions have been widely used by agronomists, engineers and economists to quantify crop yield response to water with the goal to optimize water allocation. However, there is a great deal of uncertainty in both the estimated coefficients and functional forms of the production functions even at the same location for the same crop because processes that affect crop yield response to water are influenced by a number of factors that vary both in time and space. There is a scarcity of high-quality, long-term field studies to characterize uncertainty in production functions for major irrigated crops, particularly corn. In this study, a multi-modeling approach (using DSSAT-CSM, APSIM, AquaCrop and RZWQM) coupled with short-term experimental data and long-term climate data was used to generate production functions for corn that accounted for differences in irrigation management, cultural practices and climatic conditions. Uncertainty in yield response to water was quantified from ensemble of production functions generated by different crop simulation models. A robust output data set from this study will be useful for economists to conduct economic analysis of different scenarios to identify management practices that optimize net returns under limited water conditions in the target region.

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### Landscape-scale crop water productivity model for multi-year water management decisions

Robert Aiken, Associate Professor, Kansas State University
(co-authors: X. Lin, P. Colaizzi, D. O'Brien, L. Baumhardt)

Maintaining farm profitability with reduced irrigation can be supported by knowledge and management of risks associated with inter-annual and multi-year water management decisions. Increased understanding of global circulation patterns, such as the El Nino/Southern Oscillation dynamic can guide crop selection to mitigate climate-related risk. A working knowledge of landscape- and regional scale-effects on water dynamics can build on this success and identify opportunities to exploit climate-informed water management synergisms at landscape scales. Our project synthesizes current knowledge of ET mapping and working hypotheses of turbulent transfer into a physically-based modeling tool. The tool can be scaled (e.g. 30 m cells in a 10 km region) to provide information regarding consumptive water use, net primary productivity, and yield formation for multi-year crop systems ranging from dryland to full irrigation. Successful implementation of this tool will support analysis of water management policies on net economic returns at farm and regional levels.

### Calculation of evapotranspiration: Recursive and explicit methods

Robert Lascano, Research Leader, USDA - ARS
(co-author: T. Goebel)

Crop yield is proportional to crop evapotranspiration (ETc) and it is important to calculate ETc correctly. Methods to calculate ETc have combined empirical and theoretical approaches. The combination method was used to calculate potential ETp. It is a combination method because it combined the energy balance and an aerodynamic formula to calculate ETp and thus eliminated the surface temperature (Ts) from the equations. This method led to the Penman-Monteith (PM) equation to estimate ETc and is used by FAO and ASCE. The procedure is to multiply a reference crop ET (ETsz) by a crop coefficient (Kc) and both use the PM equation and are an Explicit Combination Method (ECM). Assumptions made with the ECM regarding the temperature and the humidity of the evaporating surface are not necessary when using a Recursive Combination Method (RCM), which solves ETsz by finding the temperature and humidity of the evaporating surface by iteration satisfying the energy balance. Calculated values of ETsz obtained with RCM are by preferable as they are physically correct and give the “true” temperature of the crop. To illustrate differences in calculated values of ETsz for a short grass (ETos) obtained with ECM and RCM, we used a 45-d from Lubbock, TX using 3 methods: M1) ETos calculated using RCM and a canopy resistance (rc) = 35 s/m: M2) ETos calculated using ECM and the recommended value of rc = 70 s/m, which corresponds to a short grass and; M3) ETos using RCM and using the input values recommended by FAO and ASCE. Results showed that M3 yielded the largest values of ETos. The smallest values of ETos were calculated with M2, which underestimated cumulative ETos by 7% compared to RCM. However, when the input parameters used in M2 were used with a RCM cumulative ETos was overestimated by 29% compared to RCM. In many cases, M2 yielded the correct value of ETos but for wrong reasons, and thus the 7% discrepancy obtained between them is deceptive. Results suggested that the rc value of 70 s/m used by ECM is perhaps too large. In summary, results showed that a RCM of ET is easily implemented and uses the same weather input data as ECM. From a physical point of view values of ET obtained with RCM are correct as they are derived from a solution that satisfies the energy balance.

## Session 22, Water Conservation Strategies and Practices for Agriculture

### Management strategies for adapting semi-arid corn production to limited irrigation conditions

Allan Andales, Associate Professor, Colorado State University
(co-authors: J.L. Chavez, N.C. Hansen)

When precipitation and irrigation water cannot meet seasonal crop water requirements, then limited irrigation conditions occur. In the semi-arid environment of northeast Colorado, corn (*Zea mays*, L.) is grown as a dominant irrigated crop for livestock feeding. The objective of this study was to quantify the effects of three limited irrigation scenarios on evapotranspiration (ET), growth, and yield of four corn hybrids. A factorial experiment in Fort Collins, Colorado considered 3 sprinkler irrigation treatments and 4 corn hybrids. Irrigation treatments included opportunity irrigations (once a week according to system capacity), growth-stage-timed irrigations (no irrigations during V5 – V10 corn vegetative phases), and drought (50% of opportunity treatment). There were four replications of each treatment combination. Corn was planted into strip-tilled plots in mid-May of the 2014 to 2016 growing seasons. Corn growth (canopy height, leaf area, phenology) and soil profile water content (0 – 150 cm) were monitored weekly during the 3 growing seasons. Grain yield samples were also taken at crop maturity. Weekly actual ET was estimated by soil water balance. The effects of the limited irrigation strategies on actual ET, corn growth, and yield are presented. Potential water savings and grain water use efficiencies are also compared across irrigation strategies and hybrids.

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### The Limited Irrigation Research Farm in northern Colorado

Kendall DeJonge, Agricultural Engineer, USDA-ARS

The Limited Irrigation Research Farm (LIRF) is located in north-central Colorado near the city of Greeley. The research focus is to explore management objectives focused on maintaining high crop yields with limited water supplies. Researchers, which include agricultural engineers and plant physiologists, focus on the objectives from several different angles – including quantification of evapotranspiration via water balance, development of crop coefficients, detection and quantification of stress using infrared thermometry and ground-based remote sensing, and plant-based physiological measurements. This presentation will show the project layout and experimental design, practical restrictions and limitations, and overview of the datasets being collected.

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### Nebraska Agricultural Water Management Network (NAWMN): Integrating research and extension/outreach to enhance agricultural production efficiency

Suat Irmak, Professor, University of Nebraska-Lincoln, NAWMN

To encounter some of the water availability vs. agricultural production issues, an unprecedented effort in irrigated agriculture was undertaken in 2004-2005 and the Nebraska Agricultural Water Management Network (NAWMN; http://water.unl.edu/cropswater/nawmn) was formed (Irmak, 2005, 2006) from an interdisciplinary team of partners, including UNL Extension, Natural Resources Districts (NRD), USDA-Natural Resources Conservation District, farmers, crop consultants, and other agricultural professionals. The main goal of the Network is to enable the transfer of high quality research-based information to farmers and their advisors through an unparalleled series of demonstration projects established in farmers' fields and implement newer tools and technologies to address and enhance crop water use efficiency, water conservation, and reduce energy consumption for irrigation. The Network was also designed to enhance scientific literacy of current and next generation producers and agricultural professionals in agricultural and related topics. The Network is designed to be proactive in terms of water conservation and management even in areas that may not have water issues currently. One of Network's other primary goals is to help sustainability of water resources and agriculture. All demonstration projects are supported by the scientifically-based extensive basic and applied research and evaluation projects conducted by Dr. Suat Irmak. The Network was formed with only 15 farmers as collaborators in only one of the 23 NRDs in 2005. As of 2016, the number of active collaborators reached 1,500 in 18 NRDs and 73 of 93 counties. The Network has been having significant impacts on both water and energy conservation due to farmers adopting/implementing research-based technologies and information in their irrigation management practices. The presentation will highlight some of the progress and impact data.

## Session 23, Climate Disturbance Impacts and Extreme Shifts in Hydrology over the Western United States

### The influence of climate change and climate-driven disturbances on streamflow and water balances in the Colorado River

Katrina Bennett, Director's Postdoctoral Fellow, Los Alamos National Laboratory
(co-authors: T. Bohn, R. Middleton)

Accelerated climate change and associated forest disturbances in the Southwestern USA are anticipated to have substantial impacts on regional water resources. Few studies have quantified the impact of both climate change and land cover disturbances on the basin wide water balances, and none at the regional scale. In this work, we evaluate the impacts of forest disturbances and climate change on the Colorado River basin using a robustly calibrated hydrologic model run with updated formulations that improve estimates of evapotranspiration for semi-arid regions. Our results show that future disturbances will have a substantial impact on streamflow with implications for water resource management. Annual average regional streamflow scenarios incorporating forest disturbances and climate change are at least 6-11% lower than those scenarios accounting for climate change alone, and forested zones of the basin are 15-21% lower. The monthly signals of altered streamflow point to an emergent streamflow pattern related to threshold changes in forests of the disturbed systems. For example, exacerbated reductions of mean and low flows under disturbance scenarios indicate a high risk of lower water availability for the Colorado River basin. This finding also indicates that explicit representation of land cover disturbances is required in modeling efforts that consider the impact of climate change on water resources.

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### Evaluating the impact of groundwater depletions on the dynamics of integrated hydrologic systems

Laura Condon, Assistant Professor, Syracuse University
(co-author: R. Maxwell)

Groundwater is generally the slowest moving and most stable component of hydrologic systems. Research has shown that groundwater can buffer surface water variability in natural systems and provide a stable water supply in managed systems. However, over the last century widespread groundwater development has resulted in unsustainable pumping rates and declining groundwater levels. It has been well documented that these trends threaten the long-term availability of groundwater supplies. Less is known, however, about the impacts of large-scale groundwater depletions on the dynamics of integrated hydrologic systems, specifically the ways watersheds respond to and recover from stresses. Given the potential for climate change to exacerbate the frequency and magnitude of hydrologic extremes, understanding the ways that the developed systems we have today may respond differently than the natural systems of the past is important to predicting future water availability. Here, we use an integrated hydrologic model to simulate the impacts of groundwater pumping on system dynamics and water management decision-making. Changes in land energy fluxes and streamflow variability are evaluated across the majority of the continental US by comparing a predevelopment groundwater scenario with a developed scenario that incorporates the groundwater depletions of the 20th century. Differences between these simulations isolate the impact of groundwater development from other water management changes over this time period and identify sensitive regions where groundwater losses can fundamentally alter surface water behavior. We also use long term simulations of a regional domain in the High Plains aquifer to simulate moisture dependent groundwater supported irrigation. Multi-year analysis shows the potential for positive feedbacks between groundwater drawdown, soil moisture variability and irrigation demand. Results from both simulations demonstrate the need to consider groundwater depletions both to understand previous hydrologic change as well as to better predict the response of existing systems to future extreme events.

## Session 23, Climate Disturbance Impacts and Extreme Shifts in Hydrology over the Western United States

### Climate impacts on energy and water supplies in coupled natural-human systems within the Colorado River Basin

Kurt Solander, Posdoctoral Research Associate, Los Alamos National Laboratory
(co-authors: K. Bennett, R. Middleton)

The Colorado River Basin (CRB) is one of the most important watersheds for energy, water, and food security in the United States (U.S.). CRB water supports 30+ million inhabitants, ~15% of U.S. food production, 50+ GW of electricity capacity, and one of the fastest growing populations in the U.S. Due to climate change, energy-water impacts in the CRB are projected to exponentially increase, including a higher incidence of extreme events (droughts, floods, and heat waves), widespread snow-to-rain regime shifts, and higher frequency and magnitude climate-driven disturbances (vegetation mortality, wildfire, and insects/pathogens). Taken together, the increase in energy and water demands and supply perturbations are anticipated to result in a no-analog future of these resources with respect to historic observations. Consequently, changes in climate will lead to major energy, water, and food security issues in the CRB and beyond, with a national impact. Here, we investigate how the energy-water nexus will change in the CRB through simulating climate change and climate-driven disturbance impacts on water and energy supplies in a coupled model framework that integrates climate, hydrology, water resources management, and energy production. Our focus will specifically be on reservoirs due to their importance to power production and water supplies in the CRB. Related work in the San Juan sub-basin of the CRB indicates annual streamflow declines of up to 11% by 2100 are expected from climate change and associated climate disturbances. By providing a more comprehensive study that analyzes how these impacts will vary with explicit impacts on water and energy supplies for various stakeholders, we provide more action-based scientific insight on how energy and water supplies will change to ensure management of these precious resources improves to safeguard against related threats to society.

## Session 24, Water Quality: Panel Discussion

### Beyond dead zones: The impact of agricultural nutrients on drinking water and associated legal policies, planning, and challenges for successful water quality management

Alexandra Chase, Ocean and Coastal Law Fellow, National Sea Grant Law Center;
Catherine Janasie, Research Counsel, National Sea Grant Law Center;
Ellen Essman, Director, Ohio State University Extension Agricultural & Resource Law Program;
Peggy Kirk Hall, Senior Research Associate, Ohio State University Extension Agricultural and Resource Law Program

Nutrient pollution discussions often focus on its negative environmental effects, such as the Gulf of Mexico dead zone. Attention, however, is starting to shift towards the potential public health risks of nutrient pollution. For instance, in 2014, a harmful algal bloom forced the City of Toledo to issue a two-day ban on the use of tap water. The city's drinking water had tested positive for microcystin, a toxin produced by the algae, leaving over 400,000 residents without water.

Nutrient pollution is primarily caused by nonpoint sources, such as agricultural and stormwater runoff. Under the Clean Water Act, primary responsibility for addressing nonpoint pollution falls to the states. However, controlling this type of pollution has proven difficult, as a number of challenging scientific, legal, and policy issues must be addressed when developing nonpoint source management programs.

This panel will follow a moderated question and answer format designed to highlight the common problems, effective responses, state success stories, and current legal developments in agricultural nutrient management. Panelists will discuss recent, innovative state-based efforts to reduce agricultural nutrient runoff. The panel will also address recent and ongoing litigation in federal courts, as well as recent regulatory developments under federal environmental laws. In addition, panelists will examine the role of state and local governments and consider the new administration's potential impact on water infrastructure and policy. The panel will conclude with a forward-thinking discussion of the future of agricultural nutrient management and its impact on water quality.

## Session 25, Challenges of Interdisciplinary Graduate and Undergraduate Programs in Water Resources

### Challenges and opportunities associated with two graduate interdisciplinary programs at the University of Arizona

Sharon Megdal, Director, University of Arizona Water Resources Research Center

This presentation will discuss how the long-standing University of Arizona interdisciplinary Ph.D. program in Arid Lands Resource Sciences (ALRS) provides students with the opportunity to focus on water resources from a variety of perspectives. A master's degree is required of all applicants to the program. It will also describe a newer non-thesis interdisciplinary M.S. program in Water, Society, and Policy (WSP). The MS in WSP is an applied program that provides students with real-world experience through an externally hosted six-unit project or internship. The ability of students to obtain a graduate certificate in water policy will also be addressed. The ALRS Ph.D. program is hosted by the Graduate College. Whereas two colleges officially proposed the MS in WSP, the program is housed by the School of Natural Resources and Environment in the College of Agriculture and Life Sciences. In keeping with the goal of this session, the presentation will explore some of the challenges associated with identifying funding and advisors for student applicants in interdisciplinary programs, where professors are still largely from discipline-based departments and schools. The formal presentation will be somewhat limited in time so that there is time for discussion among the panelists and with the audience.

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### Challenges and opportunities associated with the graduate Water Management and Hydrological Science transdepartmental program at Texas A&M University

Ronald Kaiser, Professor and Program Director, Texas A&M University

This presentation will outline how the Texas A&M University Water Management and Hydrological Science (WMHS) transdepartmental graduate degree program has evolved to deal with challenges and opportunities in a large university setting. The program offers a PhD, MS (thesis) and Mater of Water Management degree (non thesis) and recruits U.S. and international students. Our experience is that faculty commitment and leadership are essential in converting challenges into opportunities. One challenge for WMHS was lack of budget support from colleges and departments. This is not unusual for interdisciplinary programs that compete with department based delivery systems for financial and physical resources, faculty time and competition for students. Senior university administrators are challenged to develop financial allocation systems that minimize departmental perceptions of resource diversion. At Texas A&M University the WMHS program receives an annual budget allocation from the Provost's office allowing funding for a Program Coordinator and graduate research assistantships. This has mitigated departmental perceptions regarding resource diversion. WMHS assistantships are awarded on the basis of a faculty member providing half of the funding. This stipulation has resulted in a doubling of funds and numbers of students supported. The Texas Water Resources Institute has partnered with WMHS in providing shared funding for graduate students. Office and study space for graduate students has been another challenge. Currently the Department of Geography provides office and study space for about half of the 65 WMHS students. Faculty advisors often provide office/study space in their department for WMHS students. In some instances students lose water program identity and become associated with a department. Faculty rewards systems for participating in the WMHS program varies. The University now requires as part of tenure and promotion an evaluation letter documenting faculty participation in WMHS. In spite of these challenges enrollment in WMHS increased in student numbers and subject diversity. Our program has an annual enrollment of about 65 and over the last 12 years has graduated 125 students; 90 percent of whom are employed in the water industry.

## Session 25, Challenges of Interdisciplinary Graduate and Undergraduate Programs in Water Resources

### Choose Your Own Adventure: Crafting an interdisciplinary water resources degree

John Fleck, Director, University of New Mexico Water Resources Program

"Water Resources" is an inherently interdisciplinary field, bringing together the academic fields of geology, hydrology, engineering, biology, ecology, economics, law, political science, public administration, geography, art, and more. Tailoring a truly interdisciplinary education for graduate students taxes the traditional disciplinary structures of the university, but if successful offers significant opportunities for students. The University of New Mexico Water Resources Program is a small interdisciplinary masters degree program that offers a core curriculum of its own, introducing students to basic concepts spanning the disciplines above and introducing them to key faculty members working in those areas. For the rest of the students' academic program, we draw on the university's other disciplines to fill out the students' years with us, culminating in the completion of a professional project as an exit requirement. This allows us to tailor the program to students' specific needs and interests, including a selective emphasis on either hydroscience or policy and management. This approach works well for students who are self-directed and self-motivated with clear ideas of their goals. But it presents a challenge for students who are not. At its best, it also exploits a rich interdisciplinary network of faculty members whose work spans departmental boundaries. But in areas where the network is weakly developed, this also poses a challenge. The talk will discuss the areas in which this approach has proven successful, and the challenges to be overcome.

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### Inventing the future: A new undergraduate degree program in water resources, policy and management at Virginia Tech

Kevin McGuire, Associate Professor, Virginia Tech
(co-author: S. Schoenholtz)

Sustainable management of water resources has been identified as one of the key environmental, economic, engineering, and social challenges for the 21st century. Meeting these challenges requires unprecedented interdisciplinary approaches to education, research, and engagement. A new undergraduate degree offered at Virginia Tech is addressing these challenges through a curriculum with a strong interdisciplinary approach to education. The program was developed based on a team-driven initiative from five colleges and ten departments to leverage existing and emerging strengths on campus. The program provides students with opportunities to both deepen student-selected disciplinary education and receive broad training across various aspects of water science, policy, and management. To expand curricula beyond existing strengths in water resource engineering at Virginia Tech, this program was designed to focus on areas of hydrologic science in natural resources, geosciences, and environmental science in addition to developing equal training in planning, applied economics, and policy. The program even includes a number of engineering elective courses from the existing water resource engineering programs. The degree was originally conceptualized to require no new resources, but instead it helped acquire seven new faculty from a cluster hire in water. This presentation will provide an overview of the Virginia Tech program and experience by addressing challenges and successes in developing an interdisciplinary program in water at the undergraduate level.

## Session 26, Groundwater Management in a Changing Environment

### Alternative groundwater management strategies over the Ogallala Aquifer in southeastern Wyoming

Kristiana Hansen, Associate Professor, University of Wyoming
(co-authors: *D. Peck, K. Willis)
*Presenter - Dannele Peck, Director, Northern Plains Climate Hub, USDA Agricultural Research Service

In 1981, the Wyoming State Engineer issued an Order establishing the Laramie County Control Area (LCCA) in response to declining aquifer levels. In 2015, the State Engineer issued an Order implementing well-spacing requirements and flow meters on all wells in the LCCA by 2017. However, this Order does not slow pressure placed on the aquifer by existing uses. What should be done, if anything, then to relieve pressure on the aquifer from existing demands?

The LCCA's Groundwater Users Steering Committee is searching for effective options to reduce groundwater use. Their discussions have raised questions about potential economic impacts of alternative groundwater management strategies. Our study analyzes these economic impacts, to inform the Committee's on-going planning efforts. The five strategies of interest are:

1. Baseline: irrigators in the LCCA continue to pump at current rates;
2. Prior appropriation: senior rights are honored before junior rights;
3. Allocation: irrigators reduce pumping on all acres to an agreed-upon amount per year;
4. Buyout: a subset of irrigators are paid to retire land from irrigation;
5. Market: water transfers are allowed to mitigate economic impacts of strategies 2 and 3.

Furthermore, due to scientific uncertainty about hydrological connectivity between drawdown hotspots, we analyze each of the above strategies under two different hydrological modeling assumptions: i) no connectivity, or ii) some connectivity.

This presentation will serve as the opening remarks to our special session on Groundwater Management in a Changing Environment by describing a complex real-world situation in which an agricultural community is trying to identify an acceptable means to regulate their groundwater use. This case study will motivate discussion among session presenters and audience members about lessons learned in nearby states about hydro-economic modeling under scientific uncertainty, unexpected pitfalls in groundwater policy design, and economic impacts of alternative groundwater management strategies.

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### Analysis of groundwater (over) extraction induced by farmers' downside risk-aversion

Nicolas Quintana Ashwell, Graduate Research Assistant, Kansas State University
(co-authors: N. Hendricks, J. Peterson)

The representation of farmers' decision making processes is increasingly important in modeling the impacts of groundwater management strategies. Profit maximization is oftentimes assumed to induce farmer behavior. However, there is evidence that farmers make input allocation decisions not only based on maximizing profit (or minimizing cost) but rather seeking to ensure (at an economic cost) a minimum level of income. That is, many farmers operate with the dual goal of maximizing their expected profits and minimizing the probability that observed profits falling below a given level.

In pursue of ever higher expected yields, farmers apply an amount of fertilizer (oftentimes excessive) which increases both the average yields but their variability at harvest time. The increasing variability in precipitation associated with climate change is expected to contribute to the increased volatility in yields. The use of groundwater for irrigation allows farmers to both increase their expected yields as well as reduce the variability of yields. Consequently, there are two important components to groundwater demand; the first derived from the goal to achieve the highest possible yields; and the second derived from the desire to avoid future yields from falling below a given level—which causes uneconomical over-extraction. Understanding the farmers' down-side risk-aversion as it relates to groundwater would provide insights not only on the economic impact of alternative management policies but also into the types of policies that could induce a reduction in levels of uneconomical groundwater over-extraction.

### Comparing actual and predicted groundwater trading: The role of transaction costs and trading restrictions

Karina Schoengold, Associate Professor, University of Nebraska
(co-author: E. Juchems)

Previous research on water trading has focused on surface water trading and theoretical approaches to analyzing groundwater trading. Empirical analysis of groundwater trading is a new area of research due to limited data on recorded usage, infrequent trades, and the lack of binding constraints on groundwater use by landowners. Groundwater trading can help move water from low-value to high-value areas of use for the benefit of the participants and the public. The paper uses data on groundwater trades from southwestern Nebraska to estimate the factors that affect utilization of groundwater trading. Specifically, the paper considers both formal and informal trading of groundwater used for crop irrigation, and attempts to identify those characteristics that predict the probability of trade participation and whether an individual is a buyer or seller of groundwater rights. Results indicate a strong desire to participate in trades, but suggest that the high transaction costs associated with formal trades have limited the use of trades. Results also indicate that the operation size is an important indicator of trade activity, with larger operations more likely to participate in both formal and informal trades. Utilizing empirical models improves the accuracy of predicting trade participation and direction, and therefore the accuracy of predictive models of how policies to allow water transfers affects water supplies and stream flows. Such information is critical for policymakers who are considering introducing or expanding the use of groundwater trading.

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### Redefining borders: Options for more sustainable management of U.S./Mexico transboundary aquifers

Christina Welch, Master's Student, Oregon State University

In dry regions around the world, distinct changes in timing of snowpack melt and variability of precipitation patterns are challenging the availability of freshwater resources. As surface water quality and quantity diminishes, the reliance on groundwater to meet basic human needs will increase exponentially. Despite the known hydrologic connection between surface and groundwater, existing institutions and laws governing surface water and are not equipped to manage groundwater. While there are more than 400 international treaties managing surface water, there are only two treaties worldwide which explicitly address groundwater allocation. In the Paseo del Norte region of the Rio Grande/Bravo basin, the international treaties between the United States and Mexico and the interstate Rio Grande Compact between Colorado, New Mexico and Texas allocate the quantity and timing of surface water deliveries, yet fail to regulate groundwater abstraction. Paseo del Norte has three transboundary aquifers shared by New Mexico, Texas and Mexico thereby representing an ideal microcosm for water management across the four local, state, national, and international scales. The fifth scale is a global assessment conducted using GIS to spatially map transboundary aquifers in relation to transboundary river basins with a treaty. This research seeks to identify which legal, scientific and economic aspects of each scale can best contribute to more sustainable management of transboundary aquifers.

## Session 27, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (new practices, sources, crops)

### The challenges of increased irrigated production in the future

Thomas Marek, Sr. Research Engineer & TAMUS Regents Fellow, Texas A&M AgriLife Research
(co-authors: D. Porter, Q. Xue, J. Bell)

Currently there exists 7 billion people in the world. Reviewing multiple sources of estimation, the number is expected to be 9.7 billion by 2050. This escalation will require the global output of food, fiber and feed to increase by 100%. The majority of the increased output will not be used to feed people directly but rather primarily to supply feed for the animal industries that people rely on. Given the fact that freshwater and natural resources over the last 50 years have been significantly depleted, the question of whether such a production increase can be attained, particularly in the U.S. central Great plains, is a most valid one, both for sustainability and security reasons. Crop production of cereal grains used extensively in the livestock feeding industry in the Texas High Plains heavily depends on irrigation for not only sustainable but high yields. Given that total groundwater resources have been reduced by half or more, what production gains can be realistically realized before global demand surpasses supply? Reviewing past gains in efficiencies through advanced irrigation system technologies and control systems yields insight into what can be expected going forward. Genetic gains will be increasingly needed along with larger adoption and adaption rates. Technology selection with integrated alternate cultural practices will also be required. Applicable research of emerging genetics with advanced management and their interactions are additionally paramount to attain greater potentials. Therefore, management "prescriptions" or "recipes" will be required for advanced irrigated production scenarios. For the future, specific address areas will not only include advanced management techniques with new genetics and alterations, but also integrated systems controls, improved application technologies along with their synergistic effects, plus targeting non-optimal ET based production levels along with agricultural water and economic policy impacts.

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### Aquifer depletion in the Lower Mississippi River Basin: Challenges and solutions

Michele L. Reba, Research Hydrologist, USDA-ARS-Delta Water Management Research Unit
(co-authors: *J. Massey, M.A. Adviento-Borbe, D. Leslie, M. Yaeger, J. Farris)
*Presenter - Joseph Massey, Research Agronomist, USDA-ARS-Delta Water Management Research Unit

The Lower Mississippi River Basin (LMRB) is an important agricultural region. The underlying Mississippi River Valley Alluvial Aquifer (MRVAA) is relied upon for irrigation in the region. The prevalence of irrigation and geology of the region have led to reduced recharge and significant aquifer decline. Response to the decline has been multi-faceted with conservation practices at the forefront. Research on these practices will be highlighted from three distinct studies: innovation in rice irrigation, on-farm reservoirs, and managed aquifer recharge. Arkansas accounts for nearly 50% of US rice production which is distributed over 1 million ha. Irrigation water use in rice production is high relative to other crops and strategies for using less water while maintaining grain yields are being developed. Data collected from approximately 20 production-sized rice fields will be presented to identify opportunities in rice irrigation innovation. The use of on-farm tailwater recovery (TWR) reservoirs to store abundant surface water during the non-irrigation season for storage and subsequent irrigation use is common in the LMRB. An inventory of this practice in Arkansas revealed there are over 700 systems currently. Concern and interest in water quality within these systems has grown both locally and regionally. This study investigated and characterized water chemistry dynamics associated with surface water movements in a TWR system associated with intensive row crop agricultural production. The MRVAA is overlain in many locations by a confining clay layer of varying thickness, which represents one of the limitations in effectively recharging the aquifer with surface water. Locations where the confining layer is thin or non-existent, provide an opportunity for managed aquifer recharge. An excavation pit from a highway project provided an opportunity to measure infiltration rates of the uppermost section of the alluvial aquifer as part of a managed aquifer recharge study. Results from these three studies will be used to demonstrate how conservation, off-season rainfall capture and storage, and managed recharge are being investigated as means to reduce the on-going decline of the alluvial aquifer that is both economically and ecologically important to the LMRB.

## Session 27, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (new practices, sources, crops)

### Local aquifer alternatives: The case of the Dockum Aquifer in the Texas Panhandle

Nathan Howell, Assistant Professor of Environmental Engineering, West Texas A&M University
(co-author: R. DeOtte)

Within the High Plains, it is generally well known that the Southern High Plains has suffered from over pumping of the Ogallala Aquifer since large-scale agriculture began making use of the water to supplement rainfall in the 1950s. One option to address the challenge of a diminishing aquifer is to find new water sources. In the semi-arid Southern High Plains, surface water sources are often limited, and so an alternative aquifer is an attractive means to continue providing water for agriculture and other local needs. The last ten years has seen an increase in drilling large capacity, much deeper wells in the Dockum Aquifer in the Texas Panhandle. This aquifer is generally separated from the Ogallala Aquifer by low hydraulic conductivity geologic layers and is thus generally considered to be an independent source of water, which can be used as long as it is properly understood. Our study sought to examine the appropriateness of the aquifer as a supplement or even replacement of Ogallala groundwater irrigation, animal feeding, and municipal uses by comparing basic water quality mineral profiles between Ogallala and Dockum aquifer wells in regions where both are a viable option. To enhance the usefulness of the comparison, information concerning what is known about well yields and available water in the subsurface was also obtained. In general, we found that water quality is equivalent to Ogallala in some places but in others it is saltier exhibiting higher total dissolved solids (TDS) concentrations. Thus, we examine how one might make the best use of Dockum water in the Ogallala region as economic activity transitions away from larger-scale irrigation practices and into less water-intensive practices. One of the greatest challenges of the use of Dockum Aquifer (which may have bearing on other smaller aquifers in the Southern High Plains) is that water quality is variable spatially and with depth, water yields are often insufficient, and the expense of drilling and operating deeper wells is often not justifiable. We suggest ways that some of these uncertainties in decision-making may also be overcome.

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### Water use for beef production on pastures in West Texas

Chuck West, Professor of Plant & Soil Science, Texas Tech University
(co-authors: L.L. Baxter, C.P. Brown, P.E. Green)

The imminent depletion of the Ogallala Aquifer demands innovative alternatives to minimize losses of income when water is insufficient for irrigated row-crops in the Southern High Plains (SHP). Previous research has demonstrated the value of integrating pasture-based livestock production into cropping systems in the SHP. 'WW-B.Dahl' old world bluestem (*Bothriochloa bladhii*) (OWB) is a drought-adapted, grazing-tolerant grass whose nutritional quality declines over summer. Use of alfalfa (*Medicago sativa*) can eliminate nitrogen (N) fertilizer requirements through biological N fixation; however, it is known as a heavy water user. The objectives were 1) to determine the impact of including a legume (alfalfa, no N fertilizer added) into OWB (grass-legume, no N fertilize added) vs. OWB grass-only (receiving 67 kg/ha-yr of N fertilizer) on cattle productivity and water footprint of beef liveweight gain, and 2) to contribute field results to future life cycle analyses of beef production to address a gap in life-cycle knowledge. Average daily weight gain (means of 3 yr and 3 replicates) was 0.92 kg/animal-day for grass-legume and 0.77 kg/animal-day for grass-only. Total liveweight gain was 188 kg/ha for grass-legume and 118 kg/ha for grass-only. The greater beef productivity of grass-legume is attributable partly to the enhanced nutritional quality of the mixture compared to the grass-only system. The volume of water used (irrigation + effective growing-season rain + drinking water) per unit mass of liveweight gain (water footprint, or reciprocal of water use efficiency) was 25.4 m3/kg for grass-legume and 28.2 m3/kg for grass-only. The addition of alfalfa into the grazing system reduced the water footprint of producing a kg of beef weight gain by 10%. Superior nutritional quality of alfalfa compared to the OWB grass led to more rapid weight gain by cattle, which in turn led to a smaller water footprint for liveweight gain. Results demonstrate that alfalfa, at very low irrigation input, has a positive role in increasing the efficiency of water use when used in mixture with grasses despite its reputation as a water-wasting plant. The benefits of not having to apply N fertilizer would contribute further to a reduced water footprint and carbon footprint.

## Session 28, Are Voluntary Conservation Programs Effective?

### Targeted voluntary conservation using Farm Bill programs

Martin Lowenfish, Landscape Initiatives Team Leader, USDA-Natural Resources Conservation Service

Targeted delivery of voluntary assistance supported by the Farm Bill and other authorities has led to meaningful progress on wildlife habitat and water quality goals. The Natural Resources Conservation Service provides producers with technical and financial assistance to develop options and implement conservation systems that support the attainment of local, regional, and national conservation goals, while fitting within productive agricultural systems. In the last six years, the NRCS has worked with partners to identify areas of joint priority and achieved demonstrable results through the Working Lands for Wildlife model and Landscape Conservation Initiatives targeted to address water quality. Success using the voluntary approach is dependent on delivering accelerated technical and financial assistance to address specific needs identified through collaborative and partnership approaches. Identifying and targeting critical acres at the landscape scale helps ensure that the most vulnerable or important acres receive treatment. The targeted approach provides the following benefits:

- Prioritizes conservation in high priority areas
- Allows increased NRCS funding to address habitat/water quality concerns
- Attracts attention and outside funding
- Increases collaboration with non-traditional partners
- Supports strategic plans for habitat/water quality improvement

The Working Lands for Wildlife model was built on six key ingredients: trust and credibility, shared vision, strategic approach, accountability, leverage, regulatory predictability. NRCS has applied the Working Lands for Wildlife model to species across the United States, and regulators reached a determination either not to list or to de-list seven species under the Endangered Species Act. A few examples of successful WLFW projects are:

- Fluvial Arctic Grayling
- New England Cottontail
- Greater Sage Grouse
- Louisiana Black Bear

Some examples of watershed projects that demonstrate successful voluntary approaches to achieve water quality improvement include:

- Indian Creek watershed, IL
- Big Creek/East Fork Big Creek watershed, LA
- Walker Creek watershed, CA
- St. Francis River, AR

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### Nonpoint source contamination in Oklahoma watersheds

Shanon Phillips, Water Quality Division Director, Oklahoma Conservation Commission

According to the EPA, more than 55% of rivers and 70% of monitored lakes in the U.S. do not meet state water quality standards for one or more parameter and of these impaired waters, more than 80% are impaired by nonpoint source pollution. This significant need to address pollution problems is driving partners to find workable solutions and many fear greater regulation of industries is the only possible solution. However, in Oklahoma, partners have come together to develop a process that documents meaningful, measurable success in water quality restoration through voluntary conservation programs. Through a partnership among landowners, conservation districts, the United States Department of Agriculture (USDA) Natural Resources Conservation Service, the Oklahoma Conservation Commission, and the Environmental Protection Agency, we've been able to showcase 55 and counting watersheds across the state where voluntary conservation programs supported by USDA have resulted in water quality improvement sufficient for full or partial removal from the State of Oklahoma's EPA 303(d) list of impaired waters. These 55 streams lie in 10 of Oklahoma's twelve diverse level III Omernik Ecoregions. These streams were impaired by diverse causes including low dissolved oxygen, excessive turbidity, fecal bacteria, poor biological communities, unknown toxics, oil and grease, pH, and excessive salts. In other words, these voluntary programs haven't only been able to solve one type of problem in one type of stream. However, there are many similarities in the approaches followed toward these successes that can be followed in watersheds across the nation.

## Session 28, Are Voluntary Conservation Programs Effective?

### Cost-effective conservation programs for protecting water quality: What are the challenges?

Marc Ribaudo, Chief, Conservation and Environment Branch, Economic Research Service - USDA
(co-author: R. Claassen)

Balancing agricultural production and environmental quality is an ongoing issue in U.S. agricultural policy. Agricultural production can affect environmental quality through loss of sediment and nutrients to water, changes in wildlife habitat, and the emission of greenhouse gasses and other air pollutants. Conservation tillage, cover crops, nutrient management, and integrated pest management are a few of the many practices that are encouraged with financial and technical assistance from USDA conservation programs. Cost-effective conservation programs support the adoption of conservation practices that yield relatively large environmental gains relative to adoption cost. Designing cost-effective programs that rely on voluntary participation, however, can be challenging. Agricultural land, climate, and production practices vary widely leading to large differences in environmental impact and conservation needs. A large body of literature shows that much of the sediment and nutrient runoff from crop production can be traced to a relative small portion of U.S. cropland. These lands may be producing a disproportionate share of nutrient and sediment loss because they are particularly vulnerable to loss (due to topography, soil types, or proximity to water) or are managed in a way that leaves the land vulnerable to soil erosion and nutrient runoff. While research has shown, for example, that benefit-cost targeting can dramatically improve the cost-effectiveness of conservation programs, identifying these lands and producers and encouraging or requiring them to adoption environmentally effective practices can be difficult. Part of the challenge is that conservation decisions are influenced by a more complex array of attitudes and factors than costs and returns. Understanding these factors is therefore critical to designing effective policies.

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### Litigation over phosphorus pollution of the Scenic Illinois River Watershed in northeastern Oklahoma

Robert Taylor, Professor Emeritus, Auburn University

After years of trying to work with poultry integrators over phosphorus pollution resulting from poultry waste in the Scenic Illinois River Watershed (IRW), the Oklahoma Attorney General and the Oklahoma Secretary of the Environment filed suit in Federal Court in 2005. Litigation was initiated by Oklahoma in Federal Court because about two-thirds of the phosphorus in IRW was generated upstream in Arkansas where the Oklahoma Legislature has no authority. Litigation was filed against the poultry companies, known as integrators, and not against contract poultry growers, because the integrators own the bird and feed (containing phosphorus) and make all decisions about where growers are located. The integrators thus determine where poultry waste is generated, which largely determines where it will be land applied. Except when commercial fertilizer prices are very high, it is not profitable to transport litter more than about five miles from where it is generated.

Poultry litter contains all three major plant nutrients, N, P, and K, which may be valuable as fertilizer in the right place at the right time, but may also be pollutants. The State alleged that the integrators had polluted the IRW and caused algal blooms and other associated problems. The integrators claimed that there was no problem, but if there was a problem, they were not responsible.

A four-month long bench trial (the Judge is the Jury) ended in February 2010. Now, after almost seven years, the Judge has yet to issue a verdict. Through various voluntary programs as well as federal and state subsidies, 75-85% of the litter generated in the IRW is now being trucked out, with a marked reduction in phosphorus in the water. Although a verdict has not been issued, the high profile litigation appeared to provide the impetus for “voluntary” removal of the litter from the IRW.

### One water financial model: From service provision to resource allocation

Neil Grigg, Professor, Colorado State University
(co-authors: A. Maas, T. Connor)

The concept of One Water in an urban setting is applied at two levels: a basic level with integrated management of water services and an expanded level with integration with other sectors. The basic level is utility-based and financed from rate and tax policies and schemes. The expanded concept involves systems interdependence, may involve stakeholder value conflicts and cannot be financed by fees based on cost-of-service. The presentation will explain these levels, outline the financial model for separate services and the expanded level, and offer analysis about a path forward to One Water. The analysis will identify innovative examples of One Water management and how they are financed in case cities. The economic soundness of these approaches will be probed to identify the possibilities for enhancements in public support in different types of cities. Based on the findings, financial strategy and governance approaches to promote One Water will be discussed.

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### Residential water and electricity: Substitutes or complements?

Alexander Maas, Research Scientist, Colorado State University
(co-authors: M. Arabi, D. Manning, C. Goemans)

Millions of households in the southwestern United States receive their water and electricity from public or private utilities, yet surprisingly little research exists examining the relatedness of these goods at the household level. Given household budgets and the numerous ways in which water can be used as a complement or substitute to electricity, it is difficult to predict the relatedness of these goods ex ante. We use utility data collected at the household level to estimate price and cross-price elasticities. Our results suggest significant cross-price effects exist, but vary by season. The results of this work suggest that there may be substantial gains from designing residential energy and water prices and policies in tandem. Although we find that these goods are significantly related, we believe more research is necessary to determine the underlying causes and nuances of this demand relationship.

## Session 29, Understanding the Transition towards Sustainable Urban Water Systems

### A collaborative evaluation of centralized and decentralized strategies for dual water supply

Jeanne Cole, Ph.D. Candidate, Colorado State University
(co-authors: S. Sharvelle, D. Fourness, N. Grigg, L. Roesner, J. Haukaas)

More water managers are considering dual water supply and distributed water systems as they strive for more sustainable urban water management solutions. These systems can enable more efficient use of water and energy resources, alignment of water quality to the intended use, supply diversification with use of non-traditional local water sources, and more flexible and resilient systems. In a forward-looking study, four alternative strategies for the dual supply of raw water for non-potable municipal uses and treated water for potable uses were evaluated for the City of Fort Collins, Colorado. The alternatives considered in the study included centralized and decentralized water treatment approaches, varying dual distribution system scales, and integration of existing irrigation ditches with neighborhood raw water landscape irrigation systems. The methodology applied Multiple Criteria Decision Analysis (MCDA) to conduct a Triple Bottom Line (TBL) analysis to comprehensively evaluate financial, social, and environmental impacts of the alternatives versus maintaining the conventional water supply system. The methodology allowed for inclusion of incommensurable performance indicators and stakeholder preferences in the decision analysis. More importantly, it facilitated a collaborative and iterative process involving multiple city departments, technical experts, and stakeholders. The results suggest dual water supply system alternatives provide many social and environmental benefits over a conventional water supply system that may justify initial capital costs; and the optimum strategies are dependent on local conditions and community priorities.

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### Framework and parameterization of a decision support tool for stormwater infrastructure

Colin Bell, Post Doctoral Research Fellow, Colorado School of Mines
(co-authors: K. Spahr, J. McCray, T. Hogue)

Green infrastructure has demonstrated its potential to supplement traditional, grey infrastructure managing urban stormwater runoff and pollution. However, the performance and cost of green infrastructure techniques over their entire lifecycle are still relatively uncertain. This makes deciding between implementation of grey, green, or hybrid approaches challenging. A decision support tool is needed that integrates the hydrologic and water quality benefits of green and grey infrastructure with a comprehensive life-cycle cost assessment that includes direct economic costs as well as co-benefits to society. This work summarizes the framework of such a planning-level, integrated decision support tool, called i-DST. Once developed, i-DST will contain modules that simulate continuous runoff and water quality, both using history climate data and under climate change scenarios. It will also use a multiple-criteria decision analysis to optimize stormwater infrastructure based on user-defined economic, environmental and societal objectives. Additionally, this work details a database of regional green infrastructure cost and performance parameters that allow for application of the tool across the different climatic regions of the United States.

## Session 30, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects I

### Nutrient and sediment export from a corn/soybean rotation planted with winter cover crops: A paired watershed study

Gurbir Singh, Graduate Student, Southern Illinois University Carbondale
(co-authors: K.W.J. Williard, J.E. Schoonover, J.F. Crim)

In the midwestern United States, cover crops are being promoted as a best management practice for managing nutrient and sediment losses from agricultural fields through surface and subsurface water movement. To date, the water quality benefits of cover crops have been inferred from plot scale studies. This project is one of the first to analyze the impacts of cover crops on stream water quality at the watershed scale. The objective of this research was to evaluate nitrogen, phosphorus, and sediment loss in stream water from a no-till corn/soybean rotation planted with winter cover crops (Cereal rye, *Secale cereale*, and hairy vetch *Vicia villosa*) on paired-watershed site located at Southern Illinois University, Carbondale, IL. The paired-watersheds are under mixed land use. Watershed #1, the treatment watershed (cover crops), had a total area of 46.5 ha comprised of 66.4% crop land, 30.3% forested cover and 3.3% impervious surface. Watershed #2, the control watershed, had a total area of 29.8 ha comprised of 91% crop land, 6.6% forested cover, and 2.4% impervious surface. During a 3-year calibration period, 42 storm events were collected and Event Mean Concentrations (EMC) for each storm event were calculated for total suspended solids (TSS), ammonia-N ($NH_4$-N), nitrate-N ($NO_3$-N), dissolve reactive phosphorus (DRP) and total discharge. Predictive regression equations developed from the calibration period were used for calculating TSS, $NH_4$-N, $NO_3$-N and DRP losses of surface runoff for cover crop watershed #1. The treatment period consisted of total 11 storm events, 8 of which were collected during the cereal rye cover crop season. Cover crops reduced TSS and DRP by 38.8% and 0.4% in watershed #1 during the treatment period. However, surprisingly, EMC's for $NO_3$-N, and $NH_4$-N increased by 50.4% and 0.27%, respectively. Discharge from the cover crop watershed also slightly increased by 1.6%. Stream discharge from the paired-watersheds will continue to be monitored to determine if the current water quality results hold or new patterns emerge. The treatment watershed is currently planted to hairy vetch (a legume), which may have a significant impact on nitrate export.

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### Monitoring agricultural sub-watersheds containing conservation practices in the Black Hawk Lake Watershed, Iowa

Leigh Ann Long, Research Associate II, Iowa State University
(co-authors: C. Brendel, M. Soupir, C. Ikenberry, M. Helmers, A. Kaleita)

Black Hawk Lake in Iowa is drained by a 13,156 acre watershed, dominated by corn-soybean production (74.6%). The lake is a major recreation area for, and is economically important to, the surrounding area; outside visitors spend 16-19 million dollars annually. However, the lake is impaired for poor water clarity due to high levels of algal and non-algal turbidity. An active watershed improvement program since 2011 has implemented best management practices (BMPs) to reduce the amount of sediment and nutrients reaching the lake. Uneven distribution of implemented BMPs within the watershed has allowed for paired comparisons of first-order streams and subsurface tile outlets in three sub-watersheds (221-822 ha). In 2015 and 2016, monitoring of water quantity and quality has occurred during base flow and storm events from March-November each year with funding support from the EPA National Water Quality Initiative. Composite samples from surface water and tile outlets have been analyzed for total and volatile suspended solids (TSS and VSS), ammonia ($NH_3$-N), nitrate-nitrite ($NO_3$-N), total nitrogen (TN), dissolved reactive phosphorus (DRP), and total phosphorus (TP). During 2015, a 24% reduction in nitrate load, a 44% reduction in total phosphorus load, and a 96% reduction in suspended solids load were observed from the sub-watershed with >90% of its area covered by BMPs as compared with the sub-watershed with approximately 25% of its area covered by BMPs. The majority of phosphorus (63.1%), TSS (72.2%), and VSS (74.0%) loads occurred during storm event flow while nitrogen loads occurred primarily during base flow (66.6%). This project provides rare insight into the impact of conservation practices on temporal nutrient distribution between surface and tile drain flow at the small watershed scale. The data collected to date demonstrate the positive impact that high levels of conservation practice implementation can have on surface and tile water quality.

## Session 30, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects I

### People-Land-Water: Testing agricultural BMPs at the farm and watershed scales

Thomas Fisher, Professor, Horn Point Laboratory, University of Maryland Center for Environmental Science
(co-authors: R. Fox, A. Gustafson, K. Kvalnes, M. Lepori-Bui, J. Lewis, K. Fisher)

Best Management Practices (BMPs) are widely installed on US farms to reduce losses of N, P, and eroded soil. However, few BMPs have been tested for effectiveness at the watershed scale, and there is little monitoring of installed BMPs to examine spatial differences in efficiency or to inform farmers concerning effectiveness of their BMPs. Furthermore, there is little evidence that agricultural BMP applications at national, regional, or local scales have resulted in measureable improvements in water quality, generating skepticism in both the farming and scientific communities. To address the lack of BMP testing, we are working in four 6-12 $km^2$ watersheds dominated by agriculture (60-80%) in the Choptank Basin of the Mid-Atlantic region. Three watersheds are experimental, and one is a control. Within the experimental watersheds, farmers are encouraged and funded to install new BMPs, while control farmers receive neither guidance nor funding. Approximately 2/3 of the 40 farmers within our four watersheds are cooperating by installing new BMPs, allowing sampling on their properties, and/or taking surveys evaluating their attitudes towards BMPs, management and economics of farming, and water quality. The effectiveness of BMPs is tested directly on three spatial scales: (1) in ditches and groundwater on farms, (2) in small streams draining several farms, and (3) at watershed outlets. We have evidence of improved water quality through direct management of groundwater levels from drainage control structures and from bioreactors; both practices reduce agricultural nitrate in tile lines and ditches. In the control watershed, N increased at the outlet, but we observed significant decreases in N, particularly nitrate, at two of the experimental watersheds. The third experimental watershed has the lowest farmer cooperation rate, the highest N concentrations, and steady increases in baseflow N over the last 13 years. We will continue monitoring these trends through 2018.

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### Comparing the effectiveness of increased winter land cover on nutrient export across two Indiana agricultural watersheds

Matt Trentman, Ph.D. Student, University of Notre Dame
(co-authors: J. Tank, S. Christopher, B. Hanrahan, U. Mahl, K. Prior, S. Speir)

Watershed-scale studies are valuable for testing the efficacy of agricultural conservation in working lands, where excess nutrients from fertilizer runoff can degrade water quality. Watershed comparisons are often logistically challenging, but can be powerful for comparing conservation practices in areas with similar land use (i.e., row crops) but with contrasting site characteristics (e.g., soils, regional climate). We are quantifying how watershed-scale conservation alters nutrient runoff to adjacent freshwaters in an agricultural landscape. Since 2013, we have monitored the Shatto Ditch Watershed (SDW), with three years of continuous watershed-scale cover crops (~70% of croppable acres). In spring 2015, we added the Kirkpatrick Ditch Watershed (KDW) to our study, with the goal of incrementally increasing cover crops to the same level of "saturation" as SDW, starting with 20% in the first year. In each watershed, we collect water samples every 14 days from representative tile drains (n=12-25) and longitudinally-distributed stream sites (n=6-10) to quantify the effect of cover crops on nitrate-N and dissolved reactive phosphorus (DRP) in tile drains and at the watershed outlet. In SDW, over three years, cover crops reduced spring nitrate-N flux from tile drains by ~40%, when cover crops are actively growing. Similarly, after only one year of cover crops in KDW, there was ~50% reduction in spring nitrate-N flux with cover crops. In contrast, DRP concentrations and flux from tile drains were generally unchanged but spatially variable after cover crops in both watersheds, highlighting the importance of field-specific management practices. We have also added real-time monitoring in both watersheds, including discharge, water quality parameters, precipitation, and nitrate-N concentrations. Future work will contrast the use of conventional grab samples with real-time data to evaluate the effects of cover crops, both in SDW where cover crops are saturated, and in KDW where cover crop acreage is incrementally increasing.

## Session 31, Water Resources Education: Roles of Commercial Projects and Field Stations

### Getting out of the laboratory – Our experience and lessons learned from the National Science Foundation Innovation Corps Program

Allen Berthold, Research Scientist, Texas A&M University
Kelly Brumbelow, Associate Professor and Assistant Department Head for Undergraduate Programs, Texas A&M University

Now that research at the university is nearing completion and a product has been developed, what can be done with it besides publish a paper? Are there any other opportunities available to see if we could commercialize our technology? What would our business model look like? These were the questions we faced as a project was nearing completion. The project focused on developing software to provide homeowners with their own water data and observe if behavior changed and water consumption was reduced. Beta testing indicated that we saved an average of 8.7% in winter months and 17% in summer months, proving to be successful. We knew the potential to commercialize the technology was there but the path forward was unclear. Our experience in the National Science Foundation Innovation Corps (NSF I-Corps) program proved to be invaluable in helping us find direction. The NSF I-Corps program focused on getting our team of a Principal Investigator, an Entrepreneurial Lead, and an Industry Mentor out of the building to conduct customer discovery interviews to identify true “pain points” of potential customers and validate or invalidate our hypotheses. Startups do not have a business model but are in search of it and only through the customer discovery process can you truly identify whether there is a need for the invention and whether your hypothesized business model is on point. Through the NSF I-Corps program, over one hundred customer discovery interviews were conducted and our experience and lessons learned about the true needs of water utilities will be shared.

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### Commercial projects at university hydraulics laboratories: Research relevance, student training, or unfair competition?

Robert Ettema, Professor, Colorado State University

This paper discusses the merits of university laboratories engaging in commercial projects. The discussion considers historical imperative and precedent, current circumstances, and intrinsic merit. The latter two considerations are especially important for helping to keep contemporary, university hydraulics laboratories vibrant. The exclusion of commercial projects from university hydraulics laboratories can lead to slow demise of such laboratories. To be sure, there is the potential risk for conflict of interest and preoccupation with commercial projects. Moreover, the issue of unfair competition is sometimes raised by fully commercial laboratories. However, the paper concludes that university engagement in commercial projects should be pursued in a manner that such engagement is synergistic with universities primary missions in education (student training and dissemination of research findings), basic research and appropriate service. Such engagement should not occur at the expense of those missions. The paper draws on the writer’s experience as a faculty member affiliated with two major, university hydraulics laboratories.

## Session 31, Water Resources Education: Roles of Commercial Projects and Field Stations

### Field stations as ambassadors and agents for bridging silos: Engagement in watershed protection, research and natural resource literacy in a land of private property

Tom Arsuffi, Director, Texas Tech University Llano River Field Station
(co-authors: T. Broad, K. Wagner)

Given the gap between scientists and the public: “Scientists must find new ways to engage the public” - President Obama. A “sense of place” in nature is fundamental to understanding and an informed citizenry. Field Stations are such places: a 2014 National Academy of Science report concluded that the place-based knowledge that field stations provide makes better informed resource managers, decision-makers, and citizens. Consider Texas, where the 90% urban/95% private property disconnect provides “field stations” the opportunity to increase science-based environmental literacy-rural/urban connections. Texas Tech University Llano River Field Station in the Texas Hill Country enjoys a strategic geographic position to conduct water/watershed, invasive species impacts, agricultural, ecological and education in a critical region encompassing an area larger than 10 states. An important feature is the Edwards Plateau, characterized by a large number of springs and forming the headwaters of 7 major river systems. LRFS provides a comprehensive spectrum of collaborations focused on finding solutions to regional problems related to watershed and range science, freshwater systems and natural resource education, with national and international implications. We engage/partner with state & federal agencies (14), school districts (65), professional scientific/educational organizations (8), funding agencies, NGOs, municipalities, landowners, and other universities who share expertise, planning and resources. New and ongoing projects are: 1) Watershed Planning through stakeholder coordination with EPA’s Healthy Watersheds framework, 2) partnerships with the National Park Service, 3) a role with the USGS South Central Climate Science Center, 4) range, riparian and watershed demonstration projects, 5) human diversity initiatives with the Ecological Society of America and community colleges, 6) evaluating ecosystem services, and 7) environmental literacy through LRFS’s Outdoor School, internationally recognized as a Texas Exemplar linking innovative curriculum with nature/outdoors. Field Stations, such as LRFS, provides a paradigm for boundary spanning by fostering horizontal integration across bureaucratic silos.

## Session 32, Coupling Surface and Near Surface Hydrologic Processes in Mountain Front Hydrology: Applications of Hydrogeophysics

### Water partitioning and storage via preferential pathways at the hillslope scale observed using time-lapse ERT

Maneh Kotikian, Graduate Student, University of Wyoming
(co-authors: A. Parsekian, G. Paige, A. Carey)

Hillslope hydrological processes, primarily soil moisture patterns and water storage, are not well understood in mountain systems. We investigate these processes in the Laramie Range in WY, where water is mainly sourced from snowmelt and feeds tributaries that source large rivers in the United States and recharge groundwater aquifers for cities. Time-lapse geophysical methods in addition to necessary hydrological measurements are used to observe changes in daily, seasonal, and annual soil moisture patterns and preferential flow pathways. We hypothesize that (1) water is directed into downward preferential flow paths due to soil texture characteristic in colluvium deposits, (2) vertical flow requires supply of water from ponding in areas with microtopographic differences, and (3) snowpack distribution is the driver of vertical preferential flow acting as a larger source of water. Changes in soil moisture are estimated with daily time-lapse electrical resistivity tomography (TL-ERT) measurements in a 2-D profile on the hillslope. The only variable to change during the resistivity measurement is water content of the subsurface resulting in a profile of estimated soil moisture values, after temperature corrections. 3D ERT measurements are made to account for out of plane effects of the 2D measurement and borehole nuclear magnetic resonance (NMR) measurements are taken to directly measure water content throughout the year. Ancillary measurements include precipitation gages, snow water equivalence (SWE) measurements, and soil texture analysis. The results show a vertical preferential flow path that begins during the snowmelt season and moves water at least 3m deeper in that location than anywhere else on the profile. Otherwise, the wetting front is relatively homogeneous in the different regions of the hillslope. During the rainfall season, there is no preferential flow path or deep wetting front. These results indicate that vertical preferential flow requires certain conditions and moisture patterns differ seasonally with precipitation type.

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### Shifts in seasonal snowpack dynamics and the effect of water transport schemes in modeling spring melt-out

Mark Pleasants, Graduate Assistant, University of Wyoming
(co-author: T. Kelleners)

Throughout much of the western United States, the snow melt period represents the largest and most important hydrologic event of the water year. The magnitude and timing of snowmelt water fluxes to the soil surface are important controls for the hydrological response of hillslopes. Point measurements of snow wetness and density are combined with continuous datasets of snow temperature, depth, and melt flux to identify seasonal shifts in the dynamics of a sub-alpine snowpack in the Snowy Range of southeastern Wyoming. Snowpack measurements are supplemented with a 1-dimensional model of snowpack dynamics using SNOWPACK. In snowpack modeling, one of the most common assumptions is that water flow within the snowpack is driven entirely by gravity, and the effect of capillarity is usually ignored. However, recent studies have begun to take snowpack capillarity into account and show that snowmelt runoff predictions can be improved by implementing a modified version of Richard's Equation to govern water flow through the snowpack. This study focuses on, in part, the importance of snow capillarity on the prediction of both snowmelt runoff and snowpack dynamics. Measurements of snowpack liquid water content, density, temperature, depth, and meltwater discharge for the 2015-2016 winter are used to verify the model. Predictions of melt water discharge with and without Richards Equation are compared to measured snow lysimeter discharge to better understand the effect of capillarity on snowmelt runoff predictions.

## Session 32, Coupling Surface and Near Surface Hydrologic Processes in Mountain Front Hydrology: Applications of Hydrogeophysics

### Identification of surface and subsurface flow paths affecting return flow: Merging hydrology and geophysics

Niels Claes, Research Associate, University of Wyoming
(co-authors: G. Paige, A. Parsekian)

Irrigated agriculture accounts for 80 to 90 percent of water use in the western US. Increasing demands on water resources and changes in water availability and timing due to drought and climate change point to the need for sustainable management of these resources. Return flow, the amount of water that returns back to the streams, after being applied on irrigated fields, is estimated to be 50%. However, the amount and timing of return flow can vary dramatically with location, soils and management and is rarely quantified in these dynamic systems. While overland flow may occur relatively quickly, subsurface return flow may indeed be subject to delays and storage processes. Conventional techniques, such as breakthrough curves, staining techniques and soil structure models have been used in other studies to assess infiltration rates and predict preferential flow paths. These methods, however, lack the spatial and temporal resolution necessary to address the dynamic hydrologic processes involved in infiltration and return flow. We address this question in a field study that combines the use of geophysical methods - time-lapse electrical resistivity (ERT), borehole NMR and induced polarization – with traditional hydrologic methods, in situ soil moisture measurements and lab analysis. Application of borehole NMR, which is directly sensitive to water content, in combination with the temporal and spatially dense time-lapse ERT measurements, gives us the ability to directly quantify the dynamic redistribution processes of soil moisture during flooding and drying cycles that take place in a flood irrigation scheme. Extraction of hydrologic parameters from these detailed geophysical observations in combination with classical soil moisture measurements and textural analysis, improves the level of detail with which we are capable of addressing questions related to future irrigation planning. The result of this hydro-geophysical investigation facilitates a more sustainable management of these increasingly stressed water resources.

## Session 33, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Irrigation systems)

### Corn management in the Texas High Plains

Qingwu Xue, Associate Professor, Texas A&M AgriLife Research
(co-authors: T. Marek, W. Xu, J. Bell)

Corn production in the Texas Panhandle accounts for 58% of total state production with an annual economic value of $1.4 billion. Corn is also a major irrigated crop in this region and irrigation used about 53% of total agricultural water budget from Ogallala Aquifer. Currently, the declining water table along irrigation pumping restrictions by water districts is challenging the sustainable corn production. The objective of this article is to evaluate corn management practices in the Texas High Plains. Four major management practices are focused in this paper, including irrigation, hybrids selection, seeding rate and planting date. Among these practices, irrigation management remains the most important issue because of the nature of irrigated agriculture. Based on our multiple-year studies in Etter, TX, using irrigation amounts to meet 75-80% of evapotranspiration (ET) demand can result in the same yield as compared to meet 100% ET demand in years with an average or above average seasonal rainfall. Also, water use efficiency is generally maximized at this irrigation level. Hybrid selection is another important factor for corn producers. The newly developed drought tolerant corn hybrids provided significant yield benefits (10-15%) under lower irrigation levels. We have evaluated interactions of seeding rates and hybrids at multiple irrigation levels. The seeding rate ranged from 26,000 to 56,000 seed per acre and planting date ranged from the middle of May to early July. At full irrigation level in some hybrids, corn yield increased as population increased initially, but yield did not increase further at population higher than 38,000 or 44,000 seeds per acre, depending on hybrids. Corn planting date in the Panhandle ranged from late April to late June. We conducted field trials in 3 years and evaluated planting date and hybrid interaction for corn yield and water use. The planting dates we used were May 15, June 1, June 15, and July 1. The results from this study indicated that high yield can still be achieved with a longer-season hybrid (e.g., >111 d) when planted in the middle of May and early June. When planting date was delayed to late June and early July, mid- and short- season hybrids showed the yield advantage over the long season one.

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### Effects of irrigation technology and management on WUE and crop yield: A meta-analysis

Donna Mitchell McCallister, Research Assistant Professor, Texas Tech University
(co-authors: C. West, A. Cano, D. Rudnick)

As water resources from the Ogallala aquifer begin to decline, producers are faced with the challenge of maximizing crop yield using sustainable irrigation practices. Irrigation technologies have developed over time and have become more efficient by minimizing water loss due to evaporation, runoff, and deep percolation. Producers can now utilize strategic irrigation management methods using soil moisture monitoring and irrigation scheduling to ensure the right amount of irrigation water is applied at the right time to achieve maximum profitability while still conserving water. Studies across the Ogallala Aquifer region have analyzed the impact of irrigation type, timing, and rates on the crop yield response to water and water use efficiency; however, results of this studies have not been fully synthesized. The objective of this study is to integrate existing research from replicated trials and experiments from peer-reviewed journal articles as well as extension publications using a Meta-Analysis approach. A meta-analysis is a quantitative procedure used to combine results from various studies. This study will use journal articles and extension experiments to perform a meta-analysis across the Ogallala Aquifer region. This analysis will include data from USDA climate hub sites and the Ogallala Aquifer Program. Through this analysis, we will quantify the effect of irrigation technology and management systems on water use efficiencies and agronomic yields. Technologies pertaining to this analysis include Low Energy Precision Application (LEPA), Low Elevation Spray Application (LESA), Sub-surface Dip Irrigation (SDI), Precision Mobile Drip Irrigation (PMDI) and Variable Rate Irrigation (VRI). Examples of management activities that will be analyzed include planting dates, seeding rates, soil types, irrigation amounts, fertilizer application, and crop varieties. To collect relevant articles, a search was performed using the Web of Science and Google Scholar. A search of keywords (water use efficiency, Ogallala, High Plains Aquifer, yield, and deficit irrigation) produced 185 results. A restriction on studies published from 1990 to present resulted in 160 studies. Treatment and replication data will be recorded for each study. The results of this analysis will be to determine the most promising irrigation and management systems. The meta-regression will determine relationships between crop yield and water use efficiency on irrigation type and rates, weather, rainfall patterns, soil characteristics, and cropping patterns.

## Session 33, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Irrigation systems)

### SDI increases water use efficiency of grain crops in Southern High Plains

Steven Evett, Research Soil Scientist, USDA Agricultural Research Service, Bushland, Texas
(co-authors: D. Brauer, P. Colaizzi, G. Marek, S. O'Shaughnessy, J. Moorhead)

In the semi-arid Southern High Plains, nearly all irrigation water is derived from the declining High Plains (Ogallala) aquifer. As well capacities likewise decline, one tactic for continued irrigation is to install subsurface drip irrigation (SDI) systems with zones sized to accommodate the limited flow. Other reasons for adopting SDI include the documented increases in cotton yield and water use efficiency (WUE) with these systems compared with sprinkler irrigation, the much reduced evaporative loss compared with sprinkler systems, and the promise of increased WUE with other crops. Improvements in grain crop WUE with SDI have not been sufficiently documented, nor have the underlying mechanisms leading to increased yield and WUE been well understood. We compared yield, water use (evapotranspiration, ET) and WUE for sorghum and corn crops grown using SDI and a linear-move sprinkler system equipped for mid elevation spray application (MESA). ET was determined using four large precision weighing lysimeters and a network of eight neutron probe access tubes in the field around each lysimeter. Each lysimeter was in the center of a square 4.4-ha (11-acre) field. Grain corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) were planted in 2013 and 2014, respectively. In those two years, using SDI saved 85 and 53 mm (3.3 and 2.1 in) of water that was lost to evaporation early in the season (pre-plant to 25 days after planting), compared with MESA irrigation. In the relatively dry 2013 season, SDI reduced overall corn water use by 147 mm (5.79 in) while increasing yields by 1.88 Mg $ha^{-1}$ (1,680 lb $acre^{-1}$, 20%) and WUE by 0.64 kg $m^{-3}$ (1740 pounds $acre\text{-}ft^{-1}$, 61%) compared with MESA full irrigation. Short season sorghum, although not a crop ordinarily considered for SDI, was grown successfully using SDI with yields averaging 6.48 Mg $ha^{-1}$ (5,780 lb $acre^{-1}$).

### Efficiency in the Imperial Valley: What does it mean for the Salton Sea?

Lucia Levers, UC Riverside
(co-authors: T. Skaggs, K. Schwabe)

We developed a hydro-economic optimization model of the Imperial Valley (IV) of California, which receives agricultural water from the Colorado River through the Imperial Irrigation District (IID). Using steady-state yield functions that account for salinity and evaporation, we tracked applied water, evaporation, and drainage water, which is disposed of in the Salton Sea, an artificially created lake in California that provides habitat to millions of migratory water fowl and many sensitive and endangered species . As an agricultural drainage water sink for the IV, the Salton Sea is highly saline, and its waters cover polluted soils. As the IID reduces agricultural water use and increases water sales to urban water users, the amount of drainage water produced in the region decreases, leading to a shrinking Sea. The smaller sized Sea exposes the polluted playa and reduces ecosystem benefits. To explore these issues and water use in the IV, we analyzed allowable urban water sales and efficiency and fallowing programs. We found that the growers in the IV have likely historically over irrigated, possibly driven by the desire to maintain water rights. We also found that by engaging in water markets, the IID has revealed it may be willing to accept $85 million per year for Colorado River water to be transferred directly to the Salton Sea, reducing salinization, habitat loss, and playa exposure, yet resulting in very little overall farm production reduction. This would be a far cheaper than a proposal to address the Sea which has an initial price tag of $10 billion, with yearly upkeep at $150 million.

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### Determinants of water market prices in the western United States

Craig Broadbent, Professor of Economics, Brigham Young University Idaho
(co-authors: Q. Beeson, K. Toll)

Markets have been utilized to allocate scare natural resources and as a public policy option to remove lead from gasoline and reduce sulfur dioxide producing acid rain. Over the last three decades the western United States has seen an increase in the utilization of economic markets to allocate or reallocate water resources on a permanent and temporary basis. Basta and Colby (2010) investigated data for the western U.S. establishing overall trends by state. While they found that average prices are rising they did not investigate the impact that transaction type (permanent transfer or lease) has on the price, nor the impact of hydrologic conditions (average rainfall) on prices. Since, Shupe et al. (1989) proposed the use of temporary transfer markets for water rights there has been an increased use of this market type throughout the Western U.S. What is unknown is if this temporary transaction has a different impact on the price of a water right from a permanent transfer, and if the length of the temporary transfer (1 month verses multi months) impacts water market prices.
Using data from 1987-2010 published by Water Strategist we investigate price determinants for water rights in the Western U.S. This analysis investigates the impact that a water lease versus a permanent transfer has upon the transactions price along with the how the location of the transfer (state) and hydrologic conditions impact market prices. The expectation is that during times of scarcity (drought) prices of water rights should be higher than in times of plentiful water supply. This might not always hold true as other factors such as the type of transaction, time of year and type of agents engaging in the transaction also impact the price of transfers. If water markets are to be successful in allocating scarce water resources in the future it is important to understand the determinants of price in the marketplace so that all economic agents involved in the transaction can maximize benefits from transactions.

### Irrigation rate structure to address agricultural water scarcity: An example from North Louisiana

Naveen Adusumilli, Assistant Professor, Louisiana State University Agricultural Center
(co-author: B. Baiamonte)

The presumption that increasing block rate in agricultural water use would bring conservation efficiencies similar to residential and/or industrial use is yet to show promising results. Most rate structures for agriculture water use are designed so that the first tier satisfies most or all of the crop water demand. Moreover, conservation price structures in agriculture water use mostly depend on how irrigation districts and irrigators define conservation. We developed an irrigation rate structure for the Red Bayou project, a federally funded irrigation project built to allow farmers to pump water for irrigation in the Red Bayou Watershed in North Louisiana. With no preexisting rate structure, our objective was to develop a rate structure that takes into account not only the operating costs but also incorporates a premium that reflects water scarcity and encourage efficiency.

## Session 35, Stretching Our Water Supplies: Planning and Implementing Reuse I

### A risk based framework for decentralized non-potable water systems

Sybil Sharvelle, Associate Professor, Colorado State University

Use of onsite water sources (e.g. roof runoff, stormwater, graywater and wastewater) to meet non-potable demands is gaining much interest as a strategy to minimize import and export of water, ensure reliable water sources, increase system resiliency, and promote energy efficiency. Here, these systems are referred to as decentralized non-potable water (DNW) systems, which are defined as systems in which water from local sources is collected, treated, and used for non-potable applications at the building, neighborhood, and/or district scale, generally at a location near the point of generation. Widespread adoption of DNWs has been hindered by the need for guidance on performance targets to be met by such systems, a consistent management approach and approaches for monitoring DNWS to assure reliability so that public health is adequately protected. An independent advisory panel was formed by National Water Resources Institute NWRI to develop guidance for DNWS with focus on multi-user building to neighborhood to district scale projects. The DNWS framework includes risk-based guidance based on estimated pathogen log reduction targets (LRTs) for various source waters and end uses. Source waters addressed include blackwater, graywater, domestic wastewater, roof runoff, stormwater, and foundation water. Only non-potable end uses (toilet flushing, clothes washing, unrestricted access irrigation and dust suppression, and cooling towers) are considered, yet the approach described can be used to establish guidance for any source water-end use combination. Presentation of the framework will be accompanied by example applications of the framework to DNW system projects to demonstrate application of the DNW framework for selection of LRTs, appropriate treatment processes, monitoring and controls, and guidance for management to ensure public health targets are met.

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### Responsible management of decentralized non-potable water systems

Ed A. Clerico, CEO Emeritus, Natural Systems Utilities, LLC

Use of onsite water sources (e.g. roof runoff, stormwater, graywater and wastewater) to meet non-potable demands is gaining much interest as a strategy to minimize import and export of water, ensure reliable water sources, increase system resiliency, and promote energy efficiency. Here, these systems are referred to as decentralized non-potable water systems (DNWS), which are defined as systems in which water from local sources is collected, treated, and used for non-potable applications at the building, neighborhood, and/or district scale, generally at a location near the point of generation.

In the past, such systems were predominantly part of green building projects and were permitted and managed as components of the building's mechanical systems. However, as their popularity expanded, application to larger mixed use and multi owner projects began to demand a better understanding of the management requirements and the best management structure. This has resulted in a mixture of public and private ownership of the assets and performance responsibilities that varied widely.

In addition to the scientific aspects of public health and safety, concern has also been focused on having an adequate management structure in place to assure dependable and affordable results. Decentralized non-potable water has many of the same safety concerns as potable water, but the size and system operations and control mechanisms pose a different set of management considerations and require an appropriate structure to assure optimum performance. Wide flow fluctuations, site specific water source characteristics, specialized system mechanisms and dispersed assets all require a unique combination of automation and asset management. In addition, placement of assets within private buildings and on private property greatly complicates use of a traditional public utility management approach.

An independent advisory panel was formed by National Water Resources Institute NWRI to develop guidance for DNWS with focus on multi-user building to neighborhood to district scale projects. The DNWS framework includes identification of the key management aspects and how these can best be addressed. Presentation of the management aspects of the framework will be accompanied by example applications from existing projects to demonstrate the pros and cons of each approach and how responsibility and accountability can be achieved and result in safe, affordable and dependable service, commensurate with that of traditional centralized systems.

### Stormwater reuse in Carver County: An innovative approach to reducing pollutant loads to water resources

Tim Sundby, Water Resources Tech, Carver County

Carver County Water Management Organization (CCWMO) was established in 1996 to protect the water resources of Carver County, Minnesota. In 2012, rules for treating stormwater were updated to include a volume reduction component. Due to heavy clay soils that make up the majority of the county, stormwater reuse has become an option to meet volume standards. Regulating and monitoring stormwater reuse as a volume control BMP presents several challenges that have required the CCWMO to take innovative approaches to meet them. These challenges include correlating annual precipitation to the 0.5 inch storm event; how irrigation rates and irrigation area effects the volume credit; establishing a method for giving appropriate amount of credit based upon design criteria; transferring credits from a community reuse system to individual developments; and the effects of vegetation and soil on volume retention. To address these challenges, CCWMO has worked on better documenting the review and monitoring process including the following steps; requiring pumping meters be installed and read by CCWMO Staff; evaluation of site design criteria such as irrigation rates, dimensions and use of irrigation area, soil and vegetation types; documenting daily precipitation events; and evaluation of permitted volume credit and actual usage. To date, 14 reuse sites have been approved through our process and one regional reuse bank to offer volume credits for new development in a city. Five reuse sites started operation in 2016. A total of 2,042,762 gallons of stormwater was utilized for reuse during the 2016 season within 4 sites; removing 3.98 pounds of TP and 1,368 pounds of TSS from reaching downstream water bodies. This volume is equal to removing 10.4% of the total rainfall draining off impervious surfaces within these developments. In terms of cost, these sites had an equivalent 2016 savings of $6,593.84 in water usage rates.

## Session 36, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects II

### Real-time monitoring provides insight into nitrate-N export during storms in two contrasting agricultural watersheds

Shannon L. Speir, Ph.D. Student, University of Notre Dame
(co-authors: J.L. Tank, T.V. Royer, U.H. Mahl, M.T. Trentman, B.R. Hanrahan, K. Prior, S.F. Christopher)

Traditional monitoring approaches using grab samples can present limitations to accurately estimating watershed nutrient export during storms. Continuous nitrate-N sensors offer an opportunity to examine nutrient dynamics on a more resolved temporal scale that could help document benefits of conservation and restoration. We deployed continuous nitrate-N sensors in two agricultural watersheds in northern Indiana where agricultural conservation practices are being adopted at the watershed scale. We used the high-resolution data to evaluate nitrate-N export during storms in the Shatto Ditch (SDW) and Kirkpatrick Ditch Watersheds (KDW). Nitrate-N concentrations were generally greater in KDW as compared to SDW. Nitrate-N loads varied with storm size in SDW and increased linearly with storm size until direct runoff was >80% of total flow. There was no dilution effect observed in SDW in fall 2016. In contrast, in KDW, a notable decrease in nitrate-N concentrations during large storms suggests a considerable dilution effect in fall 2016, but dilution events of a similar magnitude were not observed in spring 2017 in KDW. Despite minimal increase in nitrate-N concentrations with the largest storms in both watersheds, we observed significant increases in nitrate-N loads leaving both watersheds. More accurate quantification of nitrate-N export will become more essential as the frequency and magnitude of precipitation events intensifies with global climate change, and high-resolution nutrient data will aid quantifying the impacts of conservation by improving estimates of nutrient export during these critical storm periods.

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### Understanding hydrologic pathways and assessing conservation benefits in the Western Lake Erie Basin

Mark Williams, Agricultural Engineer, USDA ARS
(co-authors: K. King, D. Smith, S. Livingston, C. Huang)

In 2002, USDA Agricultural Research Service (ARS) Soil Drainage Research Unit at Columbus, OH and National Soil Erosion Research Lab at West Lafayette, IN received congressional mandate to establish a watershed-scale project to minimize pesticides (mainly Atrazine) in the source waters for Columbus and Ft Wayne. This source water protection project started a close collaboration between these two laboratories and became a part of the USDA Conservation Effects Assessment Project (CEAP) with expanded conservation objectives including water quantity, soil and water quality, and aquatic habitats. The challenge we have faced is to take the process level understanding at the field scale and scale them up to a watershed where multiple processes and interactions occur and the collected data can only be analyzed empirically. Recently, minimizing nutrient runoff has gained attention as the algal bloom at the West Lake Erie Basin (WLEB) has directly impacted human lives. In this presentation, we highlight our efforts in evaluating field scale practices, such as controlled drainage, conservation tillage, gypsum application, ditch dredging, blind inlet and nutrient management on water, sediment and nutrient runoff WLEB. At the watershed scale, understanding hydrologic processes and solute transport pathways is essential to provide the scientific basis in the interpretation of hydro-and chemo-graphs. Using detailed hydrology and water quality data from CEAP watersheds, we evaluate spatial and temporal variability of hydrological fluxes and associated nutrient transport to facilitate a better understanding of the interaction between scale, connectivity, and pathway dominance under varying environmental conditions, as well as, conservation practices to mitigate nutrient delivery in headwater agricultural watersheds of the WLEB.

## Session 36, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects II

### Quantifying changes in nutrient export from an agricultural watershed following the planting of winter cover crops

Brittany Hanrahan, Ph.D. Candidate, University of Notre Dame
(co-authors: J. Tank, S. Christopher, M. Trentman, U. Mahl, S. Speir, K.R. Prior, T.V. Royer)

In the Midwestern US, excess nitrogen (N) applied to agricultural fields is transported to adjacent streams via subsurface tile drainage and can degrade local and downstream water quality, fueling algal blooms and subsequent hypoxic “dead zones” far from the nutrient source. We quantified changes in nitrate-N retention and export from agroecosystems following a watershed-scale manipulation of land cover via the planting of winter cover crops in the Shatto Ditch Watershed (Kosciusko Co, IN). We collected 1 year of baseline data prior to cover crop planting by sampling 25 tile drain inputs and 7 stream sites throughout the watershed every 14 days. During Fall 2013-2016, cover crops were planted on 70% of croppable land and we continued our comprehensive, biweekly sampling regime. Cover crops consistently reduced nitrate-N inputs from tile drains; median nitrate-N flux from tile drains with cover crops was 60-80% lower than tiles without cover crops. Moreover, reductions in annual watershed nitrate-N export ranged from 1-18% over the 3 years with cover crops compared to baseline conditions, and was 17% less than the 6 year average prior to cover crop planting. The effect of cover crops on nitrate-N export varied seasonally and was strongest in Spring when cover crops were actively growing. Spring watershed export decreased by 30-45%, driven primarily by a reduction in nitrate-N exported during storms (defined as Q= >95% baseflow). Median nitrate-N export during Spring storms decreased from ~245 kg N in 2013 to ~140-190 kg N in 2014-2016, a reduction of 24-43%, exceeding the ~20% decrease predicted by the change in the number of storms over the same period. In summary, watershed-scale cover crops may significantly reduce nutrient export from agricultural watersheds while simultaneously buffering the impacts of increased storm frequency predicted for the Midwestern US under a changing climate.

### Needs assessment: Delivery of watershed science to locally-elected water resources managers

Troy Gilmore, Groundwater Hydrologist, University of Nebraska - Lincoln
(co-authors: J. Korus, L. Pennisi, D. Martin)

Nebraska's twenty-three Natural Resources Districts (NRDs) are unique, local systems of governance, geographically bounded by watersheds, with responsibilities over water, soil, and other natural resources. NRD board members are elected locally and may come from a wide range of educational and professional backgrounds, but they are charged with making increasingly complex watershed management decisions. NRD staff are responsible for making recommendations to the NRD board and in some cases need to provide watershed management education for board members. Since there is no readily accessible, comprehensive Watershed Management training program for Natural Resource District board members and staff, we conducted a formal needs assessment, including focus groups and a survey questionnaire, to determine the content, form of delivery, and perceptions of NRD board members and staff regarding the availability of information on watershed science. The needs assessment will be used to develop pilot curriculum modules, which will be evaluated in collaboration with three NRDs. Given the broad responsibilities of Natural Resources Districts, the results of the stakeholder survey will inform the development of a unique training program that will be widely applicable as a model for other natural resources governance structures in the U.S. and globally.

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### Learning preferences for water resource information from extension and other sources

Drew Gholson, Program Specialist - Water Resources, Texas A&M AgriLife Extension Service
(co-authors: D. Boellstorff, S. Cummings)

Texas A&M AgriLife Extension Service in conjunction with a national needs assessment project initiated through the Pacific Northwest Regional Water Program facilitated a random sample survey of Texans to evaluate citizen awareness, attitudes and willingness to act on water issues in 2008. The survey was re-issued to a random sample of Texans in 2014. The study assesses outreach effectiveness to particular populations, audiences' media preferences for learning about water issues and examines preferences for additional information on particular water resource topics. In addition, this study examines possible trends in information sources related to socio-demographic changes from 2008 to 2014. Respondents residing within city limits were more likely to receive information from television than those living outside city limits (likelihood ratio test, $p = .015$). Surprisingly, city and municipal water districts reached the greatest number of people with 68.2% of the total population and 73.9% of respondents living within city limits (likelihood ratio test, $p < .0001$) receiving water information from these sources. Visiting a website went from being ranked fourth in 2008 to the most popular method for learning in 2014. Younger respondents were more likely to visit a website or watch a short video, while older respondents were more likely to prefer fact sheets, bulletins, or brochures, and to read a newspaper article/series. Overall responses varied based on respondent age and residence location, and indicated outlets and delivery media through which specific audiences are more likely to be successfully reached.

## Session 37, Water Resources Education: Training Tools and Outreach

### Successes and challenges in training adult professionals through distance learning

Ruth Kline-Robach, Outreach Specialist, Michigan State University
(co-author: L. Wolfson)

The Institute of Water Research at Michigan State University has cooperated in the development of several online training courses aimed at a diverse set of nontraditional students. The courses address water resources and climate change topics, and vary from self-paced learning modules to a six-week course with pre-scheduled live chats featuring experts on unit topics. The courses include: An Introduction to Lakes, targeting lakefront property owners and local government officials; Protecting Drinking Water with Innovative Tools, aimed at community and noncommunity public water supply system owners and operators; and Climate Change Academy 101, which was developed specifically for Extension educators to enable them to confidently speak with clientele about climate change issues. Two of the courses were previously offered in person and are being transitioned to an online format in order to engage individuals across a wider geographic area and decrease travel time for instructors. One course was developed exclusively for online learning and has never been presented live. This presentation will provide an overview of the online courses, including topics presented, format, external partnerships and funding sources. Outcomes of the online instruction, both positive and negative, will be shared, along with techniques that have been successful in converting to an online format, including discussion forums, live FAQ chat sessions and videos. Techniques used to engage participants, incentives for attracting attendees and limitations to online teaching will be addressed, in addition to the evaluation of student performance and course effectiveness.

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### Science informing policy: Mississippi case study

Jeff Johnson, Director, Delta Research and Extension Center, Mississippi State University
(co-authors: K. Whittington, S. Mabry)

Although Mississippi does have an abundance of water resources, the Mississippi Delta region is experiencing an overdraft of the primary irrigation aquifer, Mississippi River Valley Alluvial Aquifer. Eighty percent (80%) of the permitted groundwater wells in the State are located in the region which makes up approximately 25% of the land area but has a large majority of the irrigated cropland of the State. The Governor of the State of Mississippi established the Delta Sustainable Water Resources Task Force in 2014 consisting of several water-related agencies and NGOs and led by the Director of the Land and Water Office of the Mississippi Department of Environmental Quality (MDEQ). The goals of the Task Force are to promote conservation measures and irrigation practices, advise MDEQ on policies, and prepare implementation of strategies related to Delta surface and groundwater supplies. The Task Force has established very close and successful relationships with state and federal researchers. The success of the Task Force from a researcher's viewpoint is that science informs policy through the Task Force. Recent applied research results have been incorporated into local water district policy through permit requirements. Positive implementation rates have been identified as a result of aggressive Extension education and demonstration efforts.

## Session 38, The US-Mexico Transboundary Aquifer Assessment Program: Accomplishments to Date

### The US-Mexico Transboundary Aquifer Assessment Program - The first five years

William Alley, Director, Science and Technology, National Ground Water Association

Transboundary aquifers are an essential, and in many cases, the sole source of water for communities on both sides of the hot and dry US-Mexico border. This critical resource has been overexploited and polluted by untreated wastes, agricultural chemicals, and industrial byproducts. Despite its importance and serious problems, for many years both the United States and Mexico undertook relatively limited monitoring and assessment of groundwater along the border and these efforts were largely independent of one another. The US-Mexico Transboundary Aquifer Assessment Program (TAAP) established in 2006 provided an opportunity to provide much needed binational assessment, but its success depended on a truly collaborative effort by the two countries. Transforming the program into a true binational effort required building a partnership that respected the legal and institutional frameworks of both countries. These efforts took place at both local and national levels. Technical meetings, site visits, and joint planning activities were conducted to share information on data and modeling, as well as to build support and common understanding of priority needs. Despite the challenges, the two countries made steady progress. On August 19, 2009, a Joint Cooperative Process was signed in a ceremony on the International Bridge between El Paso and Juárez. This agreement established the basic framework for binational aquifer assessment activities. After successfully working through the myriad challenges of establishing a joint program, funding was cutoff in 2011. Although some funding was reinstated in 2016, the program's future remains uncertain. It demonstrates how efforts to address transboundary aquifer issues require multiple levels of engagement, mutual respect, and tenacity.

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### Assessment of the Mesilla Basin/Conejos-Médanos and Hueco Bolson Aquifer Systems under the Transboundary Aquifer Assessment Act

Andrew Teeple, Hydrologist, United States Geological Survey
(co-author: *D. Humberson)
*Presenter - Delbert Humberson, Hydrologist, United States Geological Survey

The Transboundary Aquifer Assessment Act was enacted in December 2006 with the purpose of assessing priority aquifers along the United States-Mexico International Boundary. These priority aquifers include the Mesilla Basin/Conejos-Médanos and Hueco Bolson aquifer systems near El Paso, Texas, and Ciudad Juárez, Chihuahua. Assessments of these aquifers by the United States Geological Survey (USGS) in cooperation with other entities are currently (2017) ongoing as part of a larger collaborative effort involving scientists from numerous institutes and universities.

During 2010–12, the USGS in cooperation with the United States Bureau of Reclamation used geophysical and geochemical methods to investigate the Mesilla Basin/Conejos-Médanos aquifer system. Electromagnetic analysis provided insights into groundwater salinity distribution and indicated large areas of low electrical resistivity in the southernmost part of the study area near El Paso, Tex. Geochemical results indicated that recharge to the shallow Rio Grande alluvium and deeper hydrogeologic units of the Mesilla Basin/Conejos-Médanos are largely from Rio Grande seepage, inflows from deeper or neighboring groundwater systems, and mountain-front recharge.

In 2016, the USGS began an ongoing assessment of the Hueco Bolson aquifer system in cooperation with major users of Hueco Bolson groundwater, including the U.S. Army Air Defense Artillery Center. To date, samples have been collected from 20 geospatially distributed wells to determine the baseline geochemistry of the aquifer system near El Paso, Tex. The samples are being analyzed for major ions, trace elements, nutrients, pesticides, and isotopes.

## Session 38, The US-Mexico Transboundary Aquifer Assessment Program: Accomplishments to Date

### US-Mexico Transboundary Aquifer Assessment Program - New Mexico investigations

Anne-Marie Matherne, Unit Chief, Environmental Geosciences, USGS New Mexico Water Science Center
(co-author: A. Robertson)

The 2006 enabling legislation for the Transboundary Aquifer Assessment Program (TAAP) named the Mesilla/Conejos-Médanos Basin in New Mexico, Texas, and Chihuahua, Mexico as a priority groundwater aquifer designated in the TAAP Act. Investigations in this basin in New Mexico address the objectives of the TAAP Act to characterize, map, and model priority aquifers along the US-Mexico border. An updated and refined hydrogeologic framework was developed for the Basin; the new framework compiles and summarizes the results of 10 years of collaborative efforts, showing basic hydrostratigraphic and structural-boundary conditions, as well as lithofacies distribution at a scale of 1:100,000. Data collected for the TAAP and other concurrent investigations are being used by the U.S. Geological Survey (USGS) in cooperation with U.S. Bureau of Reclamation to develop an integrated hydrologic model of the Palomas, Mesilla, and Conejos-Médanos Basins. The model will facilitate the systematic analysis of conjunctive use, such as the effects of overlapping cones of depression formed by groundwater withdrawals, surface-water/groundwater exchange, and Rio Grande Project operations. Beginning in 2016, additional work began to determine the contribution of deep groundwater flow to the shallow groundwater system and the Rio Grande. A combination of geochemistry, isotopic tracers, and geothermal profiles are being collected and compiled to identify sources of deep groundwater, rates of recharge, and the spatial distribution of upflow zones. The USGS New Mexico and Texas Water Science Centers are working collaboratively to sample wells using geochemical and isotopic tracers to detect evidence of cross-aquifer groundwater transport between the Mesilla and Hueco Basins in Fillmore Pass.

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### The Binational Study of the Transboundary San Pedro Aquifer: Successful experience on binational work

Ismael Minjarez Sosa, Professor, Universidad de Sonora
(co-authors: J. Callegary, E. Tapia Villaseñor, R. Monreal Saavedra, F. Grijalva Noriega, F. Gray, C. Scott, L. Oroz Ramos, S. Megdal)

The Binational Study of the Transboundary San Pedro Aquifer was performed within the framework of the IBWC "Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program" signed by the principal engineers in August 2009. The Binational San Pedro Basin (BSPB) is located along the eastern portion of the Arizona-Sonora border and includes the towns of Cananea, Sierra Vista, Tombstone, and Naco-Bisbee. It is located in a transitional zone between the Sonoran and Chihuahuan Deserts. The San Pedro report presents information about climate, geology, soils, land cover, land use, and hydrology, with scientific outputs that will be discussed in this presentation. Among the most important findings we can say that the analyzed geologic units on the BSPB are product of a complex tectonic evolution and a series of informal lithostratigraphic and lithodemic units were proposed to encompass similar formations in the study area. Thanks to the available geophysical information, we concluded that the BSPB is mainly controlled by tertiary normal faulting with NNW structures. The sedimentary fill of this basin is mainly silty-clayed with some sand and gravel. Three hydrostratigraphic units were proposed for the area: Unit 1.- Gravel and sand from sedimentary basin fill; Unit 2.- Silt and clay from the upper basin fill; Unit 3.- Tertiary and older rocky units. The groundwater type in the transboundary aquifer is calcium bicarbonate and the total estimated binational extraction volume is about 39.4 $hm^3$. The largest water use is industrial (38.5%), followed by the public/municipal/water company use (34.4%), agricultural/irrigation (21%), domestic/rural exempt wells (4.5%), and livestock (1.5%). In addition to the different accomplishments, comments about the experience of working in a binational team will be presented.

## Session 39, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Irrigation systems & scheduling)

### Geo-spatial analysis of soil water redistribution of different irrigation technologies

Tobias Oker, Graduate Research Assistant, Kansas State University, Southwest Research-Extension Center
(co-authors: I. Kisekka, C. Hillyer)

Proper soil water redistribution is an important aspect of irrigation management and is a key consideration when selecting irrigation systems. Three different irrigation application technologies including Mobile Drip Irrigation (with 2 gph and 1 gph emitters), bubblers and Low Elevation Spray Application, spaced 1.52 m apart were evaluated for water redistribution on a Ulysses silt loam near Garden City, Kansas. The soil was bare and initially dry following a long period of no rainfall or irrigation. For each irrigation method, five neutron probe access tubes, spaced 0.381 m apart, were installed between application devices to measure soil water content before and after irrigation. Irrigation water depth applied was 25.4 mm. Three days after irrigation, soil water content was measured using neutron attenuation. Semi-variogram and krigged 2-D images of soil water redistribution within the different profiles were generated using geospatial analysis software (GS+). Pre- and post-irrigation variograms for all methods indicated a Gaussian distribution of the soil water data with a nugget value of zero. Semi-variance for 2 gph, 1 gph, bubblers, and sprinkler were: $1.61e^{-3}$, $1.22e^{-3}$, $2.42e^{-3}$ and $1.36e^{-3}$ respectively. Sprinklers are expected to have the least measure of semi-variance, as its spread water evenly on the soil surface, allowing uniform water redistribution. The results of this study show that both drippers (1 and 2 gph) have relatively similar water redistribution. The ability of drippers to match the water redistribution of sprinklers complements their high water application efficiency. For all the irrigation methods, the highest change in soil water content, three days after irrigation, is at depth range of 0 – 0.9 m. Soil water "spatial structure" pre- and post-irrigation is relatively similar. This suggests soil water is redistributed in the soil profile over an extended period, like a growing season, and is manifested for a long period after irrigation.

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### A GIS-based precision irrigation system design for irrigation in the Western U.S.

Susan A. O'Shaughnessy, USDA ARS
(co-authors: M.A. Andrade, S.R. Evett, P.D. Colaizzi)

Limited water resources and climate variability affect sustainable crop production. Farmers are continually challenged to find methods to manage water more efficiently and under less than predictable circumstances. One strategic method for improving crop water use efficiency (WUE) in regions with limited water resources is the irrigation scheduling supervisory control and data acquisition (ISSCADA) system developed at the USDA-ARS Conservation and Production Laboratory in Bushland, Texas. The GIS-based framework integrates a variable rate irrigation sprinkler with wireless plant, weather and soil water sensors to provide dynamic canopy temperature, plant water status and prescription maps. Recent changes to this system incorporated the combination of thermal stress index thresholds and varying levels of irrigation (based on percentages of peak daily water use) to provide decision support for maximizing grain yields and controlling WUE. In growing season 2016, maize (Pioneer AQUAMax P0157AM) was managed under a six-span center pivot ISSCADA controlled system. The hybrid was managed using two methods- (1) weekly direct soil water readings with a neutron probe, and (2) plant feedback- canopy temperature and weather data sensing to formulate an integrated crop water stress index (iCWSI). Three irrigation levels were applied- 100%, 50% and 30% replenishment of soil water depletion to field capacity (I100, I50, I30) for those plots managed with neutron probe readings (designated M100, M50 and M30). Corresponding combinations of pre-established thermal stress thresholds and irrigation amounts for treatment plots managed by the ISSCADA system (designated C100, C50 and C30) were embedded in the software for irrigation scheduling. Prescription maps were automatically created every 3 days and used to control both methods of irrigation. Results demonstrated that grain yields compared between methods within the same irrigation treatment were similar at the I100 and I50 levels. Mean WUE values were significantly smaller for the M100 and M30 treatment plots. Yields from this study were 50% greater than reported by farmers using the same hybrid and farming within 100 miles of Bushland. It is expected that refining the irrigation levels at each stress threshold can provide better control of water use efficiency. Future work should include outfitting an ISSCADA package onto a variable rate irrigation system in the western United States to investigate feasibility of maximizing yields and improving crop WUE of irrigated crops in other semi-arid regions.

## Session 39, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Irrigation systems & scheduling)

### Free online irrigation management tools: From universities to producers

Jonathan Aguilar, Assistant Professor, Kansas State University
(co-authors: D. Rogers, I. Kisekka, D. Porter, C. Hillyer, A. Andales, D. Rudnick)

Agricultural producers have a big responsibility and deal with a lot of considerations in running farm operations. Besides the agronomic, economic, and technical issues one has to deal with, the producer has to learn how to optimally and strategically irrigate their field on almost a daily basis. State universities with extension roles provide an important service to producers by helping them navigate through all the decision making process. Here we present some of the tools developed by universities that producers could freely use in order to implement irrigation strategies suitable on the farm operations. The major focus of this session is to introduce and explain the decision support tools for irrigated crops available in Kansas and the High Plains region. Primarily, the Mobile Irrigation Lab website (www.bae.ksu.edu/mobileirrigationlab), which hosts a suite of web-based and downloadable tools that help producers make pre-season (Crop Water Allocator), mid-season (Crop Yield Predictor), and daily (KanSched) decisions, will be featured and will also include other online tools available from other websites and regions that have similar capabilities. It is the objective of the session to introduce the attendees to the available online tools and to update some who already know the tools about new features of these irrigation management tools.

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### Education and technology transfer in agricultural water management: Effective communication with stakeholders

Dana Porter, Professor, Extension Program Leader and Associate Department Head, Texas A&M University
(co-authors: K. Wagner, J. Aguilar, D. Rogers, T. Marek, G. Marek)

Effective communication with stakeholders is key to success in promoting appropriate technologies and practices in agricultural water management. Technology transfer, education and outreach are increasingly emphasized by natural resources agencies, public and private sector funding entities, businesses and trade associations, and research organizations, as they recognize the importance of stakeholder understanding, engagement and “buy-in”. Tasks in an effective communication plan may include: a) identifying and understanding target stakeholders/audiences; b) building upon existing successful programs, networks, and partnerships; c) emphasizing internal and external communication; d) providing quality information, educational resources and opportunities; e) improving accessibility of available resources; f) promoting value and visibility of programs and partnerships; and g) packaging information to match interests and format preferences of target audiences. Stakeholder groups differ in their technical and educational backgrounds; interests, needs and limitations; and information delivery preferences. A variety of media and formats, technical levels, and interpretation generally are needed to meet diverse audiences, yet the message must be reliable, accurate, clear and consistent.

Agricultural irrigation comprises the largest water demand sector in many areas, including the Ogallala Aquifer Region, and groundwater levels are declining in much of the region. Yet, agricultural irrigation is an important as an economic risk management tool (mitigating effects of drought to improve probability of desired crop yield and/or quality) at the farm level, and by extension an important economic component of local/regional economies. Efficient advanced irrigation technologies, decision tools and management strategies offer potential to optimize use of limited water resources. Adoption of these technologies and management practices varies, and even where adoption is relatively high, proficiency in application often can be improved through education, technology transfer and technical support. Coordinated, collaborative, multi-state, interdisciplinary efforts are addressing needs for stakeholder education in agricultural water management, especially in irrigation management.

## Session 40, Economic Implications of Agricultural and Municipal Water Management in the Southwestern United States

### Heterogeneous water demands: Implications for conservation and welfare

Alexander Maas, Research Scientist, Colorado State University
(co-authors: C. Goemans, D. Manning, S. Kroll)

As water scarcity concerns grow, understanding how households respond to policies and weather will be critical in planning water supply and distribution systems. However, predicting residential water use has been notoriously difficult due in large part to high levels of dispersion and unobserved heterogeneity in household characteristics. We endeavor to more accurately estimate water demand by using a finite mixture model to endogenously identify distinct water use patterns for different types of households in the southwestern United States. We find strong evidence that heterogeneity exists in consumption responses to temperature, precipitation, and price. Estimated price elasticities are consistent with previous literature and range from -0.1 in the spring season for the unresponsive class to -0.8 in the summer for the responsive class. Once specific class response patterns were identified, we briefly examine the distributional effects of residential water price changes across income level and find that the majority of water conservation will come from high income homes.

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### The cost of stability consumption-based fixed rate billing for water utilities

Amy Schmidt, Bates College
(co-author: L. Lewis)

Municipal water utilities in the United States face the challenge of balancing the potentially conflicting goals of sending signals about water scarcity and maintaining revenue stability. Times of extreme shortage such as the current extended drought in California seriously challenge and can jeopardize this delicate balance. Mandatory or voluntary conservation strategies can be detrimental to revenue stability. This study explores the ability of the Consumption-Based Fixed Rates pricing method (CBFR, Spang et al 2014) to solve this dual dilemma of scarcity pricing and revenue stability in both normal times and times of drought. CBFR proposes using a proportional consumer pricing system directly based on utility supply costs. We utilize utility-side cost data from Lomita, CA and Longmont, CO, to estimate how consumer prices change under the CBFR method. Using simulations comparing current pricing mechanisms with the CBFR, we find that the latter solves the revenue problem, but creates greater problems with equity and scarcity versus the former. A modified structure of CBFR, with prices based partially on household income, seems to alleviate some of these problems and could prove to be a useful tool during times of drought.

## Session 40, Economic Implications of Agricultural and Municipal Water Management in the Southwestern United States

### Rural to urban water transfers and the future of rural agricultural economies in the semi-arid West

Kevin Crofton, Graduate Student, Colorado State University
(co-authors: D. Manning, C. Goemans, H. Cutler)

Agriculture remains the single largest user of water in the Western United States. Many rural communities throughout the West exist, at least in part, due to the economic activity created by agricultural activities. As urban areas throughout the West have grown over the last several decades, there has been an upward trend in water transferred from agriculture in rural regions to municipal and industrial (M&I) uses in urban regions. Despite the significant role that transfers are likely to play in meeting future M&I demands, the impact of these transfers on the future of the agricultural sector and the economies of rural communities in the West remains an open question. To date, there has been no systematic analysis that we are aware of that investigates how the future impacts of rural-urban water transfers are likely to differ between rural regions as a function of different economic and geographic characteristics, varying degrees of linkages between urban and rural communities, and of institutional arrangements that govern water transfers. We develop a dynamic, regional computable general equilibrium (CGE) model that is capable of capturing changes in economic activity associated with increased competition for land and water resources driven by urban population growth. The model, capturing economic activity across a water basin, consists of multiple sub-regions where each sub-region differs based on initial economic activity, the relative abundance of land and water, and projected population growth. Results highlight how transfers of water impact the overall regional economy and the evolution of the economies in each of the sub-regions depending on the strength of linkages between the rural and urban sub-regions.

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### The impact of preference aggregation on support for groundwater management policies

R. Aaron Hrozencik, Research Assistant, Colorado State University
(co-authors: D. Manning, J. Suter, C. Goemans, R. Bailey)

More than 40% of global water resources utilized for irrigation come from groundwater (Abdullah, 2006). However, many of the world's most productive aquifers are pumped at rates that exceed natural recharge, depleting scarce groundwater resources, and threatening the future viability of irrigated agriculture. Heterogeneity in aquifer characteristics and agricultural production conditions complicate efficient groundwater management. Hydro-economic models are a means to inform the creation and implementation of groundwater management policies that capture well-level heterogeneity while accounting for the dynamics that link hydrologic and economic systems. This research develops a spatially explicit, dynamic hydro-economic model of the Republican River Basin of Colorado to explore how alternative management policies impact heterogeneous groundwater users across time and space. We utilize the integrated modeling framework to analyze the role of policy and voting scale on support for localized and basin-wide conservation policies.

Despite the potential long-term benefits of groundwater management (Steward et al., 2013), efforts to implement policies have often failed to gain traction. By allowing resource users to participate in policy implementation, voting on policies can increase the likelihood of success in achieving conservation. However, there remain significant uncertainties regarding how the aggregation of heterogeneous users' preferences determines conservation policy support. We address this gap by utilizing results from the hydro-economic model to predict the outcome of alternative voting aggregation approaches assuming groundwater users vote in support of the policy that imposes the lowest cost and/or generates the largest benefit. We compare voting results aggregated at the basin and local management district level to explore the relationship between the level of aggregation and voting outcomes and how those outcomes contrast with least cost policies. Preliminary results suggest that greater economic gains are realized when voting occurs at localized management districts, rather than the (larger) basin level. Our research informs the design of effective voting institutions that include resource users in conservation policymaking.

## Session 41, Stretching Our Water Supplies: Planning and Implementing Reuse II

### Concepts to increase global water supplies

Anish Jantrania, Associate Professor / Extension Specialist, Texas A&M AgriLife Extension and Research
(co-author: J. Wolfe)

To reliably provide safe drinking water to support growing water demands from cities, towns, communities, individual homes, and businesses, it is imperative to rethink the fundamentals of our existing water infrastructure. Adding reuse into existing water supply portfolio has potential to increase overall water availability and resilience to extreme climatic conditions. Science-based research will be required to develop, test, deploy, operate, monitor, and maintain innovative, yet reliable, additional water sources such as a/c condensate and rainwater harvesting, desalination, and underground storm water storage. As the US Congress considers investing multi-billion dollars to improve the nation's future water infrastructure, there is a critical need for efficient planning tools to determine sustainable management scenarios for surface/groundwater sources, inclusion of alternative water sources (i.e., rain and desalinated water, a/c condensate, storm water), and improvement of water use efficiency through reuse at the local levels. Epidemiological and toxicological research is needed to ensure the long-term safety and health of the public when reuse water supplies are used to supplement natural water sources. A team of scientists, engineers, and students at Texas A&M University are establishing a Center to Increase Global Water Supplies; a center for technology and workforce development to address reoccurring and ongoing water shortages in Texas and beyond. The focus of the Center will be to develop science-based research, education, and training programs that will result in influencing water infrastructure planning decisions and creating transformational shift in the way water is used and reused world-wide. This presentation will give details on the status of the Center, lay-out concepts for developing a sustainable and integrated water infrastructure that can meet the growing water demands with constant or depleting water resources, and start conversation on the role of academic institutions to rethink water science and engineering curriculum.

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### Combining climate change scenarios and hydrological modeling to support water infrastructure planning with a focus on aquifer storage and recovery (ASR)

June Wolfe III, Associate Research Scientist, Texas A&M AgriLife Research - Blackland Research and Extension Center
(co-authors: J. Jeong, A. Jantrania, R. Bailey)

Strong, science-based, resiliency plans can offer major benefits to maintaining daily operational water requirements as well as long term protection of both natural and built infrastructure. Without such plans, historical mistakes such as the famous over-allocation of Colorado River water (i.e., 1944 USA–Mexico treaty) will likely be repeated. This illustrates why factoring climate into water availability predictions is critical. Future demand, based on population growth projections, is equally important. Aquifer Storage and Recovery (ASR) technology offers a robust solution to save excess surface water, available during wet periods, for use during exceptionally dry periods.

Feasibility studies are the first step toward considering application of any concept or technology. Recent ASR feasibility studies in Texas have estimated future water availabilities based on historical surface water records from USGS river flow gauges. This approach relies heavily on past records without considering unknowable future conditions. A better approach uses historic rainfall data to drive hydrological models which incorporate relevant climate change scenarios. Selecting and applying smart schemes such as ASR options represents a sound approach based on defendable, scientifically credible information rather than politics or business interests.

ASR has been used in Texas since the 1940s; currently there are three operational ASR facilities serving the cities of Kerrville, San Antonio, and El Paso. Kerrville and San Antonio operate strict ASR systems (i.e., storage and recovery is done through the same well) while El Paso Water operates a hybrid system (i.e., there are separate wells for injection and recovery). The 2017 draft State Water Plan specifically recommends ASR as a water management strategy for several regions which are experiencing unprecedented urban growth and expansion.

The objective of this presentation is to outline a sound, scientific approach to applying climate information at local scale that can provide water infrastructure resiliency through an anticipatory planning strategy for considering application of ASR into future infrastructure planning options.

## Session 41, Stretching Our Water Supplies: Planning and Implementing Reuse II

### Designing an aquifer geochemical characterization program to enhance water reuse project planning

Kelly Donahue, Senior Geochemist, Brown and Caldwell
(co-authors: S. Wang, M. Schumacher, T. Dufour, E. Mackey)

Drought conditions in California coupled with over reliance on groundwater supplies have resulted in groundwater overdraft and seawater intrusion within the Soquel Creek Water District (SCWD). SCWD is pursuing the development of an innovative water reuse program that will directly inject treated effluent into the aquifer and replenish local groundwater supplies. Potable reuse applications have a long and successful history, but typically minimal aquifer geochemical characterization work is conducted during project planning and development. Injection of treated water into groundwater aquifers has lead to geochemical reactions resulting in mobilization of arsenic, iron, uranium and other regulated metals. Aquifer geochemical characterization to evaluate the potential for mineral dissolution or desorption can provide the necessary information to mitigate metals mobilization.

A geochemical characterization study focusing on mineralogical and soil leaching analyses was designed to evaluate the potential for metals mobilization. Archived soil samples from nearby monitoring wells were available for geochemical characterization; however, there were very limited quantities of sample material. X-ray diffraction (XRD) analysis provided mineralogy data necessary for future geochemical modeling. A modified Synthetic Precipitation Leachate Procedures (SPLP) analysis was conducted to obtain a full analytical suite while conserving sample mass. The SPLP leachate solution simulates a "worst-case" water quality condition to evaluate the potential for aquifer materials to leach constituents. Data from the geochemical characterization suggest there is a potential for aquifer materials to react with purified water in a way that could negatively impact water quality. Spatial differences in mineralogy and soil leachability emphasize the importance of characterizing each potential injection unit individually. Results of the SCWD geochemical characterization will be used to focus additional site characterization efforts, such as bench-scale geochemical testing on more favorable potential injection sites and evaluating water treatment methodologies to reduce metals mobilization.

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### Development of low-cost water reuse system by minor modification of the wastewater treatment plant: Engineering evaluation

Hafiz Ahmad, Associate Teaching Professor, Florida State University
(co-author: J. Miller)

Reuse and reclamation of wastewater has evolved to be an attractive option due to the increasing demand of fresh water. However, implementation of the project at low-cost in a less-complex way is a challenge. This study presents a successful design and development of a water reuse system by minor modification of the existing wastewater treatment train and its disposal facility. The wastewater treatment plant located in Monticello, Florida, USA, used to pump secondary treated (activated sludge process) effluent through an existing 12-inch transmission line for tertiary treatment (to constructed wetland system). The tertiary treated water was then re-pumped more than 5 miles through another existing 12-inch transmission line and discharged to a natural wetland. Maintaining the tertiary treated water quality using the constructed wetlands was a challenge due to its frequent maintenance requirement. This led to the new water reuse system design, which involved conveying the secondary treated water to a new pump station and wet weather storage facility. The treated effluent (meeting the regulatory requirements) is then re-routed to a local nursery for reuse as irrigation rather than discharging to the natural wetlands. This presentation discusses the evaluation of the modified treatment train of the plant and the hydraulic analysis of the re-routed transmission line of the new design that led to the successful operation of the project in recent years.

## Session 42, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects III

### Linking soil health to improved water quality via the planting of cover crops in two Indiana watersheds

Ursula Mahl, Senior Research Technician, University of Notre Dame
(co-authors: S. Christopher, J. Tank, B. Hanrahan, M. Trentman, K. Prior, S. Speir, T. Royer)

The planting of winter cover crops can improve soil health while reducing nutrient leaching from fields to subsurface tile drains, which can convey excess fertilizer nutrients from fields to adjacent waterways. We are quantifying the influence of cover crops on soil and water quality in two agricultural watersheds in Indiana, the Shatto Ditch Watershed (SDW) and Kirkpatrick Ditch Watershed (KDW). We found that soil organic matter (OM) did not increase during the first two years after cover crop planting in SDW, where fields had historically been in conservation tillage. In contrast, in KDW, where fields were conventionally tilled, OM increased after only one year of cover crops (ANOVA, $p<0.05$). Nevertheless, cover crops increased labile soil organic carbon in both watersheds, despite historic tillage differences, suggesting a general improvement of OM quality with cover crops. For dissolved nutrients, water extractable phosphorus (WEP) in soils tended to be lower in fields with cover crops, and soil WEP was correlated with dissolved reactive phosphorus in tiles ($p<0.05$). We also found that during Fall and Spring in both watersheds, soil nitrate-N was lower in cover cropped fields compared to those without (ANOVA, $p<0.05$), and there was a significant release of dissolved inorganic N after cover crop termination. These results suggest N retained in cover crop biomass may reduce the pool of dissolved N that can be lost from soils during runoff events, but that these nutrients may be readily available for cash crops after cover crop termination. Indeed, there was a significant correlation between soil and tile drain nitrate-N ($p<0.05$), while nitrate-N was lower in both soils and tile drains when cover crop biomass was higher. In summary, multi-year, seasonal sampling of soil and tile drain chemistry has been critical in linking the soil and water quality benefits of watershed cover crops.

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### Response in dissolved organic carbon dynamics and greenhouse gas emissions to watershed-scale implementation of winter cover crops

Kara Prior, Ph.D. Student, Indiana University
(co-authors: T. Royer, J. Tank, S. Christopher, B. Hanrahan, U. Mahl, S. Speir, M. Trentman)

Dissolved organic carbon (DOC) in streams plays an important role in water quality, both directly and indirectly, serving as an energy source for heterotrophic bacteria, a reactant in biogeochemical processes such as denitrification, while in excess it can compromise drinking water supplies. Agricultural soils contain large pools of organic carbon, which can be transported to adjacent waterways as DOC. We are quantifying how the watershed-scale adoption of winter cover crops impacts DOC dynamics and the relationships between DOC and greenhouse gas emissions from streams. As part of watershed-scale cover crop project in northern Indiana, we analyzed monthly dissolved carbon dioxide, methane, and nitrous oxide samples from tile drains and streams in one watershed, and bi-weekly DOC samples from two intensively farmed watersheds beginning in June 2015. We found significant differences in DOC concentrations across seasons, as well as between streams (mean = ~3 mg C/L) and tile samples (mean = ~1.5 mg C/L). We used instantaneous DOC loads to examine watershed contribution via tile drains to the total steam load over the course of the year. For both carbon dioxide and methane, concentrations in the streams were several fold higher than in water from tile drains. The relationships between DOC dynamics and concentrations of greenhouse gases provide a more thorough picture of the agroecosystem carbon cycle, with potentially important implications for water quality and future climate change.

## Session 42, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects III

### Long-term research and monitoring of conservation practice effects in Iowa watersheds

Thomas Moorman, Microbiologist, National Laboratory for Agriculture and the Environment, USDA-ARS
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Impacts of conservation practices on water quality can be demonstrated at the plot and field scales in research or on-farm settings. Watershed-scale monitoring is often used to examine the cumulative effects of conservation practice implementation for that drainage area. The Upper Mississippi River Basin is dominated by corn and soybean production and the export of nitrate-N is an important contributing factor to development of hypoxia in the Gulf of Mexico. In response to this challenge the use of winter cover crops, denitrification bioreactors and wetlands have been demonstrated to be effective at the plot and field scale for nitrate removal. We present long-term water quality data for two different Iowa watersheds: the South Fork of the Iowa River (SFIR) and Walnut Creek (WC) in Jasper Co. The SFIR has intensive row crop and swine production while reconstructed prairie has been progressively added in WC. These settings will illustrate many of the issues in assessing effectiveness of conservation practices over time.

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### Re-aligning stream rehabilitation theory and practice to attenuate edge-of-field and in-stream nitrate export and in agricultural waterways in Canterbury, New Zealand

Brandon Goeller, Ph.D. Student, University of Canterbury
(co-authors: C. Febria, H. Warburton, K. Collins, K. Hogsden, H. Devlin, J. Harding, A. McIntosh)

In lowland Canterbury, New Zealand, waterways are agricultural drains tices and are currently impacted by aquatic weeds, deposited fine sediments, nutrient levels well above acceptable human health limits, and depauperate freshwater communities. We attempt to overcome the common hurdles in stream rehabilitation practice by incorporating societal, ecosystem service and ecological scales into a single regional-scale experiment called the Canterbury Waterway Rehabilitation Experiment (CAREX). Using a network of nine one-kilometer long waterways across 14 farms, we articulated restoration goals based on the desired freshwater services. Several restoration tools are available, but evidence of their effectiveness and best practices associated with their use are lacking, particularly in combination with one another. We used baseline data at various spatial scales to identify the most appropriate spatial scale for the application of each restoration tool. To complement existing stock exclusion and riparian planting measures, edge-of-field denitrifying bioreactors and in-stream additions of labile carbon were trialled to reduce downstream export of nitrate-N. Bioreactors reduced downstream nitrate-N export during all seasons without impeding the drainage function of agricultural waterways; however, in-stream solutions are needed to address the large downstream flux of nitrate-N that is not removed by edge-of-field and riparian nutrient tools. This emphasizes the need for a toolbox-based stream rehabilitation approach which addresses the scale and source of nutrient problems in agricultural waterways. Practical, cost-effective stream rehabilitation tools are recommended to address downstream nutrient export while catchment-scale nutrient plans are developed to address losses from land.

## Session 43, Integrating Science and Management in a Decision-Making Framework

### Using synthetic data as an uncertainty assessment tool

Stephanie McAfee, Assistant Professor of Geography/Dep. State Climatologist - Nevada, University of Nevada, Reno
(co-authors: C. Woodhouse, G. McCabe, G. Pederson)

The Colorado River provides water to over 40 million people in the southwestern U.S. and is likely one of the most researched basins in the Nation, if not the world. As such it has been the focus of numerous technologically advanced modeling studies. These efforts have been enormously useful in understanding the basin's response to potential climate change. However, such research is computationally costly and requires significant model set-up. Here we demonstrate a substantially less time-consuming method that uses a very simple statistical model of flow and synthetic climate time series to (1) estimate the range of variability in flow that could occur under similar climate change scenarios, and (2) investigate how much of that is related to variability in the timing of cooler, wetter, warmer, and drier years, which is still considered largely unpredictable, and to basin conditions at the start of the run. This method allows for uncertainty quantification, as well as a way to identify specific climate scenarios for more detailed and physically robust analysis.

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### The Upper Missouri Basin Impacts Assessment and Missouri Headwaters Basin Study

Patrick Erger, Supervisory Hydrologist, Bureau of Reclamation
(co-authors: G. Benock, L. Dolan, J. Heffner, M. McGuire, J. Lanini, D. Broman, G.T. Pederson, J. Martin, C.A. Woodhouse, E.C. Cook)

The Bureau of Reclamation (Reclamation) is collaborating with the Montana Department of Natural Resources and Conservation in the Upper Missouri Basin Impacts Assessment (UMBIA) and Missouri Headwaters Basin Study (Basin Study), whose spatial domains encompass the hydrologically complex Missouri and Musselshell Rivers upstream of the Army Corps of Engineers' Fort Peck Reservoir. These activities are made possible through the WaterSMART Program, which was established by the Department of the Interior to implement Section 9503 of the Secure Water Act - Public Law 111-11. The SECURE Water Act authorizes federal water and science agencies to work together with state and local water managers to plan for a range of future water supplies and to take action to secure water resources for the communities, economies, and ecosystems that they support. In the UMBIA, we seek to understand historical variability in the basin's water resources as well as impacts of climate change upon a wide range of basin water uses. We have expanded our collaborations to include researchers at the U.S. Geological Survey who are developing the first hydrologic reconstructions from tree rings in this region. By utilizing this information, and based on a range of approaches, we anticipate a better understanding of historical hydrologic variability over the past 1100 years. We developed a RiverWare operations model to test current operational rules and water uses under hydrologic conditions over the instrumental historical record, the paleo record based on tree rings, and projected future conditions. In the subsequent Basin Study, we will build upon information developed in the UMBIA to evaluate strategies that affect Reclamation's ability to deliver water, hydropower generation throughout system, recreational benefits at Reclamation facilities, fish and wildlife habitat, water quality, water-dependent ecological resiliency, and flood control management throughout the system. We further discuss how the tools and information developed in the UMBIA will be used in the Basin Study and how the study addresses stakeholder needs in the basin.

## Session 43, Integrating Science and Management in a Decision-Making Framework

### Applied paleohydrologic information for improved water management in the Upper Missouri Basin

Gregory Pederson, Research Scientist, U.S. Geological Survey
(co-authors: J. Martin, C.A. Woodhouse, E.C. Cook, M. McGuire, J. Lanini, D. Broman, P. Erger, L. Dolan, S. Gangopadhyay, G. Benock)

The Upper Missouri River Basin (UMRB) is the only major watershed in the western U.S. for which hydrologic reconstructions from tree rings have not been systematically generated. This knowledge gap is critical given that the region is facing an array of water resource issues that are challenged by climate change and natural hydrologic variability, and has experienced both severe floods and droughts in the recent past. Providing a longer context for understanding past flow variability is critical for anticipating and managing future water supplies. Here we present recent progress in a collaborative research project with the U.S. Bureau of Reclamation (USBR) and Montana Department of Natural Resources and Conservation (DNRC) that seeks to address this data and knowledge gap. Working with stakeholders and water managers, we co-designed research objectives; identifying 21 major UMRB gages that allow for characterizing historical natural streamflow in the basin, bracketing reconstruction uncertainties stemming from methodological approaches, and targeting information that would span changes in streamflow over the past 1200 years. To bracket uncertainties in streamflow reconstructions, we produced records using the more traditional principal component based regression methods alongside a more novel "climate-informed" best subsets regression approach. Reconstructions were then statistically disaggregated to daily flows and routed through the USBR and DNRC constructed RiverWare operations model to test current operational rules against the sequence of historic flood and drought events. In conjunction with future hydrologic scenarios, information generated from this study is intended to help guide operational improvements and assess water management options for adapting to severe drought and flood conditions. Strengths and limitations of this effort will be discussed along with lessons learned for future work.

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### Overcoming the "last-mile" problem of use-inspired research

Jeffrey Lukas, Research Integration Specialist, Western Water Assessment, University of Colorado Boulder

In mass transit, the "last-mile" problem refers to the disproportionate difficulty of getting a passenger the final increment to their actual destination, after a bus or other mode has efficiently gotten them most of the distance from their starting point. In use-inspired research, there is an analogous problem: When a research project conducted in partnership with a decision-maker successfully produces information that matches a previously identified decision need, but the remaining distance—the intended integration of that information into a formal decision framework—is unexpectedly difficult and time-consuming.

The Western Water Assessment (WWA), a NOAA Regional Integrated Sciences and Assessments (RISA) program, has worked to connect climate science with water resources decision-making at the regional and local scales in Colorado, Utah, and Wyoming through dozens of collaborative research projects. This work has produced information at multiple spatial and temporal scales, including paleohydrology reconstructions, drought monitoring indices, modeling of recent perturbations to snowpacks, seasonal climate forecasts, and projections of future hydrology under climate change. Reviewing the outcomes of these diverse projects, we find that initial success in co-producing apparently relevant and useful information has often been followed by protracted struggles to ingest the information into management and planning processes. In other cases, this transition is much easier. And sometimes the new information is better used outside of formal decision-making frameworks, e.g., informing a manager's mental model of their system. Synthesizing past WWA research outcomes and identifying the factors that are associated with more or less difficulty in going that "last mile" may allow for future use-inspired research to anticipate these challenges and better connect with decision-making.

## Session 44, The US-Mexico Transboundary Aquifer Assessment Program: Ongoing Work and Future Directions

### The U.S. Mexico Transboundary Aquifer Assessment Program in Arizona: Current and future efforts

Elia Tapia, Graduate Associate, University of Arizona Water Resources Research Center
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The binational United States-Mexico Transboundary Aquifer Assessment Program (TAAP) was officially launched on August 19, 2009. The Mexican and U.S. Principal Engineers of the International Boundary and Water Commission (IBWC) signed the "Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program". This IBWC "Joint Report" has served as the framework for U.S.-Mexico coordination and dialogue to implement transboundary aquifer studies. In 2016, the Binational Study of the Transboundary San Pedro Aquifer was published. In this report, the United States and Mexico seek to contribute with scientific knowledge and binational data on climate, geology, soils, land cover, land use, and hydrology for the San Pedro aquifer. The report compiles and creates a database of scientific information from both countries, and identifies data gaps and information to be updated for subsequent phases. Current TAAP efforts focus on completing the Binational Study of the Transboundary Santa Cruz Aquifer; sharing results from the San Pedro study to different stakeholders in the U.S. and Mexico; surveying hydrologic models and completing high-resolution regional climate projections for the Santa Cruz Aquifer. Future directions include the development of groundwater hydrology projections for the Mexican portion of the Santa Cruz Aquifer to complement the climate change studies previously conducted in the U.S. and to update the information produced during the development of the Santa Cruz and San Pedro reports. Also, a long term goal could be the development of binational hydrologic model for these two aquifers that are specified as priority aquifers by U.S. Public Law 109-448.

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### Aquifers shared between Mexico and the U.S.: Management perspectives and their transboundary nature

Rosario Sanchez, Research Scientist, Texas Water Resources Institute
(co-author: G. Eckstein)

36 aquifers have been identified along the Mexico-U.S. border. Of these, only 16 have adequate data to provide a reasonable level of confidence to categorize them as transboundary. Limited and/or contrasting data over the other aquifers in the region reflects the void in transboundary groundwater management and assessment mechanisms throughout much of the Mexico-U.S. border. This paper identifies management mechanisms related to transboundary aquifers shared between Mexico and the United States. It also evaluates the differences in the transboundary nature of these aquifers, and how their combined hydrological and geographical considerations interrelate with local and regional social, economic, political and even scale dimensions to create complex management challenges.

## Session 44, The US-Mexico Transboundary Aquifer Assessment Program: Ongoing Work and Future Directions

### Effects of changing available water regimes on riparian vegetation in the Mesilla Valley Basin Aquifer New Mexico, USA

Aracely Tellez, Graduate Research Assistant, New Mexico Water Resources Research Institute
Maria Milanes-Murcia, Post-Doctoral Scholar, New Mexico Water Resources Research Institute

Due to increasing levels of groundwater pumping as well as consecutive drought seasons in the Southwest, the Mesilla Valley basin aquifer and the Rio Grande are projected to experience declining water levels. These water changes can consequently influence stream ecosystem attributes including riparian vegetation, wildlife habitat areas, and the surrounding agriculture. Surface water availability has shown to have a stronger impact on riparian vegetation than groundwater nevertheless; both water systems can have a connection to riparian zones and show current conditions of both water systems. Studies have demonstrated the importance of riparian areas due to their multiple functions and their diverse ecosystem; however, less attention has been given to riparian areas along the lower Rio Grande in New Mexico due to the extensive agriculture that dominates the area.

The analysis of strategies to develop policies and groundwater management plans are essential to ensure the sustainability of the Mesilla Valley basin aquifer and other aquifers along the U.S.-Mexico border. Priority aquifers established under the Act need additional research and cooperation efforts to avoid the tragedy of the commons and protect water resources through conservations practices able to be implemented. The financial support from the U.S. and the international cooperation with the United Nations in Mexico would contribute to support activities on both sides of the border able to organize plans to improve the management of transboundary aquifers.

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### Additional dialogue on the US-Mexico Transboundary Aquifer Assessment Program: Past, present, and future

Jacob D. Petersen-Perlman, Research Analyst, Water Resources Research Center, University of Arizona

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The Transboundary Aquifer Assessment Program (TAAP) between Mexico and the United States has existed for several years. With coordination through the International Boundary and Water Commission (IBWC) and the joint cooperative framework in the “Joint Report of the Principal Engineers Regarding the Joint Cooperative Process United States-Mexico for the Transboundary Aquifer Assessment Program” by the U.S. and Mexican Principal Engineers, coordination and dialogue between the countries have continued to the present on several aquifers important to users in each country. This presentation will highlight key findings, lessons learned, and future directions of the TAAP highlighted in the two-part session. Panelists and the audience will be invited to participate in further dialogue on the TAAP framework and cooperative efforts.

## Session 45, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Policies)

### The economics of local enhanced management areas in southwest Kansas

Bill Golden, Assistant Research Professor, Kansas State University
(co-author: B. Guerrero)

The purpose of this research was to provide input into the water planning process for select subareas in southwest Kansas. The study considered two groundwater use scenarios. Stakeholder input suggests that a reduction in groundwater use may be desirable in order to preserve the Ogallala Aquifer and extend its economic contribution to both the producer and the regional economy. This research estimates measures of producer net profits and regional value added in an endeavor to define the benefits and costs of water conservation policy. This research placed a monetary value on the conserved groundwater and considers a future where the growth in irrigated crop yields is assumed to continue. The results of the models that assume the goal is to maximize producer profits, suggest that the LEMA framework of groundwater management will provide benefits to both the agricultural producer and rural communities. The magnitude of these benefits vary by Subarea. Subarea 1 will receive the greatest benefit, increasing cumulative net revenue by 6.3%, while Subarea 2 and Subarea 3 increase cumulative net revenue by 2.1% and 2.7%, respectively. The variation in Subarea specific results are due to Subarea specific variations in initial hydrological conditions, current and projected irrigated crop mix, and dryland production options which determine how the irrigated crop mix varies over time and the rate at which irrigated cropland is converted to dryland production. This research suggests that generally, the rural economy receives as much if not more benefits from groundwater conservation as compared to the agricultural producer. Subarea 1, Subarea 2, and Subarea 3 generated 8.3%, 2.7%, and 1.8% respectively more cumulative value added under the LEMA scenario as compared to the Status Quo scenario. These findings raise the question as to the extent to which value added could be increased if groundwater was managed based on maximizing value added as opposed to maximizing producer profits. If Subarea 3 were to manage their groundwater based on implementing a LEMA and maximizing value added, cumulative value added would increase from a 1.8% gain to an increase of 18.7%. While an in-depth analysis of how this concept would impact other areas in southwest Kansas, and how we might implement such a policy goes beyond the scope of this research, the topic certainly necessitates future research.

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### Sustainable Groundwater Management Policy in California: Its implementation so far

Samuel Sandoval-Solis, University of California, Davis
(co-author: M. Flores Marquez)

Late in 2014, California passed a legislation, called Sustainable Groundwater Management Act (SGMA), intended to manage groundwater for the entire state. SGMA is comprised of a set of actions and procedures that incentivize the local management of groundwater. As part of the process, local Groundwater Sustainable Agencies (GSAs) are forming throughout the state, with the mandate to develop a Groundwater Sustainable Plan (GSP) to avoid six undesirable consequences: lowering of water tables, overdraft, degradation of groundwater quality, seawater intrusion, land subsidence and disconnection of surface water and groundwater interactions. The present study analyzes the implementation, so far, of SGMA. Specifically, it will focus on the GSA formation throughout the state and some of the formation processes that are seen as successful, or unsuccessful. In addition, it will focus on the different approaches to develop groundwater budget to integrate GSP.

## Session 45, Irrigation Aquifer Depletion and Challenges to Sustainability: Innovative solutions (Policies)

### Implementing the Sustainable Groundwater Management Policy in California, Case of Study: Ukiah Valley Groundwater Basin

Maritza Flores Marquez, Graduate Student Researcher, University of California, Davis
(co-author: S. Sandoval-Solis)

The Sustainable Groundwater Management Act (SGMA) is the first legislative effort of its form in California geared towards reforming groundwater management throughout the state after years of uncoordinated and voluntary management of groundwater. SGMA will enforce the management and monitoring of groundwater resources at a local scale by requiring medium and high priority groundwater basins to form a Groundwater Sustainability Agency (GSA). GSAs are required to submit a Groundwater Sustainability Plan (GSP) addressing how their groundwater resources will be managed to achieve groundwater sustainability by avoiding six undesirable results by the year 2040. Before the development of the GSP, there is a need to characterize the groundwater basin by estimating a groundwater budget of inflows, outflows and change of storage in the respective aquifer. The objective of this study is to describe (a) the implementation of SGMA in the Ukiah Valley Groundwater Basin, and (b) the calculation of the groundwater budget for the groundwater basin. The Ukiah Valley Groundwater Basin, located in the North Coast Hydrologic Region of California, was classified as a medium priority groundwater basin. In collaboration with local stakeholders, a groundwater budget was calculated (from year to year on a monthly time step) to characterize the Ukiah Valley Groundwater Basin. Results from the groundwater budget will inform on how groundwater trends have changed through time as a function of water supply and water demands. Results from the groundwater budget will inform the GSA of the groundwater basins' current and historical conditions. These results will provide the GSA guidance on proposing action plans and monitoring protocols for the GSP that will allow them to achieve and maintain groundwater sustainability by the year 2040 and onward.

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### Do water user associations increase the adoption of micro-irrigation systems? A conceptual framework and implications for water policy design

Yubing Fan, Post-Doc Research Associate, Texas A&M AgriLife Research
(co-authors: *S. Park, Z. Nan)
*Presenter - Seong Park, Associate Professor, Texas A&M AgriLife Research

Water scarcity has brought new challenges for social development, ecosystems, and agricultural production worldwide. In northern China, uneven distribution of water resources makes some densely populated regions be classified as severe scarcity. Limited water availability and rare precipitation are constraining local economic development and threatening people's livelihood. Thus, rational allocation and effective management of water resources are critical in these areas. This study presents an integrated conceptual framework of farmers' participation in water user associations (WUA) and installation/application of micro-irrigation systems (MIS). A preliminary analysis of its applicability is conducted with a multivariate probit regression model. We use data from a farmer survey conducted in Minqin county, Northwestern China. In this study, three outcome variables are membership of WUA, installation and application of MIS (Yes=1, No=0). Farmers' participation dimensions of WUA include whether they participate in the establishment process, selection of association leaders, etc. Farmers' opinions of WUA's functions are investigated, for instance, canal maintenance, conflict resolution, etc. Independent variables include farmer characteristics, perceptions of water scarcity, information and incentives. The results show significant correlations between the outcome variables and participation dimensions as well as perceptions of WUA functions. Factors significantly increasing the participation in WUA and installation and application of MIS include perceptions of water shortage and irrational water allocation, information from WUA, and incentives of government investments and conserving water. Participation in WUA is also increased by education level of senior middle school or higher and larger farming areas. Furthermore, installation and application of MIS are encouraged by a positive attitude of water conservation. Institutional design for public participation is still insufficient. Policies should target decentralized water management institutions and more public participation in managing WUA and promoting MIS.

## Session 46, Arizona Programs and Projects to Address Future Colorado River Shortages

### Colorado River shortages to Arizona under the 2007 interim guidelines

Vineetha Kartha, Colorado River Management, Arizona Department of Water Resources

The Colorado River supplies approximately 41% of Arizona's water needs. Since 2000, the Colorado River Basin has been experiencing a historic, extended drought that has impacted regional water supply and other resources such as hydropower, recreation, and ecologic services. To prepare for possible shortages in the Lower Basin and to guide Colorado River operations during low reservoir conditions, water delivery operations are described and contemplated in the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Interim Guidelines). Each year, the Secretary of the Interior determines the projected plan of operations of the storage reservoirs in the Colorado River Basin and determines when normal, surplus, or shortage conditions occur in the Lower Colorado River Basin. According to the 2007 Interim Guidelines, a shortage condition is determined when insufficient mainstream water is available to satisfy 7.5 million acre-feet (maf) of annual consumptive use in the Lower Division states. A key factor for determining annual operations is the amount of storage (as measured by water elevation) in Lake Mead. If a shortage is determined, Arizona bears the brunt of the reductions, with the Central Arizona Project (CAP) taking most of the reductions.

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### Water banking in Arizona

Terri Sue Rossi, Technical Administrator, Arizona Water Banking Authority

The Arizona Water Banking Authority or AWBA was created in 1996 in response to underutilization of Arizona's 2.8 million acre-foot Colorado River entitlement and fear that if left unused, water demands in California and Nevada would become dependent on Arizona's water. Since 1997, the AWBA has developed over 4 million acre-feet of water credits to support its water management objectives and interstate water banking with Nevada. Unlike water banking elsewhere, the AWBA is not an exchange. Rather, it is a self-developed 100-year insurance policy against future shortage impacts realized when Colorado River supplies and user demands intersect. Historically, the AWBA's primary function was to store unused Colorado River water to "monetize" the insurance policy. Because supplies and demands are now intersecting, water available for the AWBA has dwindled and is expected to end in the near term. Consequently, the AWBA's function is shifting from monetizing the insurance policy to using it. Using the insurance policy is the act of "recovering" the developed water credits for use by AWBA customers. Recovering the AWBA's water credits is not meant to mitigate the probability of shortage, but rather to respond to shortage impacts as they occur. Much uncertainty exists for the AWBA and its customers including the frequency and depth of shortage impacts, how to leverage the use of the water credits over an extended period and the dramatically increasing cost of developing more credits. This session will focus on what water credits are and how they are developed and used and how many additional credits should be developed and for what purposes. Additionally, this session will focus on issues and tough decisions facing the AWBA as it transitions from developing to using these water credits.

## Session 46, Arizona Programs and Projects to Address Future Colorado River Shortages

### Recovery of banked water in Arizona: Planning and implementation

Laura Grignano, Senior Policy Analyst, Central Arizona Water Conservation District (CAWCD)
(co-author: K. Seasholes)

For nearly two decades, the Arizona Water Banking Authority (AWBA), the Arizona Department of Water Resources (ADWR) and the Central Arizona Water Conservation District (CAWCD) have been engaged in an ambitious program to store excess Colorado River water in the aquifers of Central and Southern Arizona. The need to recover this water will unfold over many decades and will be triggered by different factors such as shortages on the Colorado River and specific interstate contractual obligations. In 2014, the Joint Recovery Plan, developed by CAWCD, AWBA and ADWR, was finalized. This document laid the foundation for how this water will be recovered. Many factors will determine the timing, magnitude, location and methods of this recovery and numerous agencies and stakeholders will be involved; therefore, effective planning and coordination among AWBA, ADWR, CAP and stakeholders is essential to the successful recovery of this water. Like any long range planning effort, there are elements that are uncertain and subject to change, but by jointly producing this Plan, ADWR, AWBA, CAWCD and stakeholders have recommitted to ongoing collaboration. Since the development of this document, numerous activities have been underway to implement recovery when needed. CAWCD will be a recovery agent for the AWBA when firmed entities are affected by shortages and/or when Nevada requests its water. CAWCD will implement recovery either through exchanges or direct recovery, most likely a combination of both. Implementation activities include the development of the draft CAP System Use Agreement in conjunction with the Bureau of Reclamation, the development of associated agreements to implement recovery such as a Recovery Exchange Agreement and Firming Agreement, the development of a blended cost concept, updated modeling efforts, as well as feasibility studies for potentially drilling new well fields.

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### Voluntary programs to protect lakes Powell and Mead - Colorado River Pilot System Conservation Program and drought response actions memorandum of understanding

Chuck Cullom, Colorado River Programs Manager, Central Arizona Project
(co-author: D. Ikeya)

Due to a 16-year drought and an imbalance between supplies and demands in the Lower Basin, modeling projections starting in 2012 showed that without proactive conservation, Lake Powell and Lake Mead could decline to levels that would greatly affect water users in all seven Colorado River Basin states. The Central Arizona Project (CAP), in partnership with other major water utility organizations from throughout the whole Basin and the Bureau of Reclamation (BOR), sought ways to benefit the Colorado River system through two pilot programs that explore ways water users can cooperatively take voluntary, proactive measures, identify modifications to water policy management, and contribute funds to increase reservoir storage to protect Lake Mead and Lake Powell elevations. The Pilot System Conservation Program (PSCP) achieves increased reservoir storage through voluntary compensated reductions in consumptive use in both the Upper and Lower Basins. The Lower Basin Pilot Drought Response Actions Memorandum of Understanding (MOU) is based on coordinated actions among the Lower Basin states and BOR to store additional water in Lake Mead. Protecting reservoir elevations in the largest reservoirs in the United States would not be possible without interstate and intrastate cooperation. CAP has partnered with 12 irrigation districts, 4 cities, and 1 industrial user to create conservation within Arizona, as well as working with the Arizona Department of Water Resources to coordinate interstate actions. The participation in these pilot programs has spanned over all 7 Basin states, demonstrating the reach of these programs and the recognition that efforts of this magnitude can only be possible with involvement throughout the whole Basin.

## Estimation of available surface water for managed aquifer recharge in California's Central Valley: A case study on the Cosumnes River Basin

Erfan Goharian, Postdoctoral Researcher, University of California, Davis
(co-authors: S. Sandoval-Solis, G. Fogg)

Frequent incidents of drought along with a high rate of population growth and other warning signs force water managers to seek plausible new sources of fresh, clean water for the future. In California, during drought, the over-exploitation of wells supplying up to 60% of the agricultural water demand, has caused a fast decline in the water level of aquifers. This jeopardizes sustainability of groundwater systems. Management of Aquifer Recharge (AMR) has become a common and fast-growing management option, especially in areas with high water availability variation intra and inter annually. Enhancing the recharge by the use of peak runoff requires integrated river basin management to improve prospects to downstream users and environmental flows, particularly during droughts. This study implements a quantitative approach to estimate surface water availability for managed groundwater recharge the American-Cosumnes River basin, CA. For this purpose, three settings are considered, first, pre-development condition which is represented by unimpaired flows. Secondly, available peek flow releases from Folsom Reservoir derived from historical releases from the reservoir. Finally, the Folsom Reservoir is re-operated in order to maximize the available water for recharge without violating from other objectives. The simulation of Folsom Reservoir is done by use of a new developed model, Folsom Simulation model (FolSim). Preliminary results show peak flows from winter (Dec-Feb) and extended winter (Nov-Mar) from the American River flow can be captured within a range of 190,000 to 295,000 Acre-Feet per Year (AF/year) during wet seasons through the Folsom South Canal for groundwater recharge in the southern basin. Results from this study shows replenishing excess surface water during wet seasons can reduce the overdraft and help to manage the groundwater in a more sustainable fashion.

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## Managing artificial recharge in Las Vegas and southern Nevada

David Kreamer, Professor, University of Nevada, Las Vegas

The metropolitan area in, and directly surrounding, Las Vegas, Nevada, USA supports a population of over 1.95 million people with a population growth of 41.91 percent since 2000. Las Vegas is situated on the edge of the Mojave desert, with a subtropical, hot desert climate, an average annual rainfall of about 10 cm, and 134 days with high temperatures over 32 degrees C. The city is in the rain shadow of several mountain ranges which rise up more than 3000 m above sea-level. Approximately 90% of the area's water comes from the Colorado River at Lake Mead, which is limited by Compact. Since 1987, Las Vegas has been taking unused portions of it water allotment from the Colorado River during the low-demand winter months and pumping it underground, where it serves as an additional water source for the high-demand summer months, now having 70 dual-purpose, reversible, recharge/ recovery wells, will screened intervals at about 200-300 m depth. This is complicated by the existence of a low quality, shallow regional aquifer at less than 100 m, necessitating the need for deeper injection. The system, said to be the largest of its kind in the world, has a capacity of approximately 3785 $m^3$/day, and has recharged over 394 million $m^3$. This and other innovative water conservation strategies serve as the route to accommodate a burgeoning population in this dry climate.

Keywords: Managed Aquifer Recharge, Artificial Recharge, Groundwater Management

## Session 47, Aquifer Recharge & Cloud Seeding

### Tracking hurricane precipitation signatures in aquifer recharge: An exercise in citizen science

Kristine Uhlman, Retired: University of Arizona WWRC
(co-author: C. Eastoe)

Climate directly influences the amount of water recharged into aquifers by controlling the amount, and seasonality, of precipitation and evapotranspiration. In the arid southwestern United States, groundwater resources are being consumed at a rate that exceeds recharge. Rapid assessments of groundwater character and its connection to climate can provide valuable information to local water managers and citizen groups. These assessments, built on relatively inexpensive isotope geochemistry analyses of samples from volunteered domestic wells, have the additional advantage of encouraging a water management ethic in the citizen participants. In most aquifers we evaluated across Arizona, Carbon-14 based age-dates indicated that recharge likely occurred at the end of the Pleistocene, when the climate was colder and wetting than the current era. Aquifers tapped by some remote rural communities in Arizona, however, exhibit relatively recent aquifer recharge because the resource has not been over-developed. These younger aquifer systems are more vulnerable to drought, but they are also more likely to retain the isotopic signature of recent recharge. Working with the community in 2010, we had performed the first rapid assessment of groundwater vulnerability to climate variability using this inexpensive, interactive method in Arivaca, Arizona. The community had responded to the surprising results with increased interest in managing their water for sustainability in the face of climate variability and change. Investigators were then contacted by the community five years after project completion to assess the status of the aquifer. The stable isotope signature of the 2014 southern Arizona Hurricanes (Norbert, Odile, and Simon) confirmed aquifer recharge where the landowners practiced active stormwater management and capture. These results encouraged the community to continue stormwater management to enhance natural recharge of their water supply aquifer, changing behavior to an active and individual water management ethic.

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### Weather modification in Colorado

Erik Skeie, Program Assistant, Colorado Water Conservation Board

Ever since the 1950s, Colorado has been active in weather modification practices in order to increase winter time precipitation. The Colorado Water Conservation Board administers Colorado's Weather Modification Program in the State, which has a total of seven permitted programs that utilize over 100 ground based cloud seeding generators to produce more snow.

Colorado's Water Plan states that our population could nearly double by 2050, leaving us with a supply and demand gap between 310,000-560,000 AF of water. Cloud seeding has been shown to increase the precipitation of seedable storms by 5-15%, and is a relatively cheap method of increasing our water supply. After the drought that began in 2000, the Colorado River Basin States began to increase activity in weather modification. The Lower Basin States have been providing funding to help fund cloud seeding efforts in Colorado, Utah, and Wyoming since 2006; and weather modification has been established as one of the main components of the Upper Colorado River Basin Drought Contingency Plan.

The silver iodide used in Colorado's operations provides a nucleus for super cooled liquid water in the clouds to form ice crystals. This moisture would not have precipitated out of the cloud due to a lack of ice nucleating particles in the atmosphere. Silver iodide has been studied since the 1960s, and through these multiple studies and decades of data has been shown to have negligible impact (i.e. findings of no significant effects on plants and animals).

Colorado will continue making their seeding operations more efficient. Recent climatology studies combined with new measurement and dispersion technologies have given Colorado a clear path forward to not only improve current programs, but develop new programs in areas where cloud seeding can have a high impact.

## Session 48, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects IV

### Agriculture partners to protect water quality in the Western Lake Erie Basin

Andrea Stay, Grants and MAEAP Training Liaison, Michigan Department of Agriculture and Rural Development

The agriculture community has been working in the Western Lake Erie Basin (WLEB) for nearly two decades to improve water quality. Farmers and agribusiness, as well as the state and federal governments, have marshalled additional resources over the past four years to ramp up management changes that will positively impact water quality. The Michigan Department of Agriculture and Rural Development is the lead agency on the Tri-State Western Lake Erie Basin Regional Cooperative Partnership Program (RCPP) Project. The RCPP provides $17.5 million in cost share to farmers in the WLEB region over five years (2015-2019). Over $21 million in partner match was committed by over 40 partner organizations including: state and federal agencies, university and research entities as well as private industry, local agencies, non-profit organizations and local organizations to leverage the $17.5 million from USDA Natural Resources Conservation Service(NRCS). Priority NRCS practices funded include: cover crops, nutrient management plans, no till, strip till and modified no till, phosphorus/nutrient placement and variable rate applications, as well as underground outlet/blind inlet, tile outlet control structures/drainage water management and animal waste management. Michigan's collaborative effort includes voluntary assistance for farmers through the Michigan Agriculture Environmental Assurance Program. This program is designed to reduce farmers' legal and environmental risks through a three-phase process: 1) education; 2) farm-specific risk assessment and practice implementation; and 3) on-farm verification that ensure the farmer has implemented environmentally sound practices. Technicians are trained and knowledgeable about practice implementation, available contractors and resources, and federal program assistance to make it easier for the farmer to implement the changes. Through the RCPP, Michigan, Ohio and Indiana have worked together on program promotion, technician training, watershed-scale conservation implementation, and sharing monitoring and research results. Our team continues to evolve to bring together more voices to the discussion and boots to the ground.

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### Water quality targeting success stories: Achieving cleaner water through farm conservation watershed projects

Michelle Perez, Senior Policy Specialist, American Farmland Trust

How do you clean up impaired waterbodies with farm conservation practices? One targeted watershed project at a time. This presentation will share lessons learned from six "Water Quality Targeting Success Stories" featured in a new report due in May by American Farmland Trust and World Resources Institute. The projects used instream monitoring to detect water quality improvements attributable to farm conservation practices adopted in the watershed. Successful projects were found in California, Oklahoma, Iowa, Wisconsin, and Indiana. Given that hundreds of similar projects exist under several USDA programmatic frameworks (e.g., Mississippi River Basin Healthy Watersheds Initiative and National Water Quality Initiative) and hundreds more are getting started (Regional Conservation Partnerships Program), the report highlights best practices to increase the likelihood of similar levels of success.

Findings include:

- Four projects (CA, WI-1, WI-2, and IN) relied on the outreach, education, and technical services of their state's local conservation districts to design and implement the project),
- Three projects (CA, OK, IA) relied on farmer leadership to design their projects and encourage farmer participation
- Three projects (OK, IA, WI) used their state Phosphorus Indices (PI) to geographically target project resources to fields with the highest phosphorus losses;
- Two projects (IA & WI) used the PI to also estimate field-scale and project-level environmental outcomes;
- Two projects detected about one-third less instream phosphorus loads within a year after practice implementation (IN, preliminary results) and after a three-year practice implementation phase (WI-2); and
- Two projects proposed their streams be delisted for *E. coli* (OK) and sediment (WI-1).

Methods included literature reviews and interviews with USDA staff, farm conservation and water quality experts, and leaders of the six projects. Project leaders attribute their success to 16 key factors. Comparing the case studies yielded 11 lessons about designing, implementing, and evaluating successful targeted watershed projects. Recommendations are provided for USDA, EPA, Congress, the research community, charitable foundations, and the corporate supply chain sustainability community to help other projects achieve and measure landscape-scale environmental outcomes.

## Session 48, Quantifying the Water Quality Outcomes of Watershed-scale Conservation Projects IV

### Conservation practice effectiveness and application for water quality improvements in agricultural subwatersheds of the Mackinaw River, Illinois, USA

Maria Lemke, Aquatic Ecologist, The Nature Conservancy
(co-authors: D. Kovacic, M. Day, M. Wallace, W. Perry, J. Kraft, K. Kirkham, A. Maybanks, K. Bohnhoff, T. Noto, M. Linsenbigler)

The Mackinaw River is a major tributary of the Illinois River, which feeds into the Mississippi River. This 740,000-acre watershed contains some of the most productive agricultural land in the nation, and plays a key role in the livelihood of farmers and the Illinois economy. Urban development and row-crop agriculture have stressed freshwater resources, leading to habitat loss and reduced water quality. Our research has shown that surface water oriented conservation practices are not enough to improve water quality in these tile-drained, agricultural watersheds and has led to subsequent research testing effectiveness of infield and edge-of-field practices to reduce nonpoint source runoff. Strategies include: (1) field-scale and watershed-scale monitoring of wetland effectiveness, (2) bundling in-field (cover crops, nitrogen (N) management) and edge of field practices, and (3) watershed mapping of tile drainage to strategically implement conservation practices. Nine years of site-scale data from wetlands show up to 50% reduction of nitrate-N from field drainage tiles. In a parallel paired watershed project, we are measuring effectiveness of constructed wetlands at the 2,000 to 10,000-acre watershed scale. From 2012 to 2015, we worked with a Farmer Network in a 43,000-acre drinking water supply watershed to address N management practices. During that time, the % of participants that applied 80-100% fall N declined and those that applied 80-100% spring N increased. Current efforts include working with the agricultural community to move 3000 acres from fall to spring N applied. University partners have used LiDAR, GIS and aerial infrared data to estimate tile drainage patterns in the 43,000-acre watershed and map locations for conservation practices. Science and continued development of partnerships are providing the necessary tools to develop and apply sustainable, conservation-based solutions to improve water quality and diversity in this agricultural watershed.

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### Agricultural watershed projects and conservation practices: Synthesis and lessons learned from 13 watersheds across the United States

Deanna Osmond, Professor, NC State University
(co-authors: D. Meals, D. Hoag, M. Arabi, D. Line, A. Sharpley)

From 2004 to 2006, the USDA National Institute of Food and Agriculture (NIFA) and the NRCS jointly funded 13 watershed projects across the nation to evaluate the measurable effects of agricultural conservation practices on trends in water quality at the watershed scale. Conducted under the Conservation Effects Assessment Project (CEAP), a multi-disciplinary team synthesized information from these projects to illuminate critical lessons learned about managing agricultural landscapes to meet physical, biological, and chemical water quality goals. Although much was learned in the projects about monitoring and modeling of the effects of conservation programs and about social and economic factors influencing adoption of conservation practices, most of the NIFA-CEAP projects were unable to demonstrate water quality changes for many reasons. Lessons learned from the Synthesis demonstrated that implementation of conservation practices to address agricultural water quality issues is far more than a technical or financial exercise. Cost-share and other incentives are usually necessary but seldom sufficient to drive implementation. Conservation practices have been selected that did not address the water quality problem(s) of concern and were not applied to critical source areas in the watershed. If conservation is to be linked to demonstrating water quality change, then water quality monitoring must be designed to meet individual project objectives and accurately measure critical indicators with sufficient precision and spatial resolution to evaluate response to land treatment. Models must be selected and applied with technical expertise. Both monitoring and modeling have important roles to play in watershed project evaluation and their collaborative use should be encouraged. The demands of decreasing budgets and increasing needs for accountability require that we not only learn from the NIFA-CEAP projects but that we apply this knowledge to move forward to more effectively achieve water quality goals.

## Session 49, Students, Fellows and Feds: Training the Next Generation of Water Resource Professionals

### The water resource workforce: Impressions from the nonprofit sector

Larry E. Brazil, Vice President, Water Resources Management Division, RTI International

RTI International is an independent, nonprofit research institute dedicated to improving the human condition. Clients rely on us to answer questions that demand an objective and multidisciplinary approach—one that integrates expertise across the social and laboratory sciences, engineering, and international development. We believe in the promise of science, and we are inspired every day to deliver on that promise for the good of people, communities, and businesses around the world. Our staff of more than 4,700 works in more than 75 countries. Together, we tackle thousands of projects each year to address complex social and scientific challenges on behalf of governments, businesses, foundations, universities, and other clients and partners. RTI is a unique employer with global opportunities for people who want to do interesting, innovative, and meaningful work. Our culture aligns around our mission. As individuals and as an organization, we work to make a difference in the world, upholding our strong values and ethics. We support work/life balance, collaboration, diversity and inclusivity, and entrepreneurial spirit.

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### How embracing diversity improves results: Sharing experiences from a 20 year career in a water utility

Carol Webb, Water Resources and Treatment Operations Manager, City of Fort Collins

As baby boomers retire and millennials enter the workforce, Water Utilities across the nation are making important hiring decisions that will impact their organizations for many years to come. Regardless of the position (field personnel, engineers, managers), Water Utilities should consider workforce diversity as a key factor in selecting new hires and embrace it as an opportunity for improving results. As a 20-year career female in the City of Fort Collins Water Utilities, progressing over those years from an entry level lab assistant to a Water Resources and Operations Manager, I have contributed to and observed the realized benefits of a diversified workforce for the organization and the community we serve. The City of Fort Collins recognizes that a diverse workforce is key to providing exceptional service to their community and consequently has committed, through its strategic objectives, to promote, enhance, and maintain diversity within the organization. My experiences and perspectives will illuminate for others in the water resources field the value of the dimensions of diversity in achieving key organizational outcomes.

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### The United States Geological Survey (USGS) workforce: Today and tomorrow

Earl Greene, Chief of External Research & National Director of the Water Resources Research Institutes, United States Geological Survey (USGS)

The U.S. Geological Survey (USGS) is the nation's principal natural science research and information agency with approximately 8500 federal employees plus contractors, Scientists Emeriti, interns (primarily students) and volunteers. Water is one of seven USGS mission areas around which the agency partners to conduct assessments, research and management. The percentage of USGS employees in professional roles is high relative to most comparable government bureaus. This is reflective of the science mission and need for specialized experience in multiple science disciplines. Since 2010, about one in five USGS employees were "other than permanent" (OTP) federal positions. Student employees also comprise a significant proportion of the USGS workforce, e.g. 8% in 2013. Presently, workforce diversity remains below targeted levels. It is paramount to maintain USGS scientific capability, reputation and provide skilled, innovative science support. However, the USGS is facing retirements, fiscal uncertainty, shifts in societal and organizational priorities and rapid technological change; approximately 35% of the USGS permanent workforce will be eligible for retirement by 2017. As a result, increased dependence on a multisector (federal and non-federal) workforce with increased flexibility, i.e. a greater percentage of OTP, contractors, Scientists Emeriti, non-paid interns and volunteers, is expected. Cultivating communication and entrepreneurship skills in a workforce that can adapt to new technology and respond quickly to changes in science and management priorities will be increasingly important. Greater use of multidiscipline syntheses and landscape-level science will require enhanced capabilities in mapping, geospatial data integration, remote sensing, predictive modeling, scenario development, forecasting, simulation and decision support. Student training will remain a focus of USGS workforce development via the Pathways Internship Program, the National Institutes of Water Resources (NIWR) research projects, and the USGS-NIWR Internship program, among others. Student engagement is identified as one avenue toward achieving race, ethnic, gender and disability diversity within the USGS workforce.

## Session 49, Students, Fellows and Feds: Training the Next Generation of Water Resource Professionals

### How the USGS engages with universities to provide research and training opportunities for students

Eleanour Snow, Program Manager, Youth and Education, U.S. Geological Survey

The USGS has several pathways to research and training for undergraduate and graduate students in geology, ecology, hydrology, and related fields. Through a variety of cooperative and internship programs, students can engage in research with USGS scientists as part of their training. It is a win for both parties. The USGS gets bright young minds engaged with solving scientific problems, and students get exposed to research in the agency, which is often quite different from academic research. This talk will outline the various pathways students can use to work at the USGS and some tips on the application process.

University Partnerships: There are three large collaboratives, each with a different research focus, that bring USGS scientists together with university scientists, other agencies, and students to do research. They are collocated on or near university campuses, and hire student interns to work on USGS research projects. The Water Resource Research Research Institutes are located in all 50 states plus. There are 40 Cooperative Research Units in 38 states performing research in fisheries and wildlife sciences. There are eight regional Climate Science Centers, each housed at a University and working with with up to 8 other universities or research centers.

NSF Partnerships: USGS has partnered with the National Science Foundation to offer internship positions for graduate students to spend 2-12 months at the USGS augmenting their PhD research by collaborating on projects or with tools not available to them at their home institutions. Students apply to NSF for funding supplemental to a grant that is already supporting them. Students gain valuable skills, new mentors, and an understanding of applied science.

Internships: The USGS hires hundreds of interns every summer, some through the mechanisms above, but many through simply advertising open job opportunities. Science centers might recruit through connected networks like campus diversity programs or professional organizations. The applications, however, are through USAJobs. I will give some tips on the application process and talk about how to position yourself for a career in federal service.

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### Evaluating student training and STEM workforce development at the National Institutes for Water Resources (NIWR)

Mary Donohue, Program Specialist Faculty, University of Hawaii
(co-authors: E.A. Greene, P. Moravcik, D.T. Lerner)

Student training and workforce development are key academic, social and economic metrics of critical value to society. A major component of the Water Resources Research Act (WRRA) is provisioning the next generation of scientists and engineers with training through the National Institutes for Water Resources (NIWR). The NIWR has a demonstrated record in this area supporting approximately 25,000 students at >150 universities in its first 50 years. However, the compilation, analyses and synthesis of data on students trained to better understand NIWR's contributions to education and workforce development at the state and national level have been modest. Here, we investigate education and training activities of NIWR from 2000-2015 using data archived in the NIWR.net national database on "student support years" and a survey of NIWR state water resources research institute (Institute) directors. Total NIWR student support years from 2000-2015 were 10,853 (range: 518 to 788 per annum; average 678 ± 83 SD). Student support years by Institute from 2000-2015 were more variable with an average of 201 ± 102 SD per annum (range: 76 to 646). A majority of NIWR Institute directors report student or fellow support/training is very important to the NIWR mission (86%) and their respective Institutes (79%). Institutes' use of student data includes required reporting (98%), Institute promotion (45%), website or social media engagement (43%), development/donor activities (14%) and other uses (5%). Opportunities exist to augment data collection and refine use of these data, such as documenting disciplines of degrees earned by students and post-support job placement. Further exploration on the workforce placement of students supported by NIWR will clarify the value of this investment to society as well as inform understanding of NIWR's student support and the role this support plays in training the next generation of federal water scientists and managers.

## Session 50, Groundwater in the Southwest and its Role and Limitations in Mitigating Climate Change Impacts

### Using multiple data sources to identify trends and sustainability in agricultural groundwater use in the southwestern United States

Emile Elias, Research Hydrologist and Deputy Director, USDA-ARS, Jornada Experimental Range, SW Climate Hub
(co-authors: M. Lopez, C. Maxwell, D. James, R. Smith, C. Steele, A. Rango)

Prolonged drought, expected to become more frequent in the Southwest as a consequence of climate change, increases reliance on groundwater resources to continue agricultural production. We evaluate changes in past groundwater use to identify trends in reliance on groundwater resources to support agricultural production. Total agricultural water use and agricultural groundwater use data for each county comprising the Southwestern United States (Arizona, California, Nevada, New Mexico and Utah) were used to calculate the agricultural groundwater fraction (AGF) for the six years with available data (1985, 1990, 1995, 2000, 2005 and 2010). AGF trends over time provides an indication of counties within the southwest that consistently rely on groundwater and those becoming more or less reliant on groundwater resources to support agricultural production. Some counties in eastern New Mexico and Southern Arizona consistently rely on groundwater to supply all agricultural activity since 1985. Between 1985 and 2010, 69 of the 152 counties composing the SW US had an increase of 30% or more groundwater use to support agricultural production. Between 1985 and 2010, 25 of 152 counties had a decrease of 30% or more in groundwater use to support production. Since groundwater resources are continually replenished and depleted, we apply a simple water budget approach to indicate counties where agricultural groundwater use may be unsustainable. Aquifer recharge is represented by subsurface runoff values of the Variable Infiltration Capacity (VIC) model. The groundwater mining index is computed by dividing agricultural groundwater use by estimated recharge. The index identifies regional county-level 'hot-spots' where use exceeds recharge. Measured groundwater data, climate data and county changes in crop production are presented for selected counties undergoing shifts in agricultural groundwater use.

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### How does moral hazard in crop insurance affect producers' groundwater use for irrigation?

James Keeler, Graduate Student, University of Nebraska Lincoln
(co-authors: T. Mieno, C. Walters)

Multi-Peril Crop Insurance is a well-established risk management tool for agricultural producers in the United States. Since insurance policies are purchased before planting, insurance choice can alter subsequent risk management decisions and behavior. This is consistent with economic theory of moral hazard which suggests that producers have an incentive to take more risks when insured, as they are no longer responsible for possible losses. In particular, insured producers may use more of a risk-increasing input or less of a risk-decreasing input. Many of the previous empirical studies have shown that insured producers mete out fewer applications of fertilizer and pesticides, supporting unintended environmental benefits of crop insurance. In this study, we investigate the impact of crop insurance on groundwater use for irrigation. We develop an econometric model of the producer's irrigation decision including weather, soil, crop, and insurance characteristics. A Fixed Effects model was applied to section-level irrigation and insurance. Groundwater irrigation data was collected from producer wells located in Nebraska's portion of the Republican River Basin, where flow meters are required. Crop insurance (MCPI) data was obtained from the USDA Risk Management Agency and includes crop production history. Preliminary results show that insured producers use less groundwater for irrigation than their uninsured counterparts, after controlling for other factors. Producers may perceive insurance as a substitute for more intense irrigation. One implication is that insurance policies and contracts can be designed to incentivize reductions in irrigation water use.

## Session 50, Groundwater in the Southwest and its Role and Limitations in Mitigating Climate Change Impacts

### Crop suitability, surface water availability and groundwater storage effects of agricultural groundwater banking

Helen Dahlke, Assistant Professor, University of California, Davis
(co-authors: T. Kocis, A. Brown, G. Kourakos, T. Harter)

Groundwater banking, the intentional recharge of groundwater from surface water for storage and recovery, is an important conjunctive use strategy for water management in California (CA). A largely unexplored approach to managed aquifer recharge is agricultural groundwater banking (AGB), which utilizes flood flows and agricultural lands for recharging groundwater. Using cropland for groundwater recharge potentially provides a wide range of opportunities for long-term water security in CA given the large irrigated acreage and water distribution infrastructure available in the state. The study presented here considers the availability of excess streamflow (e.g., the magnitude, frequency, timing, and duration of winter high-magnitude flows) for AGB, the risks and benefits associated with using alfalfa fields and almond orchards as spreading grounds for AGB and the effect of AGB on groundwater storage and streamflow within California's Central Valley. Statistical analysis of daily streamflow records from 93 gauges within the Central Valley, CA reveal that high-magnitude (>90thpercentile) flows provide on average 1.6 and 1 million acre-feet in the Sacramento and San Joaquin River basin for AGB. Simulation of the Central-Valley-wide recharge of these estimated high-magnitude flows using the C2VSim groundwater-surface water model indicates that groundwater overdraft in the Sacramento and San Joaquin river basins could successfully be mitigated if AGB programs were implemented. Further, our wintertime on-farm recharge experiments on old (>5-year) alfalfa stands and two mature almond orchards testing variable amounts of winter water (2 feet for almonds, 4-28 ft for alfalfa) indicate no significant yields loss for both alfalfa and almonds, only short-duration saturated conditions in the root-zone, and high recharge fractions (>90%) of applied water. Together these results highlight the opportunity and potential benefits for growers and water districts to implement AGB as part of the sustainable groundwater management plans.

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### Considerations of climate risk in groundwater valuation and management

Brian Hurd, Professor, New Mexico State University
(co-author: P. Ghosh)

Overexploitation of aquifers has raised the specter of diminished food-security in many of the world's most important agricultural areas, including California, Middle East, India, Spain, and the Southwest United States. With few institutional controls, short-term economic conditions largely determine abstraction rates, which are often dominated by cash-flow and subsistence needs. This study examines the economic implications of water allocation, use, and value of increasing consideration of sustainability in the upper Rio Grande watershed. Three climate change scenarios and four alternative aquifer management scenarios are investigated using a hydro-economic model. Findings demonstrate that water use and economic impacts are sensitive to groundwater management policies. For example, results indicate that unconstrained aquifer access raises economic benefits by 50% and 3.4% percent for domestic and agricultural users, respectively compared to a program of strict aquifer preservation. Less restrictive approaches that limit aquifer pumping and enhance long-run sustainability will impose short-run economic costs while lengthening the performance period of the aquifer.

## Session 50, Groundwater in the Southwest and its Role and Limitations in Mitigating Climate Change Impacts

### Gaining a better understanding of the shared transboundary groundwater resources by upgrading the Hueco Bolson Model

Zhuping Sheng, Professor, Texas A&M University
(co-authors: D. Zhang, S. Abudu, J. Tracy, A. Michelsen, K.M. Bushira, Q. Liu, P. Yang)

The Hueco Bolson aquifer is a transboundary aquifer located across the border of the United States and Mexico. Both agricultural and urban water users have shared the groundwater resources over a century. With continued overdraft of groundwater resources by both cities of Ciudad Juarez and El Paso the drawdown cones have been observed on both sides of the border. There is a great need to understand the hydrological conditions and water availability as well as management strategies to sustain water supplies in the region. With Transboundary Aquifer Assessment Program and USDA NIFA project support we have complied additional data for better characterizing the regional aquifer and upgrade of the numerical model. In this paper we have converted the original groundwater model developed by USGS into a new version of MODFLOW with multiple node well package and updated with new pumping records. With the new model we will assess hydrological conditions and water availability under different management scenarios, such as the managed aquifer recharge, canal lining and others. In addition potential impacts of additional pumping for agricultural irrigation as well as conjunctive uses of surface water and groundwater will also be evaluated. This study will not only help us gain a better understanding of the aquifer system, but also provide guidelines for future development of the water resource in the aquifer for future water plan.

Keywords: transboundary aquifer, MODFLOW, groundwater, conjunctive use

## Session 51, Advancing Agricultural Water Security and Resilience Under Nonstationarity and Uncertainty: Evolving Roles of Blue, Green & Grey Water

### The challenge of water footprint analysis in agricultural water resource management

Marty Matlock, Professor of Ecological Engineering and Executive Director, Office for Sustainability, University of Arkansas
(co-authors: G. Thoma, E. Boles)

The application of water footprint analysis to agriculture has become common. The process involves segregating water demands into blue, green, and grey categories. This process of water inventory has utility for some purposes but has significant challenges when used to inform better management decisions. The application of water footprint concepts to basin or watershed scales can inform sources of stress and potential remedies. We will present our work linking water footprint analysis with life cycle assessment for US pork, dairy, and corn production to assess risk and impacts from competing water resource demands.

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### Agricultural use of reclaimed water in Florida: Food for thought

Lawrence R. Parsons, University of Florida, IFAS

Florida has successfully irrigated edible crops with reclaimed (RW) water for more than 30 years. Florida and California are the two largest producers and users of reclaimed water in the U.S. In 2006, Florida produced an estimated 663 million gallons per day (mgd) while California produced an estimated 580 mgd. Texas and Virginia ran a distant third and fourth place with 31.4 and 11.2 mgd, respectively. Even though Florida has about half the population of California, reuse per person per day in Florida is more than twice that of California. Total water reuse in Florida increased by 154% between 1992 and 2015 to 738 mgd. In 1992, agricultural irrigation used 30% of the RW in Florida, but competition from public access and industrial users has increased. While total RW flow has increased, agriculture reuse flow has declined to 9% of the total flow. To allay early fears about RW, Florida regulatory agencies established rules in the 1980s that prohibited direct contact of RW with crops that are not processed but eaten raw. This means that RW cannot be used for direct contact irrigation or frost protection of crops such as strawberries or blueberries. Other states do not have such limitations on RW use, and no health problems have occurred. Future emphasis may rely more on groundwater recharge with RW and aquifer conveyance as a more economical way to bring water from treatment plants to areas where it is used. While still important, agricultural use as a percentage of total flow will probably continue to decrease, and demand for reclaimed water remains strong.

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### Towards optimizing green and blue water investment portfolios to achieve food security in Sub Saharan Africa

Sarah Freeman, Ph.D. Student, University of Massachusetts, Amherst
(co-authors: C. Brown, E. Douglas, P. Weiskel, R. Vogel)

Food security and malnutrition are chronic issues facing Sub-Saharan Africa (SSA). With the population of SSA reaching 1 billion in 2015, achieving food security requires availability of reliable water resources. Investing to provide reliable water supplies typically implies irrigation, through either surface water schemes or groundwater. However, farm scale investments to harness green water fluxes may offer productivity enhancing and cost efficient opportunities to reduce the water constraint on food production. This presentation introduces a new index of green water management potential to highlight locations where green water fluxes are potentially significant in terms of achieving food security in SSA. Two-dimensional indicators of blue, green and gray water are developed at tenth of a degree resolution revealing differential influence of blue and green fluxes. The results provide initial lessons about the importance of adopting an integrated and diversified water management investment strategy for achieving food security in SSA. An optimization formulation is presented for designing location specific investment strategies that reflect the temporal variability of local water resources and the characteristics of typical green and blue water investments.

## Session 51, Advancing Agricultural Water Security and Resilience Under Nonstationarity and Uncertainty: Evolving Roles of Blue, Green & Grey Water

### Blue, green, and grey water: A current review of empirical approaches for quantifying human appropriation of water resources

Stanley Mubako, Research Assistant Professor, University of Texas at El Paso

Increasing human consumption and production activities will ensure that water scarcity remains part of the global sustainable water management agenda well into the foreseeable future. A growing population and increasing water scarcity call for approaches that are timely and accurate in providing information on blue, green, and grey water appropriation, especially for crucial but highly consumptive water use sectors such as agriculture and industry. An array of methodologies to quantify blue, green, and grey water footprints have emerged in recent years and are still evolving rapidly, as are efforts to come up with reliable indicators of water appropriation. This study will provide a thorough review of current empirical methodologies that have been developed and applied to quantify blue, green and grey water footprints, among them Life Cycle Assessment and Water Footprint Network-based, and the more spatially and temporally explicit water accounting methods. The study reviews of some of the theoretical underpinnings, data requirements, and potential for developing resilient water management policies.

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### Mesoscale data fusion to map and model the U.S. Food-Energy-Water system (INFEWSion)

Benjamin Ruddell, Director, National Water Economy Project, Northern Arizona University
(co-author: *C. Lant)
*Presenter - Christopher Lant, Professor and Head, Department of Environment and Society, Utah State University

The Food, Energy, and Water (FEW) nexus is a dynamic, coupled natural-human system manifesting at the mesoscale, in which interregional trade, river basins and aquifers, irrigation districts, crop belts, states, tribes, and cities, power grids, climate gradients, and seasonal timescales interact. To advance the science behind this complex integrated phenomenon, developing a reliable and comprehensive empirical description of the U.S. FEW system is a critical first step.

This presentation will outline the NSF-funded interdisciplinary, multi-institution $3 million project that will construct the first comprehensive empirical map of the U.S. Food, Energy, and Water system (the INFEWSion v1.0-US database). This database will be exploited to achieve four science and modeling objectives: 1) quantify the tradeoffs between the multiple objectives of performance and sustainability using several metrics, (2) analyze historical sensitivity, vulnerability, resilience, and evolution of the FEW network with attribution to observed stresses and shocks, (3) establish the role of the growth of cities within the FEW system, and (4) execute a standards-based benchmarking assessment of INFEWS program Modeling and Solutions track projects. Conceptually innovative, this project will establish a forward leap in systems-level synthetic understanding of the FEW nexus.

INFEWSion will be disseminated for public education and outreach purposes using a professionally designed web-based interactive visualization system created by and for teachers, mayoral and congressional staffs, and planners. Dissemination and engagement will involve partnerships with national institutions such as The Nature Conservancy, The Water Footprint Network, the Sustainable Cities Network, the U.S. Department of Energy, the U.S. Geological Survey, and America's Water project. This public visualization will provide interactive (and for the first time, locationally explicit) guidance on how a county or city can enhance benefits, reduce impacts and vulnerability and solidify resilience profiles by changing food-energy-water consumption patterns.

## Session 52, Integrated Forest Planning to Build Fire Resilient Watersheds with Sustainable and Quality Water Supplies

### Prioritizing fuel treatments to mitigate negative post-wildfire watershed responses in two Colorado municipal watersheds

Benjamin Gannon, Research Associate, Colorado Forest Restoration Institute at Colorado State University
(co-authors: Y. Wei, S. Kampf, L. MacDonald, J. Cannon, B. Wolk, A. Cheng, K. Jones, R. Addington, M. Thompson)

Following severe wildfire, forests become large producers and efficient transporters of sediment due to reduced surface cover, changes in soil properties, and expansion of channel networks. Post-wildfire sediment and debris delivery to water infrastructure results in operational challenges and costs to municipal water providers, e.g. dredging to recover lost reservoir capacity, increased filtration and treatment, and damage to infrastructure from floods and debris flows. As a result, many municipal water providers are investing in forest fuel treatments as part of their risk management portfolios. Forest managers are increasingly using wildfire risk assessment methods when planning fuel treatment projects, and while some have considered municipal water resources, exposure has usually been quantified using overlay analysis and effects have been estimated using expert response functions based on fire intensity, i.e. not utilizing methods that consider the local factors which influence erosion and sediment transport. We developed a framework to support fuel treatment decisions by considering the effects of forest fuel treatment on post-fire erosion via change in fire behavior. Our framework utilizes multiple process models to represent hillslope sediment production, transport to the channel network, and routing through the channel network to improve measures of water infrastructure exposure to post-wildfire hazards. We then built a mixed integer programming model to prioritize mechanical treatment and prescribed fire locations under total budget constraints, other practical treatment restrictions, and considering variability in wildfire probability. We demonstrate the model framework and present an example application for fuel treatment planning in two large watersheds (4,660 km2) which provide water to an expanding urban population in northern Colorado.

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### Erosion and sediment delivery to streams following wildfire: Processes and predictions

Stephanie Kampf, Associate Professor, Colorado State University
(co-authors: L. MacDonald, F. Saavedra, C. Wilson, S. Schmeer, D. Brogan, P. Nelson, B. Gannon)

Wildfires often lead to elevated erosion and sediment delivery to streams. Using the 2012 High Park Fire in Colorado as an example, this talk will describe erosion and sedimentation patterns after fire and compare modeling approaches for predicting erosion and sediment delivery. Post-fire hillslope erosion is affected primarily by rainfall patterns and ground cover. Intense rains after severe wildfire can cause high erosion rates and expansion of channel networks through rilling and gullying. Sediments eroded from hillslopes may be deposited before reaching major stream channels, transported through stream channels, or deposited within channels. Patterns of sediment delivery and geomorphic change in the downstream channels relate to hillslope connectivity and the types and sequences of storms that follow a fire. A variety of models have been developed for predicting post-fire erosion, and a few of these also represent sediment delivery to channels and transport within channels. The talk will discuss strengths and weaknesses of each of the modeling approaches and illustrate how predictions of post-fire erosion and sediment delivery are affected by the choice of model and quality of input data.

## Session 52, Integrated Forest Planning to Build Fire Resilient Watersheds with Sustainable and Quality Water Supplies

### A multistage stochastic program with recourse for scheduling prescribed burning to mitigate watershed fire risk

Dung Nguyen, Postdoctoral Fellow, Colorado State University
(co-author: Y. Wei)

Prescribed burning based fuel treatment may help decrease the detrimental effect of wildfires within a watershed and help increase the fire resilience of a watershed for longer term. Future fire losses may include sediments, water pollution, but can also be extended to other value considerations such as community protection, habitats. In this study, I present a multistage stochastic linear program with recourse to schedule prescribed burning by considering the probability of random future wildfires and their possible spread patterns under stochastic weather scenarios. This program uses a sample average approximation formulation to explicitly address the spatial and temporal relationships between fire behavior, prescribed burning, and suppression across multiple fire-planning periods. Test cases are designed to examine fire management situations in a watershed, and are focused on identifying good solutions to allocate prescribed burnings in the first planning period to minimize the total of management costs and fire losses for longer term. Results show there may exist a large number of alternative good solutions during the first planning period to schedule prescribed burnings that can effectively mitigate the risks from future wildfires.

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### Assessing biological and physical controls on persistent nutrient losses in severely-burned watersheds

Allison Rhea, Colorado State University
(co-authors: T. Covino, C. Rhoades, T. Fegel)

In many locations throughout the Western U.S., drought, climate change, and uncharacteristically dense forests are contributing to increased fire frequency and severity. Wildfires can influence watershed nutrient retention as they alter biological composition and physical structure in upland landscapes, riparian corridors, and stream channels. While numerous studies have documented substantial short-term increases in stream nutrient concentrations and export (particularly reactive nitrogen, N) following forest fires, the long-term implications for watershed nutrient cycling remain unclear. For example, recent work indicates that nitrate concentrations and export can remain elevated for a decade or more following wildfire, yet the controls on these processes are unknown. In this research, we use nutrient tracer injections and continuous water quality monitoring to compare biological and physical controls on persistent nutrient export across a burn-severity gradient. Results show that although there is substantial stream-groundwater exchange in burned streams, there is little biological nutrient uptake. We suggest that shifts in nutrient loading to the channel along with suppressed in-channel uptake can reduce the capacity of fire-affected streams to transform and retain nutrient inputs. These findings will be useful in assessing changes in downstream water quality and directing upland and riparian restoration.

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### Wildfire risk management, watershed health, and suppression response

Matthew Thompson, Research Forester, U.S. Forest Service
(co-author: T. Warziniack)

Enhancing and protecting watershed health is a principal management objective on public lands in Colorado's Rocky Mountains. As severe wildfire is a primary threat to watershed health and water quality, with downstream consequences for water utilities, interest is high in determining efficient management approaches to minimize fire risk. In previous work we proposed investment theory as a framework for prioritizing mitigation activities considering a portfolio of investments that included reservoir maintenance, post-fire sediment removal, and pre-fire reductions of hazardous fuel loads. Here we expand on that work by positing the existence of another possible risky investment, expanding the footprint of lightning-caused fires through moderated suppression responses. This addition recognizes two important realities of contemporary fire management: first, that myriad constraints limit the extent to which hazardous fuels reduction can be effectively implemented, especially relative to the area burned, or treated, annually by unplanned wildfires; and second, that fire exclusion in fire-prone systems tends to exacerbate future problems, possibly requiring a rethinking of society's relationship with fire. We will describe emerging tools aimed at supporting pre-fire planning and response decisions, present a few real-world examples, and discuss how the concept of changing suppression responses might fit into a portfolio optimization framework.

## Application of the Integrated Urban Water Model to assess scenarios of water conservation and reuse, climate change and urban growth

Sybil Sharvelle, Associate Professor, Colorado State University
(co-authors: M. Arabi, A. Dozier)

Water supply and demand assessment under alternative climate, land use and population scenarios is an area of great interest amongst urban planners and water managers. The Integrated Urban Water Model (IUWM) has been developed and demonstrated for forecasting urban water demand with options to assess effects of water conservation and reuse, climate change, population growth, and land use change. IUWM is deployed as an online tool with geographical information system (GIS) interfaces, hence enhancing its accessibility, ease of use and applicability at building to municipal scales. The performance validity of the model predictions was evaluated against observed monthly water use data over the 2000-2014 period for the City of Fort Collins, CO. IUWM was shown to provide very good estimates of indoor, outdoor, and total demands for each individual block group as well as the entire municipal area. The calibrated model was then used to evaluate water conservation and reuse scenarios. The scenarios analysis provided estimates of reduced demand for potable water that can achieved by installation of indoor conservation fixtures, use of graywater, roof runoff, stormwater and treated wastewater to meet non-potable demands, and irrigation conservation. Aggressive irrigation conservation including conversion to xeriscape and installation of efficient irrigation systems resulted in the highest projected demand reduction of the practices investigated. Additional scenarios were evaluated to assess changes in water demand in response to increased temperature, decreased precipitation, population growth, and land use change. Increased temperature and decreased precipitation scenarios predict increased demand for outdoor water use while population growth, including conversion of low density development to medium and high density development, resulted in projection for a decrease in water demand resulting from reduced irrigated area. The capacity of IUWM to identify areas within a water service area with higher or lower than average water use was also demonstrated.

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## Hydroeconomic modeling framework for assessing vulnerability to water demands in arid regions

Andre Dozier, Ph.D. Candidate, Colorado State University
(co-authors: M. Arabi, C. Goemans, B. Wostoupal, Y. Zhang, K. Paustian)

In semi-arid regions with rapidly growing cities, agricultural water rights are being purchased primarily by municipalities, consequently drying up historically irrigated land according to the water right appropriation doctrine, a process termed “buy and dry”. The goal of this study is to develop an assessment framework to evaluate impacts of population growth, land use change, conservation, and institutional agreements on water shortage vulnerability, the agricultural economy, and cost of water rights purchases to municipalities. A hydroeconomic model is presented that solves the permanent water rights market as growing municipalities attempt to purchase water at the least cost from profit-maximizing agricultural producers. In a case study region, the South Platte River Basin, the model shows 85-90% of total regional agricultural profit over a planning period of 40 years is attributed to sale of water to cities. Several different types of management practices being considered in the basin were studied to show the efficacy of sustaining agricultural production and consequently the rural economy. A few practices achieved the goal of sustained agricultural cropland in production, profitability of production, and productivity at the cost of lost water rights sale revenue or reliability of water supply. Some failed at sustaining either cropland or productivity. When considering only agricultural profit, the worst paths forward would be to cap municipal growth or pursue aggressive urban conservation. When considering the cost to municipalities the worst path forward would be to cap municipal ownership. Otherwise, practices usually save money for municipalities. When considering total agricultural crop production, the worst practice to implement is a fixed reduction of land purchase requirements relative to the amount of water used. All practices failed at improving total agricultural profit when considering the revenue from sale of water rights. Thus, this study raising the question, should anyone intervene with agricultural buy up when it might not really be in their interest to do so?

### Can the M&I water supply gap be met exclusively with agricultural conservation?

Doug Kenney, Director, Western Water Policy Program, University of Colorado
(co-authors: A. Dozier, M. Arabi, M. Squillace)

In the recently completed Colorado Water Plan, it was established that a gap between expected supplies and demands of roughly 185,000 acre-feet/year will likely emerge in coming decades among M&I users in the South Platte Basin. Barring any significant change in the trajectory of water management in the region, it is expected that much of this M&I gap will be met by the permanent retirement of agricultural lands, an action that would have significant economic and cultural impacts in rural areas. In this research, we investigate the potential to meet this gap exclusively through agricultural water conservation methods that maintain agricultural production, while facilitating temporary, market-based transfers of saved water to urban users.

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### Enhancing the DayCent model to analyze deficit irrigation practices in SPRB

Yao Zhang, Postdoc, Colorado State University
(co-authors: A. Dozier, M. Arabi, K. Paustian)

In the irrigated river basins of the western United States, such as South Platte River Basin (SPRB), vulnerability to water shortage is increasingly critical due to the projected decline of water supply to agriculture. To help make drought adaptation decisions for policy makers and farmers, a user-friendly web-based decision support tool was developed using an enhanced version of the DayCent agro-ecosystem model. The tool was designed to predict and optimize crop water use and yield for the current climate and climate change scenarios in SPRB. The model has been validated with both field experiment data and NASS county level crop yield data. Results showed accurate simulation of crop yield responses to irrigation for conditions in the SPRB and uncertainty analyses were also performed to assess the quality of the model predictions. This presentation will overview the features and performances of the tool.

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### Identifying effective approaches to reduce WWTF nutrient load at the watershed scale accounting for removal efficiency and implementation cost

Brock Hodgson, Ph.D. Candidate, Colorado State University
(co-author: S. Sharvelle)

Many states are considering or have recently adopted nutrient regulations requiring wastewater treatment facilities (WWTFs) to improve existing treatment operations. Therefore, the most effective approach for reducing nutrient loads accounting for cost and removal efficiency is an important consideration for WWTF managers and regulators. Many new technologies exist for nutrient removal at WWTFs and operators and managers remain uncertain of which technologies provide the most effective removal and therefore merit higher consideration. A systems level analysis was considered at a watershed scale to quantify the effects of wastewater treatment technologies on nutrient load reduction at widespread levels of adoption. The study area was the South Platte River Basin in Colorado and the technologies considered included carbon addition, struvite precipitation, chemical phosphorous removal, biological phosphorous removal, ammonia stripping and ANAMMOX. In order to accomplish the research objectives, the first portion of the analysis modeled each technology efficiency in terms of total nitrogen (TN) and total phosphorous (TP) utilizing models of calibrated and validated WWTFs or representative WWTF's using BioWin 5.0 (EnviroSim LLC, Hamilton, ON).

The model results were used to develop generalized relationship of the technologies impact to load reduction. The generalized relationships were based on identified explanatory variables to describe the removal efficiency relative to different WWTF conditions including considerations to influent wastewater characteristics, existing treatment operations, and existing removal efficiencies. The developed empirical relationships were than applied at a watershed scale to evaluate the cost effective alternatives large scale levels of adoption.

## Session 54, Gold King Mine Spill: Impacts of Legacy Mines on Watersheds

### The social impacts of abandoned mines: Using Peer Listing models to mitigate corrosive community tendencies

Rebecca Clausen, Associate Professor, Fort Lewis College

The causes and consequences of environmental disasters reach beyond the biophysical realm and extend into sociological domains. We first provide a background of the political economic context in which the Gold King Mine spill occurred, exploring the role of private property and economic priorities that mold social relationships to natural resources in our region. We then review the literature on how communities respond to environmental disaster, such as mine spills, highlighting the divergence between natural disaster vs technological disaster. Based on these findings, we explore the role of community-based peer listening models to mitigate the potential tendencies for technological disasters to create corrosive community patterns.

Using data collected through participant observation, we describe how Durango, CO community members formed a loose coalition called the Animas Community Listening and Empowerment Project to provide public spaces for sharing of stories and experiences related to the spill. Three communities along the Animas-San Juan River were involved in this project. By compiling and presenting the findings from these public listening sessions to other Animas-San Juan communities, ACLEP hopes to increase shared understanding of common values as well as recognize and acknowledge the differences based on economic, social, and cultural histories. We summarize the ACLEP model by observing strengths and weaknesses, with the hopes that it can serve as a guide to inform other communities when faced with any type of technological disaster. We end by considering the potential to create Community Mental Health Emergency Response Plans to address environmental disasters that will likely become more pressing throughout the 21st Century.

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### Building community partnerships to respond to Diné concerns regarding the Gold King Mine Spill

Karletta Chief, Assistant Professor, University of Arizona
(co-authors: P. Beamer, J. Ingram, N. Teufel-Shone, M. Begay Jr., D. Billheimer, N. Lothrop, J. Yazzie, and R. Clausen)

On August 5, 2015, 3 million gallons of acid mine drainage was released from the Gold King Mine, eventually reaching the San Juan River – the lifeblood of the Navajo Nation. Many Native American communities have subsistence livelihoods and strong spiritual beliefs that are deeply connected to the natural environment. As a result, environmental contamination from catastrophic mine spills severely impacts indigenous people to the core of their spiritual and physical livelihoods and there is potential for unique exposure pathways and greater health risks. This talk will explain what happened with the Gold King Mine Spill and how it impacted the Navajo Nation. Through a listening session that was held, five themes arose from the discussion and include 1) mistrust of outside entities conducting research, 2) concern that research findings won't come back to the community, 3) anxiety around whether water is safe for subsistence (irrigation, livestock, washing), 4) concern for lack of decision-making protocols, and 5) recognizing cumulative and future impacts to the Animas-San Juan watershed. The Dine' people say they need clean-up, security from future contaminations, and more accountability in the data collection and results communication. People were disappointed and frustrated by the response of the federal and tribal response to the Gold King Mine Spill. This talk will also share the experiences of building community partnerships to develop and implement a time-sensitive proposal to National Institute of Environmental Health Sciences entitled "Tó'Łítso, the water is yellow: Investigating short term exposure and risk perception of Navajo communities to the Gold King Mine Spill" and the Agnese Nelmes Haury Foundation Challenge Grant. This is a partnership between the Navajo Community Health Representatives (CHR) Program, University of Arizona (UA) and Northern Arizona University (NAU), Dine' College, To' Bee Nihi Dzill and Fort Lewis College.

### A perspective on the biogeochemical processes in the Animas River

Lucía Rodríguez-Freire, Postdoctoral Research Associate, The University of New Mexico
(co-authors: S. Avasarala, P. McLee, K. Artyushkova, A. Brearley, E. Peterson, L. Crossey, D. Latta, A. Ali, A. Schuler, J.M. Cerrato)

The Animas River is a complex system affected by natural mineralization, mining events and extensive agriculture. The river flows from a heavily mineralized area (San Juan Mountain, CO) to an intensive agricultural area (Farmington, NM), where it drains into the San Juan River, which is the main water source for the largest Navajo farming operation (Navajo Agricultural Products Industry, NAPI). As the AR travels through different environmentally relevant conditions (from heavily mineralized to intensive agricultural areas), the transported sediments will be affected by various biogeochemical processes that can cause metal mobilization. The objective of this study was to investigate the stability of metal mixtures on samples collected on August 17-18, 2015, two weeks after the Gold King Mine spill. Biogeochemical cycling of metals in the Animas River was investigated using spectroscopy, microscopy, diffraction, molecular biology, and water chemistry methods. Metal concentrations in the sediments are higher in the Upper Animas River watershed decreasing as the Animas River flows downstream. Contrarily, microbial diversity is low upstream and it increases downstream the Animas River. Solid-phase characterization suggest that lead, copper, and zinc are associated with clays, iron-(oxy)hydroxides, and metal-bearing jarosite which is stable under low pH. Phosphate and nitrogen species were found in water and sediments in Farmington. In addition, iron-oxidizing microorganisms were detected in the sediments from Cement Creek, while nitrogen-cycling bacteria where found in the sediments from Farmington. The solubility of jarosite at near-neutral pH and biogeochemical processes occurring downstream could affect the remobilization of metals in sediments. The results from this investigation set the foundation to further understand the complex mechanisms influencing the fate of metals in a surface water basin affected by varying environmental conditions in a semi-arid region.

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### What are the effects of the Gold King Mine Spill on San Juan County, NM agricultural irrigation ditches and farms?

Kevin Lombard, Associate Professor and Superintendent, New Mexico State University Agricultural Science Center at Farmington
(co-authors: S. Fullen, A. Ulery, B. Hunter, D. VanLeeuwen, G. Jha, B. Francis)

The majority of crop production in the western U.S., where water is relatively scarce, is almost entirely accomplished by diverting river water into irrigation ditches (acequias). Ironically, these irrigation waters originate from snowmelt found in mountainous, mineral rich, legacy-mining districts. Significant amounts of river sediments accumulate downstream annually in these irrigation ditches, laterals, and other irrigation infrastructure, which can then be deposited to agricultural lands during the growing season; and constitute a potential threat to agricultural lands if they are contaminated. When over three million gallons of orange colored, heavy metal contaminated water spilled from the Gold King Mine (GKM) into the Animas River on August 5, 2015 (EPA 2015; https://www.youtube.com/watch?v=ZBlR05tDCbI), the ~20 unique irrigation ditch cooperatives in San Juan County New Mexico and the Navajo Nation closed main diversion points for about 10 days to prevent contaminating agricultural fields. During the ban on irrigating crops our team sampled 16 non-contaminated ditch sections along transects perpendicular to each ditch to establish base-line or legacy mining metal concentrations prior to the spill for future long-term monitoring of the river/irrigation canal/agricultural field interface. One ditch in particular, we sampled sediments at six locations along ~15 miles (24 km). Through repeated measures, we resampled the same irrigation ditch locations during winter 2015-2016. We augured to 18-24 inches (46-70 cm) deep in three separate depths (6-8 inches long per core). Total metals were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES) after acid digestion. Sediment pH, an important determinant on metal mobility, was also taken. We are currently analyzing the second ditch sediment samples. These evaluations are critical to reassure growers and consumers in the region that the products grown on soils in the Animas and San Juan River Watersheds are safe and to inform policy concerning upstream legacy mining districts.

## Examination of sediment microbial communities in the Animas River Watershed following the Gold King Mine Spill

Patrick McLee, Graduate Research Assistant, University of New Mexico
(co-authors: L. Rodriquez, J. Cerrato, S. Avasarala, A. Schuler)

On August 5th, 2015 approximately 3 million gallons of heavy metal contaminated mine waste was accidentally released into Cement Creek, a tributary of the Animas River. On August 17th -18th, 2015 The University of New Mexico visited sites along Cement Creek, Animas River, and San Juan River. At these sites, sediment samples were taken to determine metals composition, and microbial communities associated with the sediment. Basic water quality parameters were also measured such as water temperature, dissolved oxygen, conductivity, pH and oxidation-reduction potential. Sediment samples were sent to Research and Testing Laboratory for DNA extraction and Illumina Next Generation sequencing. Iron and total metals concentrations were highest in sediment at sample locations closest to Cement Creek where the Gold King Mine discharged. Further downstream, concentrations of metals decrease and level off near the confluence of the Animas and San Juan rivers. The diversity of microbial samples collected at each site has been determined by calculating the Shannon Diversity Index (SDI). By this measure, microbial diversity appears to be generally lower at upstream sites with sediment containing high metals concentration. As metal concentrations decrease downstream, microbial diversity appears to recover by the steady increase in the SDI. A dramatic change in sediment bacteria family communities was observed in the Animas River upstream of the Cement Creek confluence to the downstream sample site. Upstream of the confluence, Cement Creek is rich in *Gallionellacae* (60.4% relative abundance), where the Animas River is all but missing this family (0.07% relative abundance). The family *Gallionellacae* is well documented to consist of iron oxidizing bacteria (FeOB) that mineralize dissolved Fe(II) to a precipitated Fe(III) in the form of extracellular bio-mineral structures. This process is important at acid mine drainage impacted sites because iron is usually the most abundant metallic element, and other heavy metals may co-precipitate or adsorb to Fe(III) precipitates formed by FeOB such as *Gallionellacae*.

### Impacts of large water reservoirs on precipitation: A case study of Tarbela Dam

Irfan Abid, Georgia Institute of Technology

Water occupancy of the total world area is more than 70%, whereas the water available for human consumption is less than 1% of the total water, which makes this finite source to even more precious. Therefore the consumption of water and need for storage is ever increasing with increasing population, urbanization and change in lifestyle. Dams are used to store and regulate water and have the history as old as 5000 B.C. The discussion of large and small dams has been a question for many years by now. However the environmental impacts of large dams are considered to be much higher than small dams. Pakistan is an agricultural country with more than 75% dependency in water sector and relying mainly on one water basin, named as Indus Basin. Tarbela Dam is the only reservoir on River Indus which is purpose built for water storage, water regulation, power production, and flood control, having the lake area of 259 square kilometers. This is a large reservoir which affects the local climate, resulting in effecting the local built environment. Effect of the dam has been studied on the rainfall/ precipitation pattern. Monthly rainfall data of 52 years (18 years before the dam construction and 34 years after the start of dam operation) has been used to investigate the changes induced over the dam life. The effects have been studied in two ways, one, to study the change over the dam life (temporal variation), secondly, to identify the change over different parts of the year (seasonal variation). The analysis of temporal variation shows an increase in the rainfall with a larger variability, having more rain fall in first half of the dam life with subsequent reduction in the increase of rainfall over the second half of dam life. The seasonal analysis shows an increased and more consistent rainfall for all the seasons in the dry years. There are no significant seasonal effects for the wet years.

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### Assessing groundwater vulnerability in the South Platte River Basin under future changes in land use and climate

Fatima Aliyari, Research Assistant, Colorado State University
(co-authors: R.T. Bailey, A. Tasdighi, M. Arabi)

Water resources in irrigated river basins in the western United States face competition from agricultural, municipal, industrial, and environmental users. Increasing populations can lead to transfer of water from irrigated agricultural to municipalities via agricultural dry-up or water leasing programs. Groundwater in rural areas is particularly vulnerable as transfer of surface water rights to urban areas will likely increase reliance on groundwater resources, leading to increased groundwater pumping. Also, groundwater recharge from surface water irrigation is likely to decline. This study assesses the spatial vulnerability of groundwater to over-exploitation and climate change in the South Platte River Basin (SPRB) in Colorado. The basin spans both urban and agricultural areas. Water demand for regions across the basin is determined by analyzing population and agricultural factors such as crop demand and crop productions. Water supply is quantified by analyzing climate, surface water and groundwater availability under different climate, population, and land use change scenarios. Using a coupled SWAT-MODFLOW model, groundwater vulnerability in sub-basins throughout the river basin is quantified to determine regions prone to groundwater stress. Both the magnitude and trend of stress is investigated using a Groundwater Stress Index that accounts for all groundwater inputs and outputs for a given sub-basin. The assessment of regional vulnerabilities will enable decision makers to manage water resources in a sustainable fashion over the coming decades.

### Diagnosing the effects of external forcings on streamflow

Leah Bensching, University of Colorado Boulder
(co-authors: W. Farmer, B. Livneh)

Climate change and increasing water demands are stressing water resources in some areas. With potential increasing effects of these stresses on water resources during coming decades, the understanding of the interaction between the natural hydrologic cycle and other landscape processes (e.g., water and land management practices) will be critical for water resources management and planning. As these processes are hypothesized to remain outside of the natural, stationary hydrologic cycle, other processes affecting the hydrologic cycle are here classified as external forcings. These external forcings include changes in water use, land use, land cover reservoir operations and stream-gage protocols. Currently, hydrologic understanding is determined through relations between in situ measurements of streamflow and related climatic variables. However, external forcings can skew relationships between climactic and hydrologic variables. Unfortunately, external forcings on hydrology are not well identified or quantified. External forcings and associated effects are especially important for basins like the Colorado River where mean annual water supply and demand are nearly similar. For this study, six watersheds (25 $km^2$ - 10,000 $km^2$) in the Colorado River Basin with diverse climates and varying degrees of external forcing were identified. A data base of possible streamflow drivers was developed by utilizing remote sensing products (evaporation, temperature, soil moisture etc.). Improved understanding of external forcings on the hydrology of the Colorado River basin will benefit future model development and validation efforts.

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### Water banking, recharge and recovery in Arizona: The use of long-term storage credits

Rebecca Bernat, Graduate Teaching Assistant, University of Arizona
(co-author: S.B. Megdal)

In Arizona, the 1980 Groundwater Management Act created Active Management Areas (AMAs), where groundwater use is regulated and enforced by the Arizona Department of Water Resources (ADWR). Since 1986 the ADWR has been administrating water storage for annual recovery, as well as for long-term storage credits (LTSC). As of 2014, 184 Long-Term Storage Accounts were registered in the three Central Arizona AMAs. Water can be recovered at a later time for the LTSC owner's use, or the LTSC can be sold. Most of the LTSC accrued in Central Arizona AMAs (40%) are for the accounts of governmental agencies, such as the Arizona Water Banking Authority and the Central Arizona Groundwater Replenishment District. Around 20% of the LTSC accumulated in the Central Arizona AMAs are held by the Gila River Indian Community's accounts. Municipalities, industries and investment firms also have accumulated many LTSC. In this presentation, we show that a market for LTSC has developed and may become robust, and yet, as it is a developing field, the intentions of some entities toward their LTSC use remain unknown. Here we investigate the rationale behind the accumulation of LTSC of these entities: is it for economic value, or for environmental purposes? We try to link entities intentions to their status/category of entity, and to their water rights.

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### Tools & support for integrating real environmental data into education

Liza Brazil, Community Support Specialist, CUAHSI

Using real data in a classroom setting can help students better understand scientific concepts. By working with data from a place they are familiar with they can form deeper connections to the research or they can learn about a new place by examining how environmental observations differ with geography. Students are also exposed to, and can solve, challenges faced by "real" researchers, such as interpreting metadata and data scarcity. With the support and resources provided by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), educators can more easily implement real data into their classroom. Free of cost, CUAHSI offers an extensive catalogue of environmental observations, tools for accessing data, and staff support for developing data-driven lessons. To promote collaboration and sharing among educators, all lessons are made available on the Science Education Resource Center at Carleton College (SERC) website. This presentation will describe community data tools, how researchers have used them in developing lesson plans, and the resources available to learn more.

### Selection of optimum conditions for the treatment of beef cattle wastewater by the electrocoagulation process

Erick Butler, Assistant Professor of Environmental Engineering, West Texas A&M University
(co-authors: C. Clewett, N. Spaar, R. DeOtte, O. Mulamba)

Electrocoagulation is a viable treatment process to remove nutrients, solids, and other pollutants from various wastewaters. A study evaluated the effects of varying current density (2.6 mA/cm$^2$, 5.4 mA/cm$^2$, 8 mA/cm$^2$), wastewater strength (1/3, 2/3, raw wastewater), and initial pH (4,7, 10) on the treatment of beef cattle feedlot wastewater. The results found that after thirty minutes of treatment the total organic carbon (TOC) removal efficiency ranged between 27% and 84%, while total phosphorus (TP) removed ranged between 0 and 100%. Treatment efficiency was highly affected by the current density and the wastewater strength. Further analysis using solid state NMR was determined the uptake of phosphorus within the ECF sludge. It was found that phosphorus uptake was most efficient at low pH. Overall, electrocoagulation is a viable method to treat feedlot wastewater since it can remove nutrients and TOC.

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### An Investigation of Water Use Intensity for Military Facilities

Elisabeth Jenicek, Principal Investigator/Mechanical Engineer, Construction Engineering Research Lab (USACE)
(co-authors: N. Garfinkle, N. Bartholomew, M. Kodack)
Presenter - Kelly J. Chen, ERDC-CERL (USACE)

Water is a critical resource for execution of the Army's global mission. Insufficient water supplies on installations will compromise military readiness, affecting the ability to train and support the force. Water affects every aspect of operations, however, there are insufficient data to determine the critical amount of water required and to achieve reductions directed to non-essential functions. Impairment or loss of water supplies will cause significant interruptions to an installation's mission. Whereas prioritizing demands and securing critical levels will support sustainable readiness. Installations are challenged by their unique portfolio of facilities and the lack of water use intensity benchmarks. The Engineer Research and Development Center created models to fill this void. These efforts are helping Army water managers evaluate water efficiency performance and target water end uses with the highest savings potential. Installations track water use with meter data at points of water production or purchase. Although Federal policy requires the use of building-scale utility meters, few water meters are present and therefore little building or end use demand data is available to identify the amount of water used by individual facility categories. There is also a dearth of information about the amount of water that should be consumed by these end uses. Studies of water demand off-post focus primarily on residential building classes, with little benchmark data available for commercial, industrial, and institutional facility groups. Some categories in this inventory correspond well to civilian equivalents. Others are unique to the military mission, for example, tactical equipment maintenance facilities. Certain Army facilities appear similar to civilian counterparts, but carry unique resource footprints corresponding with their use, e.g., barracks (different from dormitories) and family housing (smaller than off-post, but support larger families). The new set of water use intensity values reveals links to building size, population, training load, and other use factors as well as climate zone and water rights. Armed with this information, water managers can effectively plan efficiency programs and maintain adequate supplies of water for critical end uses.

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### Approach to determining causes of high groundwater levels in the LaSalle/Gilcrest area

Chenda Deng, Graduate Research Assistant, Colorado State University
(co-author: R.Bailey)

Regions of irrigated farmland in the South Platte River Basin (SPRB) in northeastern Colorado recently have experienced conditions of extremely shallow water table depths (hanced surface water irrigation, canal seepage, and the implementation of recharge ponds in the area. The objective of this study is to assess these individual contributions and their impact on water table elevations using a hydrologic modeling approach. The model is built for the LaSalle/Gilcrest area in the SPRB, a region acutely affected by high water tables. The model framework couples the groundwater flow model MODFLOW with the biogeochemical model DAYCENT, with the latter estimating irrigation water applied, actual evapotranspiration, and deep percolation to the water table. The MODFLOW model is refined to a daily time step, and has 10 layers that describe the geologic layering in the aquifer, with a three-dimensional map of hydraulic conductivity constructed from lithology from over 400 boreholes. The model will be run for the 1998-2012 time period, tested against measured water table elevation from monitoring wells, and then used to assess the cause of water table fluctuation. Results of the simulations will yield a ranking of stress influence.

### Use of satellite-based remote sensing evapotranspiration model results to inform parameters in cropping system models

Sulochan Dhungel, Ph.D. Student, University of Utah
(co-author: M.E. Barber)

This paper aims to use an automated satellite-based remote sensing evapotranspiration (ET) model to assist in parameterization of a cropping system model (CropSyst) and to examine the variability of consumptive water use of various crops across the watershed. The remote sensing model is a modified version of the Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC™) energy balance model. Application of an automated python-based implementation of METRIC to estimate ET as consumptive water use for agricultural areas in three watersheds in Eastern Washington – Walla Walla, Lower Yakima and Okanogan are presented. We used these ET maps with USDA crop data to identify the variability of crop growth and water use for the major crops in these three watersheds. Some crops, such as grapes and alfalfa, showed high variability in water use in the watershed while others, such as corn, had comparatively less variability. The results helped us to estimate the range and variability of various crop parameters that are used in CropSyst. The paper also presents a systematic approach to estimate parameters of CropSyst for a crop in a watershed using METRIC results. Our initial application of this approach was used to estimate irrigation application rate for CropSyst for a selected farm in Walla Walla and was validated by comparing crop growth (as Leaf Area Index - LAI) and consumptive water use (ET) from METRIC and CropSyst. This coupling of METRIC with CropSyst will allow for more robust parameters in CropSyst and will enable accurate predictions of changes in irrigation practices and crop rotation, which are a challenge in many cropping system models.

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### Stream temperature dynamics in a semiarid riparian ecosystem in north central Oregon

Nicole Durfee, Graduate Student, Oregon State University
(co-author: C. Ochoa)

Stream temperature influences multiple aspects of stream ecology, and warming temperatures are associated with negative impacts on aquatic organisms. By understanding the multiple factors that influence stream temperature, land managers are better able to determine land use management practices which protect stream ecosystems. The objectives of this study were to determine stream temperature-vegetation shading relationships, and characterize other abiotic and biotic factors (e.g., surface and subsurface flows, riparian evapotranspiration) influencing stream temperature. Field surveys were used to characterize riparian vegetation overstory and understory species composition and cover. Ambient, shallow groundwater, and stream temperature were collected using standalone sensors placed at selected locations along a 1-km riparian corridor reach in north-central Oregon. In the summer of 2015, a fiber optic cable and Distributed Temperature Sensing (DTS) were used to measure stream temperature dynamics along the 1-km reach. Stream temperature data from the point-specific sensors were compared to the data obtained by using the fiber optic cable. Weather and transpiration sensor data were used to determine riparian vegetation water uptake. Shallow wells were used to characterize stream-aquifer interactions and surface flow contributions from an intermittent stream. Data collected from the DTS and standalone sensors were observed to be in close agreement. Stream temperatures were greatest in the afternoon to early evening for most of the observation period. Fluctuations in stream temperature followed those observed in ambient temperature. Minor changes in stream temperature were observed at a confluence as a result of surface and flow contributions from a tributary. No significant differences in stream temperature were found between sensors located in shaded and non-shaded regions of the stream ($P \leq 0.05$). The results of this research indicate that other factors, such as groundwater inputs and stream velocity, may play a significant role in impacting stream temperature in this semiarid riparian corridor.

### Deriving a statistically representative removal constant from the international stormwater BMP database

Ryan Gilliom, Graduate Research Assistant, Colorado School of Mines
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Implementation of BMPs for stormwater control is commonly oriented to address a Water Quality Capture Volume, which simply assumes that 80-90% of pollutants are removed given that a certain volume of stormflow is captured from an event. There are scarce data-based methods of estimating pollutant removal performance, leaving decision-makers without a clear sense of their options for meeting stormwater effluent requirements such as TMDLs. The International Stormwater BMP Database holds a number of BMP monitoring studies, and the managers of the database publish a semi-regular statistical analysis of influent and effluent concentrations for each BMP-pollutant pair. This statistical summary allows decision-makers to see general performance trends, but provides no options for relating performance to site-specific conditions such as influent concentration and BMP design parameters. Knight's k-C* method, developed for modeling wetland performance, has since been applied to a wider range of BMP types. This method is programmed into a number of urban stormwater models, but there exists no data-based parameterization of the removal rate constant k. This poster documents the methodology and results of efforts to provide performance-characterizing values for the removal rate constants of various BMP-pollutant pairings.

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### Water quality, quantity, and usefulness of playa systems in the Texas High Plains

Nathan Howell, Assistant Professor of Environmental Engineering, West Texas A&M University
(co-authors: E. Butler, B. Guerrero)

Playas are the most dominant and noticeable surface water feature in the Texas Panhandle. They may be defined as, "shallow, depressional recharge wetlands occurring in the Great Plains region that are formed through a combination of wind, wave, and dissolution processes with each wetland existing in its own watershed" (Smith 2003). We monitored water quality and quantity parameters of playas in the summer of 2016 via weekly environmental sampling. All playas were in the west Texas Panhandle County of Deaf Smith, an area of mixed use agriculture including concentrated animal feeding operations, croplands, small-to-medium urban centers, and a few agricultural product processing facilities. The purpose the study was to provide some local and timely reference data on water quality and quantity, which would be informative towards the usefulness of playas. Thus far, data reveals that water quality does vary substantially from playa to playa depending on local soils, drainage area, and land use within the watershed. Discussions within landowners and the data itself generally indicate that playas, containing water of sufficient quality and quantity for use only infrequently and unpredictably, do not hold much promise for traditional agricultural or municipal needs. Playas are, however, useful as a means of monitoring processes which are occurring in semi-arid watersheds and likely will hold economic value for ecosystem services and areas of more intense biodiversity. Their ability to hold sway in the minds of a landowner and a local community will likely lie in our ability to demonstrate the value of ecosystem services and biodiversity especially through monetization. Moreover, in the interest of sustainability, in all meanings of the term, it is hard to conceive of a water management strategy in the playa regions which does not appropriately take them into account.

### Winter storms and climate change in the Oregon Cascades

Michelle Hu, Graduate Research Assistant, Oregon State University
(co-author: A. Nolin)

Research Question: How have winter storm temperatures varied in the Oregon Cascades over the last 30 years?
This project investigates the hydrologic significance of storm temperatures on precipitation regimes in several watersheds throughout the Oregon Cascades. Currently, only monthly averages of daily air temperature records (minimum, mean and maximum) are in use. These temperatures are not differentiated from recorded days with precipitation events and potentially create a bias and diluting the temperatures relevant to snowpack monitoring. It is the author's supposition that with climate projections indicating increasing winter temperatures and precipitation, there will be significant impacts on the hydrology and water resources of the Oregon Cascades as well as forest health, recreation, and tourism in the region. This study examines potential climate impacts on winter storms by addressing the following questions:

1. What is the mean air temperature for precipitation events during winter months?
2. What is the mean air temperature for snowfall events and the temperature of the rain-snow threshold? Do these temperatures vary by elevation or latitude?
3. Is there a significant relationship between storm temperature and climate patterns (e.g. El Nino/La Nina, Pacific Decadal Oscillation, Arctic Oscillation)?
4. Which areas in each of the selected watersheds would be impacted by an anticipated warming of 2oC? What might be the hydrologic implications of this influence

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### Non-stationary precipitation scenario development in the southwest United States

Peng Jiang, Postdoctoral Fellow, Desert Research Institute Las Vegas
(co-authors: M. Gautam, L. Chen, Z. Yu, K. Acharya)

Precipitation characteristics are assumed to be stationary by many studies which means precipitation fluctuates within an unchanging envelop of variability. It implies we can estimate a time-invariant probability density function (pdf) from observed records and then use it for assessing risks to engineering problems such as water supplies, dam constructions, and flood floodplains. However, the apparent hydro-climate changes both in magnitude and ubiquity reveal that the stationary assumption is a risk, and should not serve as the default assumption in water-resources risk assessment and planning in the future. This study aims to develop non-stationary precipitation scenarios in the southwest United States by using a stochastic precipitation model which can incorporate multi-scale temporal variability in the generated precipitation time series. By changing the time-varying parameters of this stochastic precipitation model, we can account for the impacts from substantial anthropogenic change of climate and large scale ocean oscillations on the non-stationary multi-scale temporal variability of precipitation time series. Three groups of precipitation scenarios are generated to consider all the possible human and natural climate change impacts on the evolution of precipitation in selected locations: (1) No human–induced warming effects, no changes in the El Nino/La Nina-Southern Oscillation (ENSO) Pacific Decadal Oscillation (PDO) frequency; (2) Warming effects but no changes in the ENSO PDO frequency; and (3) Both Warming effects and changes in ENSO PDO frequency. Detailed procedure as well as the comparisons between simulated and observed precipitation time series will be presented.

### Water education - A design perspective

Kathleen Kambic, Assistant Professor, Department of Landscape Architecture, University of New Mexico

Water infrastructure is facing new pressures as our environment changes. Increased climatic volatility, increased consumption by agricultural and metropolitan users, decreased storage, and increased pollutant loads are all pressuring the infrastructural systems on which we depend. As needs shift, designers of all types must respond to opportunities to revisit our assumptions about designing landscapes and cities to provide the water we need. In higher education, providing students the opportunity to focus on water issues within a design studio provides opportunities to explore new ways to treat existing water infrastructure in a time of volatile economic, environmental and social change. The studio work presented in this poster will demonstrate how water-oriented design studios and seminars can produce that work that rethinks the roles of landscape architects as change agents, demonstrates the power and beauty of water, and provides solutions to quantity and quality issues. The work addresses the Los Angeles River, the California State Water Project, and smaller speculative projects for the CU Boulder campus. These sites were chosen for their ease of access, connection to the Colorado River system, and the pressing issues they all face. The images that will be presented represent different scales of possible interventions into existing water infrastructure systems and describe how water education influenced the projects.

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### Coupling fluvial and oceanic drivers in flooding forecasts for San Francisco Bay

Jungho Kim, Research Scientist, Colorado State University
(co-authors: C. Venkatachalam, R. Cifelli, L. Johnson)

San Francisco Bay is a highly urbanized estuary and the surrounding communities are susceptible to flooding along the bay shoreline and inland rivers and creeks that drain to the Bay. A forecast model that integrates fluvial and oceanic drivers is necessary for predicting flooding in this complex urban environment. This study introduces the state-of-the-art coupling of the USGS Coastal Storm Modeling System (CoSMoS) with the NWS Research Distributed Hydrologic Model (RDHM) for San Francisco Bay. For this application, we utilize Delft3D-FM, a hydrodynamic model based on a flexible mesh grid, to calculate water levels that account for tidal forcing, seasonal water level anomalies, surge and in-Bay generated wind waves derived from the wind and pressure fields of a NWS forecast model. The tributary discharges from RDHM are meteorologically driven and dynamic, allowing for operational use of CoSMoS which has previously relied on statistical estimates of river discharge. The flooding extent is determined by overlaying the resulting maximum water levels onto a recently updated 2-m digital elevation model of the study area which best resolves the extensive levee and tidal marsh systems in the region. The results we present here are focused on the interaction of the Bay and the Napa River watershed. This study demonstrates the interoperability of the CoSMoS and RDHM prediction models. We also use this pilot region to examine storm flooding impacts from a series of storm scenarios that simulate 5-100yr return period events in terms of either coastal or fluvial events. These scenarios demonstrate the wide range of possible flooding outcomes considering rainfall recurrence intervals, soil moisture conditions,storm surge, wind speed, and tides (spring and neap). With a simulated set of over 25 storm scenarios we show how the extent, level, and duration of flooding is dependent on these atmospheric and hydrologic parameters and we also determine a range of likely flood events.

## Data visualization of environmental time-series: A demonstration of an interactive poster and information portal

Richard Koehler, National Hydrologic and Geospatial Sciences Training Coordinator, NOAA/National Weather Service

Big data is an ever-increasing challenge within water resources. Between large historic records, numerous environmental attributes, and modeling data used to generate past and future conditions, large amount of data are created. It is clearly necessary to have tools to handle, explore, visualize and analyze these large and diverse datasets. A multi-temporal visualization approach can simultaneously identify time-based events consisting of patterns, trends and processes occurring on minute, hourly, daily, weekly, seasonal, annual and inter-annual intervals across the temporal spectrum. The multi-temporal tactic allows the development of configuration metrics and use of novel multi-layer time map analyses similar to geographic information systems (GIS) data layers. Combining this time-series data exploration approach with traditional GIS data yields multi- spatial, multi-temporal maps. Such maps can be used to examine extensive historic records or to analyze numerous future scenarios critical in decision support efforts. Using an innovation interactive formatting approach with significantly less text, this poster provides multiple data visualization examples including animations. This concept is a fundamental departure from traditional conference posters and is essentially an information portal on raster-based visualization of environmental time-series.

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## An exploration of particle filtering techniques to determine aquifer properties from groundwater well data influenced by tidal forcing

Jose Kolb-Lugo, Research Assistant, University of North Florida
(co-authors: C. Brown, P. Kreidl)

Consider the problem of determining aquifer parameters from groundwater well data with embedded tidal signatures, which in coastal regions offers a low-cost alternative to the more typical approach of boring pumping wells to acquire drawdown data. Estimating key aquifer parameters such as the aquifer storage coefficient and transmissivity using such data depends on models that are nonlinear in the unknown parameters, which challenges traditional techniques. A recent study, using drawdown data for a confined aquifer, reports success with a contemporary signal processing technique called particle filtering. This paper adapts the technique to estimate confined aquifer parameters using near-field well data with tidal signatures. It includes (i) a review of the general particle filtering technique, including other studies of its applications in geoscience, (ii) the previously derived diffusion models of groundwater response that specialize the particle filter to estimate parameters using tidal data, (iii) results of the approach on previously published tidal data from a case study in China and (iv) some shortcomings of the approach as well as opportunities for future research.

## Solar river - A plan to power the CAP canal with solar power, leveraging current easements and boundaries and replacing coal power

Ben Lepley, Assistant Lecturer, University of Arizona
(co-author: A. Schwarz)

The Solar River project is a research proposal that covers and powers the 336 mile long CAP canal in Arizona. The Central Arizona Project canal is the lifeblood to the two major Arizona cities Phoenix and Tucson. The man made river is pumped uphill from Lake Havasu 336 miles and 2000 feet in elevation through some of the most arid landscapes on the continent. Currently it is powered by the largest and most polluting coal power plant in the USA, the Navajo Generation Station.

The canal uses approximately 700 MW of electricity through its 13 pumps situated along it's length. Our preliminary calculations show that we would be able to generate that same amount of electricity by mounting solar panels over the surface of the canal, for it's whole length. The proposal leverages Arizona state land, BLM, and other already controlled lands thus allowing for automatic egress and already improved sites. This plan would save tens of thousands of acres of virgin desert landscape from being bulldozed as compared to a typical solar utility of similar size. Currently we are working with CAP provided GIS data and parametric solar analysis tools to calibrate the system.

One major challenge is retaining access to the Canal for maintenance and repair operations, which has stalled similar studies by the Bureau of Reclamation. Coming at the problem through the lens of architectural problem solving, we plan on looking at numerous design iterations with many changing variables. Factors will include Canal accessibility, structural materials and strategies, previously improved land usage, easement analysis, topographical analysis, construction and feasibility variables, and solar design optimization. Currently we have already run a few simulations and design iterations for a challenging portion of the canal around the Picacho Pump. A few computer renderings will be provided as well as generation power and module specific information, should we be chosen to present our work.

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## Perceptions of safe water

Christine Martin, Little Big Horn College

Members of the Crow tribal community have been using the Little Big Horn River for generations. The river is an important part of cultural and ceremonial purposes as well as recreation uses for the Crow Nation. Understanding individual perception of their drinking water will give a better understanding to researchers to address the water issues. We recruited 33 home well owners. Participants answered in depth interview questions that were designed to gain a deeper insight into home well owner's perception of wanting safe water quality and why they believe their drinking water is safe or not safe. The study was deemed exempt by the University IRB board. Interviews were transcribed and analyzed using content analysis. We initially examined the transcripts to determine which themes related to home well owner's perceptions of their water and the most common throughout the interview process. Interviews were reviewed and coded by community advisory board members. Discrepancies were reviewed and resolved by an in depth discussion. A master list of themes was recorded once a consensus was reached. Seven themes we found from the transcripts. They were: Water/Sacredness, Risks associated with water, Knowledge, Power related to trust and knowledge, Loss and Hardship. Participants described using water for ceremonial purposes, some participants talked about not knowing how to take care of their home well, others talked about the lack of resources that prevent them from having the ability to solve their water crisis, and last some participants talked about the loss and hardship of the river and usage when compared to previous years. In conclusion, all participants had the perception of wanting clean safe drinking water for personal as well as ceremonial uses. Most participants had contaminants in their well water and had to haul clean, safe water back to their homes from nearby resources at their own expense. There is a need for water systems education to home well owners to minimize their water crisis. More research is needed to better understand home well owner's perception of clean, safe water.

## Surface and ground water flow modeling for calibrating steady state using MODFLOW in Colorado River Delta, Baja California, Mexico

Kedir Mohammed Bushira, Universidad Autonoma De Baja California
(co-authors: J. Ramirez Hernandez, Z. Sheng)

This study presents MODFLOW-based integrated hydrologic flow model (IHM) using the recently developed One-Water Hydrologic Flow Model (MF-OWHM) and its modules (WELL, RIV, UZF1, GHB, HOB) With the aim of understanding dynamics of surface-groundwater interactions in the Delta applying hydrological conceptual model into integrated hydrological flow model (MF-OWHM) for Colorado River delta (MCRD), calibrated based on averages of daily basis data throughout 8-year period. The model was developed using MODFLOW-OWHM code under the Model Muse Graphical User Interface, where surface-groundwater interactions through unsaturated zone were simulated using River package (RIV) and Unsaturated-Zone Flow (UZF1) MODFLOW packages under scars data conditions. UZF1 package was used in the area to model Hydrologic processes, such as infiltration and evapotranspiration (ET) collectively in which historically have been modeled separately from regional ground-water flow processes. Processes encountered in the calibrated parameterizations show groundwater flows axially from almost all directions of the model towards the Gulf of California at the south border of the model, match the course of the Colorado River and laterally towards new river (Rio Nuevo) in the North-west, with a larger portion flowing out southward than north-west ward. Although this study demonstrates understanding of MCRD´s surface and groundwater system interactions for calibrating steady states, remains fragile and the current model cannot be embedded in operational water management yet, it reflects the contemporary understanding of the local surface and groundwater system, illustrates how to model using UZF1 and RIV packages in data-scarce environments and provides a means to assess focal areas for future data collection and model improvements.

Keywords: Colorado River Delta, Numerical Modeling, MODFLOW-OWHM, Ground water Surface water interactions

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## Characterizing water quality of the South Platte River, from Waterton Canyon through Brighton, CO

Emily Mullins, Metropolitan State University of Denver
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The Denver Metro area is fully contained within the South Platte Watershed and so, the South Platte River is highly impacted by urban runoff and stream modification. Elevated nutrient concentrations, pesticide residue, heavy metals contamination, bacterial presence, and excessive sediment loading have been observed in the river in discrete locations. Building on these point studies, this project aims to assess water quality in the South Platte River throughout the Denver Metropolitan area. This ongoing project began in June 2015. Temperature, pH, dissolved oxygen (DO), and the concentrations of nitrate and phosphorus are being measured every three miles along the river beginning at the mouth of Waterton Canyon and extending through Brighton. Nitrate and phosphate concentrations as well as temperature show an increase through the Metro area. DO and pH do not show a distinct trend along the river. In addition to a general trend of decreasing water quality through the metro area, we also have noticed that certain locations consistently have especially poor water quality. Future work will target these areas to investigate the impacts of land use on water quality.

### Shifting peaks: When are our lakes the greenest?

Rebecca L. North, University of Missouri
(co-authors: J.L. Graham, D.V. Obrecht, H.M. Baulch, J.J. Hudson, O. Abirhire, P.J. Dillon, R.E.H. Smith, T.Y. Kim, A.P. Thorpe, C. Pollard, J.R. Jones)

The year-round peak in algal biomass in freshwater lakes occurs during the growing season - correct? If so, why are observations of high winter algal biomass becoming more common? Are the observed winter peaks a case of the more we look, the more we find? Or is it because winter, the un-monitored season, is changing. In this poster we will explore the understudied phenomena of winter algal peaks. We hypothesize that rapidly changing seasonal physical factors may be facilitating algal growth in this typically dormant season. We present data from 19 study systems ranging from a mesotrophic Canadian large lake and reservoir to eutrophic mid-west US reservoirs, representing a range in latitude and ice cover. Temporally resolved measurements of Chlorophyll a concentrations (Chla; a proxy for algal biomass) were collected on a year-round basis in all water bodies. When possible, microscopy was used for algal enumeration and identification. In the ice-covered Canadian water bodies, Lakes Diefenbaker and Simcoe, we found year-round maximum Chla peaks occurred under-ice. These winter peaks had 3x higher Chla than measured during the summer months. However, the composition of these peaks differed, with motile dinoflagellates dominating in Lake Diefenbaker, while the Lake Simcoe winter peak was composed of a non-motile diatom. In the mid-west, Chla in an urban Missouri reservoir peaked in the winter months in 2 of the 4 years sampled. In 15 diverse Missouri reservoirs, winter peaks occurred in 47%. In a Kansas drinking water reservoir, winter cyanobacterial blooms have been associated with taste-and-odor problems. This poster explores whether these shifting peaks are a consequence of climate-induced shorter winters, or whether recent efforts to expand the seasonal sampling window are capturing previously unaccounted-for algal peaks. Understanding winter algal dynamics may be important to predicting future changes in year-round lake function.

### Three Rivers QUEST – Water quality monitoring in the Ohio River Basin

Melissa O'Neal, Project Manager, WV Water Research Institute
(co-author: P. Ziemkiewicz)

Three Rivers QUEST (3RQ) is a collaboration between academic and volunteer-based water quality monitoring in the Upper Ohio River basin. The program, housed at the West Virginia Water Research Institute at West Virginia University partners with the Center for Environmental Research and Education at Duquesne University, Wheeling Jesuit University, and RedHorse Environmental, LLC. Together these partners monitor over 42 sites at the mouths of major tributaries and mainstem of the Allegheny, Monongahela and Ohio rivers. In addition to routine monitoring, the program has also conducted targeted studies on issues identified by watershed groups. The goal of the 3RQ is to provide sound science and bring multiple parties together to solve an issue or problem that may be negatively impacting our waterways. The program began as a result of high total dissolved solids (TDS) on the Monongahela River. Soon after routine sampling began in 2009, the Dunkard Creek fish kill occurred. Data collected through the program provided our team with the ability to suggest a "total discharge management" plan for coal mining effluents along Dunkard Creek. Since the initiation of this voluntary program, TDS levels have not exceeded critical limits for aquatic life in Dunkard Creek and have remained below 500 mg/L at our monitoring station on the Monongahela River. More recently in 2015, the 3RQ conducted studies on a mine discharge that was reported to have high levels of radiologicals. In 2016, the 3RQ initiated a targeted study on several water distribution systems, focused on production of total trihaolmethanes and the relationship to surface water parameters (i.e. bromide). The combination of volunteer and research partnership provide opportunity to not only gather a lot of data on a large geographic scale, but also to build relationships which help us all gain a better understanding of our water quality. Thanks in part to data collected through the program, Pennsylvania Department of Environmental Protection (PADEP) removed the Monongahela River from a list of "impaired" Pennsylvania waterways in 2015. The river was first designated as impaired due to sulfate contamination in 2010 PADEP. In 2012 known as the Mon River QUEST, the program won the NIWR Region IMPACT Award.

### Impacts of the expanding dairy industry on water usage and business composition in the Southern Ogallala Aquifer Region

Rachel Owens, West Texas A&M University
(co-authors: B. Guerrero, S. Amosson, L. Almas)

The dairy industry in the Texas High Plains region has expanded significantly in the past two decades. Many factors have caused new dairies to establish and existing dairy operations to relocate to the area. Factors such as the availability of land, the affordability of inputs like feed, and less stringent environmental policies have all contributed to this migration. This growth has led to changes in business composition and employment in the High Plains, as well as crop composition changes in order to facilitate the continued operation of these farms. Furthermore, dairies use a high amount of water, both directly and indirectly through means such as silage consumption. This study will use a regression analysis to examine the relationship between growth in the dairy industry and changes in the business and crop composition in the region as well as water use changes.

Keywords: business, dairy, economy, regression, water

### Modeling redevelopment impacts on urban stormwater runoff in Denver, Colorado

Chelsea Panos, Ph.D. Student, Colorado School of Mines
(co-authors: T. Hogue, J. McCray, D. Mollendor)

Redevelopment, known also as infill development, is the practice of building within existing developed urban areas on vacant or under-utilized parcels of land, typically resulting in an increase in impervious surfaces such as roofs, driveways, and parking lots. One example of redevelopment is replacing a low density, older single family home including a front lawn with a new, high density multi-family complex that covers the full parcel area. Through this conversion, the percentage of impervious coverage within a parcel can double. As cities worldwide reach their boundaries, redevelopment is becoming the new face of urbanization. Past studies have focused on changes in the hydrologic regime due to a transformation of undeveloped to developed land, or the extension of development into suburban areas, but have not directly addressed stormwater runoff produced through urban redevelopment. This research utilizes a version of the EPA's Storm Water Management Model (SWMM) from Innovyze called InfoSWMM Sustain to model and analyze the impacts of impervious cover change due to redevelopment on stormwater quantity and quality in Denver, Colorado, with a focus on the Berkeley Neighborhood. Less than two square miles, the Berkeley catchment receives an average annual rainfall of approximately 12 inches and has a current percent impervious area of 53%. Calibration results show accurate modeling of flow quantity (NSE = 0.983; BIAS = -0.87%; RMSE = 9.39 cfs) based on data collected in 2015 and 2016. This study also compares calibrated model results of various design storms to those predicted using Denver master planning approaches to evaluate the efficacy and appropriateness of basing decisions on such documents. Future model simulations will inform stormwater capture strategies for a broader project in the Berkeley neighborhood as well as scenarios for potential redevelopment across the City of Denver. Ultimately, research results will aid in the innovation of Denver's developing stormwater management triple-bottom-line-centered strategies with a focus on redevelopment.

### Assessment of managed aquifer recharge efficiency through the use of HYDRUS -1D

Olga Rodriguez, Research Assistant, Texas A&M AgriLife Research Center
(co-authors: Z. Sheng, S. Abudu, E. Reynoso)

The use of infiltration basins to recharge the Hueco Bolson aquifer with reclaimed wastewater has taken place since 2001, with the purposed of increasing groundwater storage for future use and preserving native groundwater levels. This study aims to evaluate the efficiency of the Managed Aquifer Recharge (MAR) program, by quantifying the amount of water reaching the aquifer and obtain design parameters for future expansion of the MAR program. Four infiltration basins were selected for such an evaluation. For each infiltration basin, recharge volumes and recharge area have been monitored over each recharge event. The dynamics of the infiltration process were monitored through measurements done with infiltrometers, soil moisture sensors, groundwater monitoring wells, and soil samples. The HYDRUS-1D (Simunek et al., 2005) package was used to estimate the contribution of infiltrated treated wastewater to the Hueco Bolson aquifer, based on meteorological and hydrogeologic data gathered at the site.

### Evaluation of riparian restoration success in southern Illinois

Benjamin Roosa, Graduate Research Assistant, Southern Illinois University Carbondale
(co-authors: K. Williard, J. Schoonover, S. Indorante)

Riparian zones represent the physical and ecological link between terrestrial and aquatic systems. Multiple ecological functions vital to the health and protection of our water resources are carried out in these transitional zones. Riparian areas also offer many advantages as agricultural land, which has had the consequence of substantial losses of riparian forest as the country's population has expanded. Now as science and society come to appreciate the essential role that riparian forests play and the many benefits that they can provide, some of these areas are being returned to forest. Our research attempts to quantify the rate and magnitude at which ecological function is returning to newly reforested riparian zones in southern Illinois. We are simultaneously working to identify several indicators of ecological function which can be used to reliably evaluate riparian restoration success. Our study pairs 50 riparian forests restored within the last twenty years with nearby agricultural fields in a similar landscape and soil context. Five soil parameters will be assessed at each site: bulk density, aggregate stability, total Carbon, total Nitrogen, and labile Carbon. We will then construct regression models comparing each parameter to the site's age which is defined by years since being restored to forest. Additionally, ten of the pairs will have a third replicate located in a mature riparian forest (>60 years old) in an attempt to determine target restoration values for each parameter. The study will also establish a baseline for the selected sites which will be used in future research on the return of ecological function. We hope that this study will give us a better idea of how riparian systems respond to reforestation and provide insights into the value of riparian reforestation, including the installation of riparian forest buffers, in protecting our water resources.

### Integrated groundwater-surface water modeling with emphasis on recharge estimation and optimal groundwater abstraction (A case study in the Neishaboor Watershed, Iran)

Alieh Saadatpour, Visiting Scholar, Colorado State University
(co-authors: A. Alizadeh, A.N. Ziaei, S. Park, R. Bailey, A. Izady)

Groundwater recharge is an important component for the groundwater management and planning in arid and semi-arid regions. Additionally, determination of groundwater recharge in these areas is neither straightforward nor easy due to the spatial variability in soil characteristics, geology, topography, land cover characteristics and land use. This study presents an integrated SWAT-MODFLOW model that couples land surface hydrology and groundwater hydrology to determine spatial groundwater recharge patterns considering allowable groundwater pumping rates for the Neishaboor watershed, Iran. The climate of the region is classified as semi-arid, with an average annual precipitation of 265 mm that varies considerably from one year to another. The mean annual temperatures changes from 13°C in the mountainous area to 13.8°C in the plain area and the annual potential evapotranspiration is about 2,335 mm. The main crops that are grown in the watershed is irrigated and rain fed wheat during fall and winter and corn silage during summer. Regarding previous studies, about 93.5% of the groundwater withdrawals in the Neishaboor watershed are consumed in agriculture, mostly for irrigation. Therefore, irrigation practices play a crucial role in the water resources balance in the study area. Within the integrated model, the pumped groundwater is applied as irrigation to the cultivated fields within the SWAT model, with deep percolation from the soil profile bottom applied to the MODFLOW model as recharge. The developed model was calibrated and tested for the 2000-2010 and 2010-2012 periods, respectively against groundwater level data. The model will be used to determine best management practices for groundwater pumping in the region.

### Quantifying the dynamics of freshwater and saltwater interface in the Upper Floridan Aquifer

Xizhen Du Schenk, Georgia Southern University

The seaward movement of freshwater naturally prevents saltwater from encroaching into coastal freshwater aquifers. Extensive groundwater withdrawals have resulted in substantial declines in the Upper Floridan Aquifer level in southwest Florida. Such reduction has, consequently, accelerated the encroachment of saltwater into freshwater aquifers. In addition, climate change affects aquifer resource by changing the precipitation and the demand associated with precipitation changes. Public water supply is estimated to reach at least 220 million gallons/day by 2050. With the increasing freshwater demand, decreasing freshwater storage, and subsequent saltwater encroachment, this study is aimed to quantify the freshwater and saltwater interface movement, better understand the relations among rainfall, pumpage, and aquifer level, and better understand regional heterogeneities. Aquifer level monitoring data, water quality data, and pumpage data were collected for 22 years. Seasonal and trend decomposition using loess was used to separate seasonal, trend, and irregular components. General linear model tests were conducted to evaluate the crossed effects among rainfall, pumping, and water level. Numerical Model DWRM was adopted to test the effects of pumping and rainfall variations on aquifer level changes. In addition, pumping sensitivity tests were conducted to evaluate aquifer responses to aquifer recharge projects. Results indicated that chloride rises substantially in most northern and central coastal areas, with as much as three times since 1992. Water levels overall have not recovered to 13.1 feet, the minimum aquifer level needed to stop saltwater intrusion in the region. Saltwater encroachment continues, although not uniform. Seasonal decomposed water level time series has decreased significantly, with much greater magnitude compared to the seasonal trend. To minimize saltwater intrusion, balancing growing demand for fresh groundwater resources in the Upper Floridan Aquifer system with both climatic and land-use stresses is key. Conservation, finding alternative water supply sources, and exploring aquifer recharge project opportunities should be continued.

### Water sampling and the effects of adsorption on aqueous heavy metals

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The goal of this study was to mimic river water samples collected from the locations along the Las Animas River in August of 2015 after the Gold King Mine Spill in Silverton, Colorado. The levels of arsenic, cadmium, and lead that were released in this tragic event are an example of how heavy metals can be released into our natural waterways and possibly contaminant drinking water sources. In environmental research, variables are always changing; that is what makes research in this field of study so difficult. It is in the researcher's best interest to reduce variability in sampling techniques in order to provide the scientific community, as well as the public, with the most accurate data possible. This research looks at variability in water sampling and storage techniques and how it can affect data results, specifically the concentration of aqueous heavy metals in twelve sampling containers spiked with lead and cadmium. The twelve sampling containers included six glass and six plastic of similar size and were also divided by storage temperature. Regular measurements for concentrations of the metals of concern were taken over the span of three days using an Inductively Coupled Plasma Mass Spectrometer. By limiting sampling conditions and focusing on a few particular variables, a better understanding of the effects that sampling techniques have on data results was achieved. An average decrease in cadmium concentration of 12% and an average decrease in lead of 46% were noticed in all samples indicating adsorption to the sampling containers. Continued research may indicate differences in adsorption to the glass versus plastic containers used in this study.

### A new model for vertical seepage in karst lake environments

Chris Slater, Ph.D. Candidate, University of South Florida

Proper resource management of water catchments is essential to communities, wildlife, and industry. Karst lakes are unique among common water bodies for their high permeability and great interaction with surficial aquifers and confined aquifers. Previously, geoscientists and hydrologists have over-simplified hydrologic model parameters of lakes. This has led to inaccuracies of the lake leakage rate; models are not widely applicable due to not enough lakes being tested. Physical properties such as infiltration and porosity can be observed to have a non-linear relationship within the lake; making permeability between the lake waterbodies and aquifers much more dynamic for an entire grouping of selected lakes. Our current model for the West-Central Florida region must be updated to distinguish between the properties and parameters for a large selections of lake waterbodies under an extended time period. To support West-Central Florida, engineered hydrology and hydrogeology calibration techniques are functioning methods used to discover the water budget dynamics for selected lakes within the domain. We have produced a model with more parameters, to test lake beds in karst lakes. Surface water interactions with aquifers were modeled with the Hydrological Simulation Program-Fortran (HSPF) application and Geographical Information System (GIS); groundwater application is modeled using the model MODFLOW. Tested against lake content data collected in a 16-year span, the model more accurately forecasts vertical seepage than previous models. The model is good at representing leakage from the lake bed; important for estimating the remaining water quantities and producing the best water resource management strategies.

### Using satellite data to build climate resilience: A high resolution multi-sensor monitor of waterbody change during the 2015/2016 East African drought

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Freshwater is one of the world's most important natural resources. It is essential to human health, ecosystem function, and livelihoods, but is a finite resource and needs to be appropriately managed. As global demand grows, there is increasing competition for resources between the water, agriculture, energy, livestock, fisheries, forestry, mining, transport, and other sectors. However, the policy challenges to meeting societal demands for water while maintaining ecosystem function are exasperated by the modification of water availability due to changing land use and climate conditions. The scarcity of in-situ hydrologic observations across many parts of the world makes it difficult to understand and predict the impact of climate change on water resources in these regions. This is a substantial obstacle to the development of appropriate water management strategies, particularly in developing countries. Remote sensing methods have been shown to be a viable alternative to in-situ measurements in data-sparse areas. Our uses study remote sensing methods to assess the impact of the 2015/2016 drought in East Africa on regional surface water. Landsat and Sentinel 1 synthetic aperture radar data are merged to create high resolution maps of surface water and its changes over the 2015/2016 East African drought. The new information provided by this research will inform decisions affecting the water, energy, agriculture and other sectors in East Africa reliant on water resources, enabling policy makers to better adapt to future challenges.

### Innovative stormwater management practices and standards for North Carolina

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Stormwater runoff has been identified in North Carolina as a major cause of waters failing to meet water quality standards. The Clean Water Act and its subsequent amendments have required communities that develop to manage stormwater through a number of ways. Development typically must plan for the one inch storm in a twenty-four hour period. Due to increasing requirements from the EPA, municipalities have spent millions of dollars to mitigate stormwater runoff. The cost of stormwater management and its negative impact on natural hydrology has stormwater managers and regulators looking for lower cost alternatives and shared responsibility among contributors of stormwater runoff. A number of Low Impact Development (LID) techniques, such as downspout disconnections, extensions to lawn areas, large rainwater harvesting systems, rain barrels, rain gardens, bio-retention ponds, porous pavement, green roofs, have been employed to help mitigate the problem and help achieve regulatory compliance. The State of North Carolina has recently redone its design standards for development for every Stormwater Control Measure (SCM), aka Best Management Practices (BMP's). The changes are based upon a North Carolina Division of Environmental Quality (DEQ) led work team comprised of researchers, local government representatives, and private sector consultants. Their efforts have produced Minimum Design Criteria (MDC's) for a variety of stormwater management practices. This paper will provide a current review of North Carolina's regulations, and engineered SCM's, as well as efforts at educating the public and private sector on requirements for stormwater management.

**Development of a control optimization system for real time monitoring of managed aquifer recharge and recovery systems using intelligent sensors**

Kathleen Smits, Colorado School of Mines
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Aquifers around the world show troubling signs of irreversible depletion and seawater intrusion as climate change, population growth, and urbanization lead to reduced natural recharge rates and overuse. Scientists and engineers have begun to revisit the technology of managed aquifer recharge and recovery (MAR) as a means to increase the reliability of the diminishing and increasingly variable groundwater supply. Unfortunately, MAR systems remain wrought with operational challenges related to the quality and quantity of recharged and recovered water stemming from a lack of data-driven, real-time control. This research seeks to develop and validate a more general simulation-based control optimization algorithm that relies on real-time data collected through embedded sensors that can be used to ease the operational challenges of MAR facilities. Experiments to validate the control algorithm were conducted at the laboratory scale in a two-dimensional synthetic aquifer under both homogeneous and heterogeneous packing configurations. The synthetic aquifer used well characterized technical sands and the electrical conductivity signal of an inorganic conservative tracer as a surrogate measure for water quality. The synthetic aquifer was outfitted with an array of sensors and an autonomous pumping system. Experimental results verified the feasibility of the approach and suggested that the system can improve the operation of MAR facilities. The dynamic parameter inversion reduced the average error between the simulated and observed pressures between 12.5 and 71.4%. The control optimization algorithm ran smoothly and generated optimal control decisions. Overall, results suggest that with some improvements to the inversion and interpolation algorithms, which can be further advanced through testing with laboratory experiments using sensors, the concept can successfully improve the operation of MAR facilities.

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**Incorporating sustainability metrics and co-benefits into a decision support tool for stormwater infrastructure selection**

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Selecting the most appropriate green, gray, and / or hybrid system for stormwater treatment and conveyance can prove challenging to decision markers across all scales, from site managers to large municipalities. To help streamline the selection process, a multi-disciplinary team of academics and professionals is developing an industry standard for selecting and evaluating the most appropriate stormwater management technology for different regions. To make the tool more robust and comprehensive, life-cycle cost assessment and optimization modules will be included to evaluate non-monetized benefits, or co-benefits, of selected technologies. Initial surveying found that decision makers lack a standard quantifiable way to compare the co-benefits of green infrastructure like the benefits reaped from open space and peak flow attenuation. Industry professionals want a means to compare the costs of project alternatives with these ancillary benefits included. Often social and environmental impacts are translated into monetary amounts that are then compared to economic markers via the triple bottom line approach. By assigning a dollar amount to environmental or social gains or losses, agencies neglect to evaluate projects on a systems level and reduce environmental and social costs to externalities. To better illustrate the potential co-benefits of installing green, grey, or hybrid infrastructure on a planning level, a methodology is being developed that presents graphical representation on social, economic, environmental, and regulatory benefits based on a multi-criteria assessment matrix. This methodology will rank co-benefits in units that appropriately measure their gains and losses. Subcategories for each decision point will be defined based off existing literature and existing decision support tools. The graphical representation of co-benefits will then be coupled with the life-cycle costs to show decision makers a holistic analysis of green, grey, and hybrid infrastructure alternatives.

### Estimating potential *E. coli* loads from livestock and wildlife sources using Python-SELECT

Vaishali Swaminathan, Graduate Assistant, Texas A&M University
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Spatially Explicit Load Enrichment Calculation Tool (SELECT) is a Visual Basic for Application (VBA) coded Geographic Information System (GIS) based tool that can estimate *E. coli* loads within watersheds based on spatial data such as land use and population distribution of potential sources. Since ESRI withdrew support for VBA in the subsequent versions of ArcGIS (v10 and further), launching and using VBA coded tools on the ArcGIS platform have become convoluted. Hence, SELECT was recoded using Python for easy access on the latest version of ArcGIS, and also overcome some of the inherent drawbacks of the older version of the tool. Fecal loads were obtained from livestock and wildlife sources, whose population were distributed on suitable regions within the watershed. Livestock comprised of cattle, horse, sheep and goat; wildlife sources were feral hog and deer. Appropriate conversion factor was applied to convert fecal load into *E. coli* load. This was further aggregated to the subwatershed level to highlight areas at risk of fecal contamination. The added features of the Python-SELECT are, (1) automated distribution of source population over county regions that are within the watershed; (2) extended application of SELECT to watersheds with more than 4 counties. A dynamic graphical user interface (GUI) was created using ArcGIS Python Toolbox and Python Add-in Application Extension. The output maps from VBA-SELECT and Python-SELECT that depict spatial distribution of *E. coli* loads within regions of the subwatershed were in agreement for livestock and feral hog; however, they differed significantly for deer due to differences in methods used to obtain contiguous habitats.

### Enhanced microbial sulfate removal through a novel electrode-integrated bioreactor

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Sulfate is regulated in northeast Minnesota, because it has adverse impacts to wild rice. The state currently has a stringent sulfate standard for wild rice waters, 10 mg/L, which is now under review by the Minnesota Pollution Control Agency. Sulfate can also contribute to methylmercury production and eutrophication. In the region, many mining operations produce runoff with low metal, but high sulfate concentrations at neutral pH conditions. Increased interest has emerged for developing new technologies to help treat the high levels of sulfate in the water. Biological sulfate reduction is a promising and economically viable plan for maintaining low levels of sulfate and sulfide, but its performance is highly variable. In this work, a novel bioreactor was developed to stimulate and sustain biological sulfate reduction and simultaneously facilitate the subsequent removal of reduced sulfide via iron electrolysis under low electrical potential. Sediment bioelectrochemical reactors with stainless steel electrodes were used to test the effect of low voltage on the efficacy of sulfate reduction and iron sulfide formation. Two different reactor configurations were designed and tested: a batch system and a column flow-through system. For both sets of experiments, reactors containing sediment collected from Second Creek near Hoyt Lakes, MN were used. Synthetic mine water with a sulfate concentration of 1000 ppm was used. The reactors operated at 2 V where cathodic hydrogen was produced and anodic iron dissolution occurred. Open circuit reactors were used as a control. Microbial community structure and relative abundance of different species associated with sulfate reduction in the reactors were examined. This study will result in a proof of concept application of electrical potential to provide electron donor substrates to biological sulfate treatment with simultaneous sulfide removal with iron species in a controlled manner.

### Considerations for soil moisture sensor use in heavy soils and a humid temperate climate

Maureen Thiessen, Louisiana State University
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Concerns over stressed aquifers in agricultural regions of Louisiana have heightened interest in irrigation management strategies. Maintaining a soil water balance based on environmentally-sensed data is a common approach to determine crop water needs in high-acreage, soil-based production scenarios. Increasing availability and decreasing costs of environmental sensors, and advances in remote, real-time data access and storage allow the technique to be more easily used by producers. However, proper and timely usage of sensor data within the soil water balance framework requires knowledge of the soil hydrological parameters and how they interact with crop- and climate- specific variables. Specifically, determination of crop water needs requires accurate estimation of crop evapotranspiration (Etc), and therefore requires crop coefficients (Kc) specific to the climate, soils, and crop under management. Additionally, the soil water redistribution element can significantly affect the soil water balance in heavy clay soils common to Louisiana, which is trivial in greenhouse and sandy soil production systems. To investigate the ability of soil moisture sensors to help irrigation managers account for these elements, a soil water balance was constructed for a production system at the Red River Research Station in Bossier City, LA. Granular matrix and capacitance sensors were installed at multiple depths in a production field and monitored throughout crop growth. Crop coefficients were determined by comparing the changes in field soil moisture to the reference evapotranspiration determined from on-site weather station data, with considerations for soil water redistribution discussed.

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### Investigation of coliform contamination in private well water on the Crow Reservation

Emery Three Irons, Montana State University

The Crow reservation has a rural population that depends on home well water and wells have bacterial contamination that are constructed at various depths or if the well does not have a suitable well cap. Coliform contamination of well water is an important health concern among Crow home well users. Fecal coliform is associated with acute health problems, such as gastrointestinal distress, diarrhea and cramps. The investigation of coliforms in home well water will provide a better understanding between coliform contamination and physical characteristics and well stewardship factors. Samples will be collected throughout the Little Big Horn Valley at home wells. The samples will be analyzed using two analysis methods; the first identifies significant spatial clusters of coliform contamination. The other evaluates the association between specific risk factors and coliform occurrence to better understand the spatial distribution of factors that are correlated with contamination. The results are expected to be used for mitigation efforts by the Crow tribe to find solutions for homeowners with contaminated wells.

### Using drought tolerant plants with integrative irrigation management to reduce groundwater reliance

Amy Uyen Truong, Texas A&M University

Cities that are reliant on groundwater are at risk during extended periods of drought. From the San Antonio Water System Semiannual Report for January 2016 – June 2016, 82.8% of water supplied to San Antonio came from the Edwards Aquifer. A 2012 Texas Water Development Board report stated 25% of total water use in San Antonio is for outdoor watering. During the 2011 drought, this increased to 31.2%. San Antonio has a strong conservation program that encourages xeriscaping and drought tolerant plants to curb outdoor watering needs. However, there is a knowledge gap regarding the actual watering needs of drought tolerant plants resulting in potential over-watering of many of these species. To address this, 97 ornamental plants were analyzed to test their drought tolerance and measure their effectiveness for water conservation in San Antonio. Plants were irrigated at 4 levels based on percentage of ETo (i.e. 0.0, 0.2, 0.4, and 0.6 ETo) to find the highest performing and lowest performing species over a 12-week drought experiment. Overall, there was a strong correlation between plant performance and adequate soil moisture levels. Under drought conditions (0.0 ETo), 21% of species survived with no supplemental water, whereas 54% of plants remained stable in the 0.2 ETo irrigation treatment. Most plants performed well at the 0.4 ETo irrigation level, and there was no statistical significance ($p<0.05$) between overall plant appearances in the 0.4 and 0.6 ETo irrigation treatments. Use of these findings can result in substantial water savings in the Edwards Aquifer region if consumers properly utilize ET-based irrigation treatments. The results allow consumers to choose landscape species that are best suited to both conserve water and meet aesthetic needs while encouraging an integrative irrigation approach to reduce the reliance on the Edwards Aquifer for San Antonio during an extended period of drought.

### Analyzing water rebate programs in Tucson, AZ

Ethan Vimont, Graduate Research Assistant, University of Arizona

As water becomes scarcer, many water providers are looking for ways to encourage conservation. Water reuse is a critical part of water management, and because there is a set amount of water, deciding how and when water is reused will be a continuing and necessary debate. A 2016 National Academy of Sciences report on graywater, a hotly argued form of reuse, identifies several areas on needed research including assessing regulatory innovations to increase onsite water use, understanding how water harvesting systems affect water use behavior, assessing user knowledge of water harvesting systems, and further understanding the extent that best management practices are practiced. This research is designed to provide insight into some of these needed research areas.

In Arizona, Tucson Water has used various measures to encourage conservation such as rebates or tax breaks for low flow toilets and fixtures, high efficiency washing machines, graywater systems, and rainwater harvesting systems. This research, focused on Tucson Water's rebate programs for installing water harvesting systems, takes a closer look at the maintenance requirements of water harvesting systems and the effect that water harvesting systems have on property vegetation. This project, under the supervision of Dr. Sharon Megdal, is composed of two parts: a survey of rebate recipients focused on maintenance and remote sensing of properties of rebate recipients to analyze changes in greenness. The survey was completed with a 43% response rate, and further analysis of the results will be completed within the next month. The remote sensing aspect will be ongoing for the next several months.

This poster will present the findings of this study, which will elucidate unstudied aspects of water harvesting. Understanding some of the ramifications of residential level water harvesting, such as the programs encouraged by Tucson Water, will be an important part of informed decisions.

### Community composition of denitrifying bacteria within sediments impacted by acid mine drainage

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An estimated 23,000 abandoned mines are scattered across the State of Colorado. These abandoned mines often leak effluent that is low in pH and high in dissolved metal concentration. This acid mine drainage (AMD) adversely affects ecosystems and is detrimental to local communities who often suffer economic and cultural repercussions with little legal recourse. However, little is known about microbial community structures within these AMD-impacted systems that may otherwise be able to provide valuable ecosystem services. Additionally, far less is known about denitrifying microorganisms in these same systems, despite their critical role in mitigating nitrogen pollution. Denitrifying microorganisms are capable of limiting excess nitrogen deposition that could otherwise lead to problems such as reduced drinking water quality, toxic effects on freshwater biota, and disruption of aquatic nutrient cycling. In this study, denitrifier diversity and community structure are assessed in relation to environmental variables within an ecosystem that has been significantly altered by AMD. This study provides new insight into the biogeochemical activity of ecosystems affected by AMD and has the potential to influence future remediation and watershed management decisions.

### The impacts of change in irrigation methods on regional water resource utilization and management in Yanqi Basin, Xinjiang, China

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Yanqi Basin is an oasis agricultural region in Xinjiang, China where the main cultivate crops are tomato, chili etc. The existing cultivated land area in Yanqi Basin is 188, 300 $hm^2$. The improved crop yields and reduced labor make farmers adopt to the drip irrigation quickly. Approximately 77.6% of cultivated land was converted to drip irrigation in 2014. The rapid application of drip irrigation resulted in increase in groundwater pumping and falling of groundwater levels. From 2000 to 2011, the number of wells was increased from 683 to 3,216. Groundwater withdrawal was increased from 125 million $m^3/a$ increased to 692 million $m^3/a$ in contrast to the estimated safe yield 400 million $m^3/a$. The groundwater has been overdraft since 2009. Source water for agricultural irrigation was changed from river water to groundwater. The irrigation methods transformed from surface flood irrigation into furrow and drip irrigation. To address elevated depletion of water resources and ecological deterioration issues, the government have taken two measures: reducing water withdrawal and retiring land. Surface and groundwater irrigation facilities are built to keep balance of water resources. Other measures were also considered, such as appropriate economic compensation for farmers to retiring land or reducing water consumption. Flood irrigation and furrow irrigation were converted to drip irrigation. It has a great impacts on water consumptions and management. Farmers become more favorable to groundwater than surface water due to high efficiency and easy implementation of new irrigation technology. It also addressed the salinization problem in some areas. However drip irrigation increases the amount of consumptive use of water resources. Hence, to design and implement comprehensive strategies is the key to prevent new problems.

Key words: drip irrigation, groundwater, water resources management, Yanqi Basin

**Index-based assessment of agricultural drought using remote sensing in the semi-rid region of western Turkey**

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World is changing at an unexpected rate in terms of climate and land use, and also these changes affect our natural resources. Normalized difference vegetation index (NDVI), soil adjusted vegetation index (SAVI), surface temperature are often used worldwide to monitor drought, monitor and predict agricultural production. The study area is located west of Turkey where has a dam and organic plain. Major climate type of the study area is Mediterranean. Main crops of the study area are citrus, grapes and olives. In this study, satellite-based remote sensing data and geographic information system tools were used for mapping of NDVI, SAVI and surface temperature for growth season. The purpose of the study is to analyze the vegetation stress in the Seferihisar Kavakdere Plain with the calculation of NDVI, SAVI values and the surface temperature. The combination of NDVI, SAVI and surface temperature, provides very useful information for agricultural drought monitoring and early warning system for the farmers.