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Department of Hydrology and Water Resources

Presents

The 16th Annual

El Dia del Agua

March 2, 2006

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Water for People
Eller School of Management

Student Research Presentations

Student Union Memorial Center ~ Grand Ballroom

8:00am ~ Registration & Continental Breakfast

8:45am ~ Opening Remarks by
Dr. Thomas Maddock, Department Head

9:00am ~ 10:00am ~ Oral Presentations
10:00am ~ 11:00am ~ Poster Session
11:00am ~ 12:00 ~ Oral Presentations

12:00pm ~ 1:30pm
Buffet Lunch ~ Registration Required
Luncheon Speaker ~ Dr. David Hargis
"When Science Gets Down To Business:
Consulting in Hydrogeology"

1:30pm ~ 2:00pm ~ Poster Session
2:00pm ~ 3:20pm ~ Oral Presentations

3:30pm ~ 4:30pm
Guest Speaker ~ Dr. Stephen E. Silliman
"Groundwater Studies in Benin, West Africa: The Importance of Collaboration with Colleagues and the Local Population"

4:30pm ~ Award Presentations

Montgomery Prize ~ By Leslie Katz
Best Oral Presentation ~ $1,000

Hargis Awards ~ By David Hargis
First Place Poster ~ $1,000
Second Place Poster ~ $400

HWR Awards ~ By Jim Washburne
Best Speaker ~ $400
Best Poster ~ $400

Message from the HWRSA President

Dear El Dia del Agua Participants,

On behalf of the Hydrology and Water Resources Student Association (HWRSA), we would like to welcome you to the 16th annual El Dia del Agua Student Research Symposium. El Dia del Agua (EDDA) is the perfect opportunity for students to present their current work at the Department of Hydrology and Water Resources (HWR) of the University of Arizona, which is known worldwide for its cutting-edge research in hydrology and related sciences.

This year we are glad to host a full-day event with ten oral presentations, twenty-one research posters and two guest alumni speakers. This symposium is an event "for the students" and "by the students" in which we can receive a first hand response from fellow hydrologists. Through the years, university faculty and professional hydrologists have supported and attended EDDA. This tradition serves to strengthen the hydrology community as well as to facilitate knowledge transfer between academia and the professional community. Furthermore, EDDA is a great place for prospective students to learn about the wide range of interesting research opportunities available to HWR students. The success of EDDA is possible thanks to the joint efforts of HWR faculty, administration, students, and sponsors. To all them goes our gratitude.

Thank you for taking the time to attend El Dia del Agua. After the awards session and closing ceremony please join us for SUDS at No Anchovies at 5 pm!

Julio Cañón Barriga,
HWRSA President

Laura Lindenmayer
HWRSA Vice-President

Deidre Brosnihan,
HWRSA Treasurer

Candice Marburger,
HWRSA Social Chair

Support your HWRSA by purchasing a T-shirt! On sale now!
Website: http://www.hwr.arizona.edu/%7Ehwrsa/index.html

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The Montgomery Prize

The Department of Hydrology and Water Resources would like to thank Errol L. Montgomery & Associates, Inc. for their support of the 16th Annual El Dia Del Agua. For several years, Montgomery & Associates has sponsored a special cash award, *The Montgomery Prize*, for the best oral presentation at the annual student symposium. This prize is in addition to the two departmental awards (best oral and best poster presentations) and will be presented to the winner by Ms. Leslie Katz, a Principal Hydrogeologist with Montgomery & Associates. The award symbolizes the company's commitment to encouraging and rewarding excellence in oral presentation of hydrologic research. Montgomery & Associates offers similar awards during annual events at the University of Arizona and Northern Arizona University Geology Departments.

Errol L. Montgomery & Associates, Inc. is a hydrogeologic consulting group with more than 20 years of experience addressing groundwater availability, sustainability, and quality issues for municipal, industrial, mining, and governmental clients. Professional services include:

- Groundwater exploration and development
- Contaminant assessment and remediation
- Artificial groundwater recharge
- Assured and Adequate Water Supply demonstrations
- Hydrologic monitoring
- Satellite image analysis
- Groundwater flow and solute transport modeling

The firm's principal office is located in Tucson, Arizona, and branch offices are maintained in Scottsdale, Arizona and in Santiago de Chile.

The Hargis Awards

The Department of Hydrology and Water Resources would like to thank Hargis + Associates, Inc. for their continued support of the Annual El Dia del Agua. This year, Dr. David Hargis will present a first and second place cash award for the best poster presentations at the annual student symposium. Evaluation will be performed by a panel selected by Dr. Hargis. The Hargis Awards are made in recognition of the need for excellence in technical communications and serve as an incentive for participating students to demonstrate excellence in writing, visual presentation, and oral communication skills in support of their research projects.

Hargis + Associates, Inc. is a nationally recognized hydrogeology and engineering consulting firm founded in Tucson in 1979. The firm specializes in consultations in water resources, environmental assessment and remediation, litigation support, and mining. In addition to its Tucson office, the firm also has offices in San Diego and Mesa.

El Dia del Agua Organizing Committees

Thomas Maddock III, Department Head

Technical Committee
James Washburne, El Dia del Agua Chair
Dennis Scheall, El Dia del Agua Co-Chair
Thomas Meixner, El Dia del Agua Co-Chair

Event Coordinator
Debbie Chester

Booklet Designer
Erma Santander

Evaluation Committee for Awards

Montgomery Prize
Leslie Katz ~ Don Young ~ Paul "Ty" Ferré

Hargis Awards
David Hargis ~ Leo Leonhart ~ Dennis Scheall

HWR Oral Award
Mike Bradley ~ Leticia Rodriguez ~ Jesse Dickinson

HWR Poster Award
Tim Corley ~ James Hogan ~ Peter Troch ~ Martha Whitaker

HWRSA El Dia del Agua Committee
Julio Cañón Barriga ~ President
Laura Lindenmayer ~ Vice-President
Deirdre Brosnihan ~ Treasurer
Candice Marburger ~ Social-Chair

Lissette De La Cruz
Jennifer Druhan
Eden Feirstein
Kristin Green
Maite Guardiola Claramonte
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Jennifer Kostrzewski
Kristopher Kuhlman
Guillermo Felipe Martinez
Andrew Neal
Prafulla Pokhrel
Jesse Roach

Department Advisory Council (DAC)

Dr. David R. Hargis
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EL Dia Del Agua ~ Lunch Guest Speakers

Dr. David Hargis

"When Science Gets Down to Business:
Consulting in Hydrogeology"

Dr. David Hargis received his Ph.D. (1979) in Hydrology and Water Resources from the University of Arizona. He is the President and Chief Executive Officer of Hargis + Associates, Inc. (H+A) with offices in Tucson, Mesa, and San Diego. Under his leadership H+A has developed special expertise in hydrogeologic assessments, water resource development, groundwater modeling, contaminant characterization, and remediation of groundwater and soil that has been impacted by various organic and metal contaminants. His firm also provides expert witness testimony and technical consultations for clients, attorneys, and potentially responsible party groups involved with water quality, water management, and water contamination issues. In addition to his professional activities, Dr. Hargis continues to maintain an active interest in our Department including serving as a member on our outside Advisory Committee and sponsoring the Hargis Awards for excellence for the poster presentations at El Dia del Agua.

EL Dia Del Agua ~ Guest Speakers

Dr. Stephen E. Silliman

"Groundwater Studies in Benin, West Africa:
The Importance of Collaboration with Colleagues

Dr. Stephen E. Silliman is a Professor of Civil Engineering and Geological Sciences, as well as Associate Dean for Undergraduate Programs, in the College of Engineering at the University of Notre Dame. He received his B.S.E. (1979) in Civil Engineering from Princeton University and his M.Sc. (1981) and Ph.D. (1986) degrees in Hydrology and Water Resources from the University of Arizona. He has worked for the U.S. Geological Survey and joined the faculty at Notre Dame in 1986. His initial research focused on flow and transport processes in heterogeneous media. More recently he has extended his activities to include water resource research in Benin, West Africa. He is also Director of the Haiti seminar which provides a service experience for undergraduate and graduate students involving water supplies in Haiti.

El Dia del Agua ~ Program Schedule

TIME	SCHEDULE
8:00 - 8:45	**Registration & Check-In**
8:45 - 8:55	**Opening Remarks:** Dr. Thomas Maddock, Department Head
Moderator	*Jesse Roach*
9:00 - 9:20	**Jennifer Druhan**: *Geochemical Analysis of Recharge and Salinization in the Northern Hueco Bolson Aquifer, El Paso, Texas*
9:20 - 9:40	**Gregory Schnaar**: *Pore-scale Characterization of Organic Immiscible-Liquid Morphology in Natural Porous Media Using Synchrotron X-Ray Microtomography*
9:40 - 10:00	**Christopher S. Magirl**: *Velocity Measurements of Rapids on the Colorado River in the Grand Canyon*
10:00 - 11:00	**Poster Session**
Moderator	*Gretchen P. Oelsner*
11:00 - 11:20	**Ayelet Blattstein**: *Analysis of Transient Flow to a Well in a Randomly Heterogeneous Aquifer*
11:20 - 11:40	**Keith Musselman**: *Quantifying the Effects of Vegetation on a Montane Snowpack, Valles Caldera National Preserve, NM*
11:40 - 12:00	**Julio Cañón Barriga**: *Precipitation in the Colorado River Basin: Low Frequency Associations with Pacific Decadal Oscillation and El Niño-Southern Oscillation*

El Dia del Agua ~ Program Schedule Continued

TIME	SCHEDULE
12:00 - 1:30	**Buffet Lunch and Speaker, David Hargis**, *When Science Gets Down To Business: Consulting in Hydrogeology*
1:30 - 2:00	**Poster Session**
Moderator	*Julio Cañón Barriga*
2:00 - 2:20	**Mehmet Akif Sarikaya**: *Glaciations in Aladağlar and Sandıras: New Paleoclimatic Clues in Turkey*
2:20 - 2:40	**Gretchen P. Oelsner**: *Quantifying Nitrogen and Carbon Sources and Sinks within the Middle Rio Grande*
2:40 - 3:00	**Concepción Carreón-Diazconti**: *Evaluating the Potential for Monitored Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in a Contaminated Aquifer: Biochemical Analysis*
3:00 – 3:20	**Jesse Roach**: *Integrated Modeling for Hydrologic Scenario Analysis in the Upper Rio Grande Basin*
3:30 - 4:30	**Guest Speaker Stephen E. Silliman**: *Groundwater Studies in Benin, West Africa: The Importance of Collaboration with Colleagues and the Local Population*
4:30	**Award Presentations** ***Montgomery Prize ~ By Leslie Katz*** ***Hargis Awards ~ By David Hargis*** ***HWR Awards ~ By Jim Washburne***

Geochemical Analysis of Recharge and Salinization in the Northern Hueco Bolson Aquifer, El Paso, Texas

Jennifer Druhan, James Hogan, Chris Eastoe,[1]
Barry Hibbs,[2] and Bill Hutcheson[3]

Department of Hydrology and Water Resources
The University of Arizona

The Hueco Bolson aquifer is a principal water resource for the cities of El Paso and Juárez. Isotopic and chemical analysis of groundwater from recently constructed test holes and wells with multiple discrete vertical zone samples has provided a unique opportunity to characterize recharge waters and salinity sources, and to identify the primary mechanisms of pumping induced salinization. O and H isotopes are used to delineate primary recharge zones in the northern portion of the aquifer. Anion, $\delta^{34}S$, $\delta^{18}O_{SO4}$, and ^{36}Cl are used to evaluate the major constituents of salinity and the distribution of these salts through the aquifer. Conservative ions indicate evidence of halite dissolution as the primary source of chloride in the basin. The majority of basin waters follow a 4:1 ratio of chloride to sulfate ratio, while some particular areas exhibit a unique secondary sulfate source. Distributions of these tracers with depth in the vertical profiles of the test holes indicate direct upwelling of saline waters as the primary source of well salinity. In several localized areas, these distributions are complicated by high and low values throughout the profile, suggesting leakage of mud and clay layers as a secondary salinity source in the freshwater zone.

[1] Department of Geosciences/SAHRA, The University of Arizona, Tucson, AZ
[2] California State University Los Angeles, Department of Geological Sciences/ CEA-CREST
[3] El Paso Water Utility

Pore-scale Characterization of Organic Immiscible-Liquid Morphology in Natural Porous Media Using Synchrotron X-Ray Microtomography

Gregory Schnaar[1] and Mark L. Brusseau[1,2]

[2]Department of Hydrology and Water Resources
The University of Arizona

Organic immiscible liquids, which include chlorinated solvents and fuels, are commonly the primary contaminant at Superfund hazardous waste sites. In Arizona, chlorinated solvents alone are the primary contaminant at 29 of 33 and 13 of 14 state and federal Superfund sites, respectively. These liquids often reside in aquifers as discontinuous, immobilized 'blobs' that slowly dissolve and thus serve as a source of contamination for decades or possibly centuries. Factors influencing the distribution and mass-transfer dynamics of organic liquids in porous media have been examined in some detail at the laboratory column scale. However, the fundamental mechanisms controlling the behavior of organic liquids at the pore-scale are not well understood. The objective of the current study was to quantitatively characterize the pore-scale morphology of chlorinated solvent blobs using a three-dimensional imaging technique. Synchrotron X-ray microtomography was used to obtain high-resolution, three-dimensional images of solid and liquid phases in packed columns. Several porous media, comprising a range of particle-size distributions, were used to evaluate the impact of porous-medium texture on blob morphology. Organic liquid blob morphology was characterized in both two-phase (water-organic liquid) and three-phase (water-organic liquid-air) systems. Additional studies were conducted to examine changes in blob morphology and associated mass flux due to dissolution induced mass removal. Direct observations of organic-liquid dissolution allow for verification and improvement of both conceptual and mathematical models of this process.

[1]Department of Soil, Water and Environmental Sciences, The University of Arizona, Tucson, AZ

Velocity Measurements of Rapids on the Colorado River in the Grand Canyon

Christopher S. Magirl and Victor Baker

Department of Hydrology and Water Resources,
The University of Arizona

Rapids on the Colorado River in the Grand Canyon attract nearly 20,000 white-water enthusiasts a year and are considered one of the premiere collections of rapids in North America. While an important recreational resource, relatively little is known of the specific hydraulics within individual rapids. While flow measurements are occasionally made in the low-velocity reaches of the river, the turbulent nature of rapids makes in-situ data collection challenging. The present study, however, measured hydraulics within some rapids. Using a boat-mounted fathometer and acoustic Doppler velocimeter (ADV), point measurements of velocity, water-surface elevation, and bathymetry were made at five moderately-sized rapids in the Grand Canyon. The boat was a 19-foot J-snout with a 50-hp Mercury outboard motor capable of maneuvering to nearly any location within each rapid. The ADV was mounted to the front of the boat 80 cm below the surface. The quality of measurements was best in the relatively uniform, smooth flow above the rapid. Waves, turbulence, and the threat of capsizing rendered specific measurements in the core of the rapid sparse. More data were collected in the plunge pool below the rapid, but waves and swirling eddies made measurement difficult. Velocity, bathymetry, and water-surface maps were constructed for each rapid measured. In addition to quantifying flow velocities in rapids, the resulting data sets can be used in predicting the erosion potential of debris fans forming the rapids. The data can also be used to aid in the development of numerical models to better characterize rapids.

Analysis of Transient Flow to a Well in a Randomly Heterogeneous Aquifer

Ayelet Blattstein, S.P. Neuman, and D.M. Tartakovsky[1]

Department of Hydrology and Water Resources
The University of Arizona

Analytical solutions of groundwater flow equations for relatively simple domains, consisting of one or at most a few geologic units having uniform hydraulic properties, have traditionally been used to analyze pumping tests. Attention has recently been shifting toward methods that characterize subsurface heterogeneities in greater detail using geostatistical and stochastic concepts. In this study, the natural logarithm, $\ln T$, of aquifer transmissivity T is viewed as a statistically homogeneous and isotropic Gaussian random field with an exponential spatial correlation function. Monte Carlo simulations are used to explore the manner in which such a field affects transient drawdown when a fully penetrating well of zero radius pumps at a constant rate from a confined aquifer of infinite lateral extent. It is found that the geometric mean transmissivity T_G and the storativity S can be determined quite accurately by the standard Cooper-Jacob method of analyzing late drawdown data. A conjecture by *Neuman et al.* [2004] that a quasi-steady state eventually develops is shown to be valid, and a type-curve method proposed by them is shown to work with late transient data, yielding estimates of the spatial correlation scale λ and variance σ^2 of $\ln T$. These parameters provide a complete statistical characterization of the $\ln T$ field.

[1]Department of Mechanical and Aerospace Engineering, University of California, San Diego, CA

Quantifying the Effects of Vegetation on a Montane Snowpack, Valles Caldera National Preserve, NM

Keith Musselman, P.D. Brooks, and N.P. Molotch[2]

Department of Hydrology and Water Resources
The University of Arizona

We evaluated the effects of vegetation on snowpack mass and energy exchange in a seasonally snow covered sub-alpine montane environment, Valles Caldera National Preserve, New Mexico, USA. Detailed field observations and ultra-sonic snow depth sensors indicated forest vegetation affected snowcover in three ways: canopy interception and sloughing, enhanced snowpack metamorphism, and shading of direct solar radiation. Manual observations of snowpack properties (i.e., snow density, depth, temperature, crystal type, and grain size) at 0.5 meter intervals from an individual spruce tree, showed that on south aspects density and grain size peak at the canopy fringe while SWE and depth peak in the open beyond the canopy fringe. On north aspects only grain size peaks at the canopy fringe while SWE, depth, and density peak in the open. Snow surveys around 16 additional trees at maximum accumulation indicated that while snow depth increased logarithmically away from trees, SWE increased linearly outward from trunks. In general, the order of mean SWE was: north side of trees interspaced (30 ±10 cm), south side of trees interspaced (27 ±10 cm), north side of trees canopy fringe (26 ±10 cm), south side of trees canopy fringe (20 ±10 cm), and north and south sides underneath tree canopies (10 ±6 cm). Catchment-wide snow surveys indicate that terrain aspect and proximity to vegetation explain the majority of the observed snow depth variability. These data provide new insight into the effects of vegetation on snowpack accumulation, metamorphism, and melt.

[1]CIRES, University of Colorado, Boulder CO

Precipitation in the Colorado River Basin: Low Frequency Associations with Pacific Decadal Oscillation and El Niño-Southern Oscillation

Julio Cañón Barriga, Javier González,[1] and Juan Valdés[2]

Department of Hydrology and Water Resources,
The University of Arizona

In this study the Standardized Precipitation Index (SPI) computed from annual and seasonal precipitation sets is used to analyze the spatial and temporal distribution of precipitation quantiles over the Colorado River Basin, giving emphasis to the occurrence of abnormal moisture conditions. From a cell by cell analysis, the area covered by abnormally wet and dry conditions during the last century shows an inverse relationship with their frequency of occurrence, which implies point intensities related with spatial extension. During El Niño years, both conditions are likely to occur while only dry conditions occur during La Niña years. Regions of homogeneous SPI realizations were delimited using Principal Components Analysis (PCA) to highlight major dynamic modes distinguishable on the basin. Then a frequency analysis was performed over delimited regions of SPI to identify low frequency oscillation modes. Common low frequency oscillations between the SPI index, the Pacific Decadal Oscillation (PDO) and the Bivariate El Niño-Southern Oscillation Time series (BEST) were also explored using multichannel Singular Spectrum Analysis (M-SSA). The linkage between SPI and El Niño-Southern Oscillation (ENSO) is confirmed as well as the coupled impact of PDO-ENSO over SPI that indicates a trend and two consistent oscillations around five and 15 years.

[1]Department of Civil Engineering, Universidad de Castilla La Mancha. Spain
[2]Department of Civil Engineering, The University of Arizona, Tucson, AZ

Glaciations in Aladağlar and Sandıras: New Paleoclimatic Clues in Turkey

M. Akif Sarıkaya, M. Zreda, and A. Çiner[1]

Department of Hydrology and Water Resources
The University of Arizona

The study was conducted on two mountains of Turkey: Aladağlar (3756 m, the Central Taurus, 37°45'N, 35°15'E) and Sandıras (2295 m, the Western Taurus, 37°05'N, 28°51'E). Well preserved, extensive moraines of Hacer Valley (1091-2585 m) in Aladağlar show that glacial activity occurred during the Early Holocene; ranging from 9,950 ± 150 years (calendar years) for the lowest moraine in the valley, to 8,400 ± 270 years for the highest moraine in the plateau below the summit. The moraines of Sandıras are not as extensive as those in Aladağlar. The average age of 20.7 ± 2.1 kyr indicates that they originated during the Last Glacial Maximum (LGM). Today, there is no glacier activity on either mountain. Our results imply that Aladağlar and Sandıras had different glaciological and climatic history. While Sandıras had small and simple glaciers during LGM and no glaciers in the Holocene, Aladağlar had extensive glaciers during the Early Holocene. Glaciological and climatic factors can explain the different ice extents on these mountains. We hypothesize that glaciers in the Sandıras developed due to much lower temperatures during the LGM, whereas those in the Aladağlar grew because of increased precipitation at the beginning of the Holocene. In addition, Aladağlar has a more suitable accumulation area to produce extensive glaciers, whereas Sandıras has a less favorable topography for ice accumulation.

[1]Hacettepe University, Ankara, Turkey

Quantifying Nitrogen and Carbon Sources and Sinks within the Middle Rio Grande

Gretchen P. Oelsner, Paul D. Brooks, and James F. Hogan

Department of Hydrology and Water Resources
The University of Arizona

Relationships between discharge, land use, and nutrients nitrogen and carbon) were developed using five years of synoptic sampling data collected along a 300km reach of the Rio Grande in central New Mexico. Average discharge in the river was significantly higher ($p = 0.01$) during 2001 and 2005 ($15.0 \pm 0.88 m^3/s$) than during the drought years of 2002 – 2004 ($8.85 \pm 1.77 m^3/s$). Both total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) concentrations increase with distance downstream; however, for TDN this trend is punctuated by large, localized inputs from urban wastewater whereas DOC increases gradually. Wastewater treatment plants (WWTPs) were the largest and most consistent source of nitrogen (1331 ± 19.8kg/day) and carbon (1163 ± 210kg/day) to the river. Downstream of the WWTPs, the average TDN concentration was 1.18mg/L (S.D. = 0.22) in wet years and 0.52mg/L (S.D. = 0.40) in dry years. Average DOC concentrations were also higher in wet years (4.44 ± 0.42mg/L) than in dry years (3.94 ± 0.74mg/L). Somewhat surprisingly, surface water draining from areas of intensive, irrigated agriculture during the growing season often had lower nitrogen concentrations than the river, while the DOC concentrations were similar to or slightly lower than the river.

Evaluating the Potential for Monitored Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in a Contaminated Aquifer: Biochemical Analysis

Concepción Carreón-Diazconti,[1,4] Johanna SantamaríaVanegas,[2] James Field,[3] and Mark L. Brusseau[1,2]

[1] Department of Hydrology and Water Resources
The University of Arizona

Tetrachloroethene (PCE) and diesel contamination have been documented in the local perched and regional aquifers at the Park-Euclid WQARF site in Tucson, AZ. Monitored natural attenuation (MNA) is currently being evaluated as a potential remediation technology for the PCE contamination at the site. Physicochemical characterization of the immiscible liquid contamination has been conducted in prior studies. The focus of this study is to evaluate the biochemical processes active at the site. Analysis of the Arizona Department of Environmental Quality (ADEQ) database shows that the original contamination in the perched aquifer, where PCE was the single chlorinated ethene involved, has evolved into a mixture containing PCE and several transformation compounds typically associated with PCE (trichloroethene, TCE, dichloroethene, DCE, and vinylchloride, VC). Microbial transformation processes appear to be the predominant attenuation component of natural attenuation at the perched aquifer in this site. Dehalococcoides ethenogenes has been identified as the responsible bacteria for the transformation of the chlorinated aliphatic hydrocarbons. The magnitude and rate of microbial transformation processes at the study site is currently investigated with microcosm studies conducted using groundwater and sediment collected from the study site.

[2]Department of Soils, Water and Environmental Science, The University of Arizona, Tucson, AZ
[3]Department of Chemical and Environmental Engineering, The University of Arizona, Tucson, AZ
[4]Instituto de Ingeniería, Universidad Autónoma de Baja California, Mexicali, México

Integrated Modeling for Hydrologic Scenario Analysis in the Upper Rio Grande Basin

Jesse Roach and Kevin Lansey[1]

Department of Hydrology and Water Resources
The University of Arizona

As the finite, and often over-allocated water resources of the western United States are challenged by a myriad of growing demands, computer based simulations can provide a powerful tool for evaluation of potential water use scenarios for hydrologic decision making and water policy analysis. To capture the overall system behavior, such models must represent the salient behaviors of, and interactions between, the groundwater, surface water, and human behavioral systems. This presentation will cover the development of a monthly, reach based water balance model of the Rio Grande in New Mexico. The model couples the groundwater, surface water, and human behavioral systems over a greater geographic area than any previous Upper Rio Grande modeling effort. This large geographic extent allows the model to consider the hydrologic effects of growth throughout the basin. Historic data from 1975 – 2000 were used to develop and calibrate the model, while 2000 – 2005 data were used for validation. The model is used in predictive mode for hydrologic scenario analysis in the basin. Preliminary results from scenario analysis will be discussed.

[1]Department of Civil Engineering, The University of Arizona, Tucson, AZ

El Dia del Agua ~ Poster Presentations

(Two Sessions: 10:00-11:00 and 1:30-2:00)

Joan B. Blainey: *Monitoring Soil Hydraulic Properties using Gravity Measurements Obtained During Infiltration and Drainage*

Erin M. Boyle: *Development of the Upper Santa Catalina Mountains Water Resource Management Plan*

Deirdre Brosnihan: *Supporting Community Water Harvesting Efforts: Impact of Water Harvesting on Street Runoff Volume and Quality*

Nataliya Bulygina: *Addressing Hillslope Heterogeneity for Rainfall—Runoff Modeling: KINEROS2 Case Study*

Eleonora Demaria: *Impact of Errors in the Global Precipitation Measurement Mission on Flood Forecasting*

Sharon Desilets: *Post-Wildfire Changes in Suspended Sediment Rating Curves: Sabino Canyon, Arizona*

Eden J. Feirstein: *Groundwater Flow Dynamics in the Colorado River Delta: An Investigation to Support Riparian Habitat Restoration in Northern Mexico*

Leland Fuhrig: *In-Situ Chemical Oxidation of 1,1-DCE in a Low-K Zone Using Potassium Permanganate*

Kristin Green: *Partitioning of Evapotranspiration in a Chihuahuan Desert Grassland*

Andy D. Hale: *Economic Impacts of Water Allocation Adjustments in the Lower Rio Grande Valley*

El Dia del Agua ~ Poster Presentations ~ Continued

Andrew C. Hinnell: *Water Content Measurement Errors Associated with Using Angled Access Tubes*

Laura Klasner: *Hydrologic Controls on Nutrient Dynamics in the San Pedro River, Arizona, USA*

Jennifer M. Kostrzewski: *Solute Flux in Paired Watersheds, Valles Caldera National Preserve, NM*

Laura Lindenmayer: *Demonstrating a Methodology for Incorporating Climate Information in a Lower Colorado River Basin Operations Model*

Mohammed Mahmound: *Scenario Development for the Southwestern United States*

Bwalya Malama: *Solution of the Groundwater Inverse Problem*

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Monitoring Soil Hydraulic Properties using Gravity Measurements Obtained During Infiltration and Drainage

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The scale of interest of many hydrologic processes is much larger than the support volume of the available measurement methods (e.g. tensiometers, time domain reflectometry, neutron probes). The use of small-scale measurements to constrain large-scale models introduces significant uncertainties. It would be advantageous to use large-scale measurements to constrain models of large-scale processes. This requires an improved understanding of the responses of these methods to large-scale processes. As an example, artificial infiltration basins are operated throughout the southwest to enhance water supplies. However, few (if any) measurements are made to characterize the hydraulic properties of the thick vadose zone underlying these facilities. These parameters could be used to optimize basin operations and to identify changes in vadose zone properties through time. We present numerical analyses of the use of gravimeters to constrain a model of infiltration and drainage beneath an artificial infiltration facility. The results show that gravimetry, coupled with hydrogeophysical analysis, can be used to infer large-scale hydraulic properties. Measurements made during infiltration and drainage provide information for different soil hydraulic parameters. Explicit consideration of measurement uncertainty allows for quantification of parameter estimation error.

Development of the Upper Santa Catalina Mountains Water Resource Management Plan

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Water resources in the Santa Catalina Mountains are limited resources highly dependent on annual precipitation. Two water distribution systems are in operation on the Mountain. The Forest Service's water system provides water to its recreational and administrative sites. The Mt. Lemmon Domestic Water Improvement District (MLDWID) provides water to private residents and businesses in the Summerhaven area. Most water delivered by the two systems comes from the same source, the Sabino Creek Watershed. Competition for the same water source has led to shortages and conflicts. Development of a water resource management plan will provide a balance between human use and sustaining the Sabino Creek Watershed. This project involves working with the Forest Service and the MLDWID in conjunction with the Santa Catalina Mountain Partnership to resolve conflicts and develop a water resource management plan. The water resource management plan will serve as an agreement between the Forest Service and the MLDWID. This plan will address: supply, demand, stakeholder issues, conservation options, implications of an instream flow water right, information needs, and operation of the two water systems. Having both water providers in agreement on how to manage the Sabino Creek Watershed will promote sustainable water use and enhance watershed protection.

Supporting Community Water Harvesting Efforts: Impact of Water Harvesting on Street Runoff Volume and Quality

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Water Resources planners in Arizona increasingly are focused on identifying and using all available sources of water. In large portions of the state, harvested rainwater has the potential to replace a significant portion of potable water use, especially water used for landscape irrigation. Efficient use of rainfall is especially important when the arid West experiences periods of drought. Considerable anecdotal evidence exists that if people were more aware of the potential of rainfall and how they could utilize it, water harvesting would be more widely practiced. Our project aims to evaluate current water harvesting opportunities and develop physical water harvesting models at multiple sites in Tucson, Arizona with corresponding educational outreach programs planned, with the first phase site being The Nature Conservancy campus of Tucson, AZ. Multiple methods of water harvesting at both the residential and commercial scale will be showcased. Additionally, the project aims to look at the potential impact on water quality that water harvesting has on street runoff as well as the potential effect widespread application of rainwater harvesting would have on stormwater runoff volume. A web based cistern sizing tool for storage volume of harvested water is also under development. This tool will become a web based resource to better correlate water supply and demand for landscapes, ultimately serving to aid the community in water harvesting efforts and thus improve water conservation knowledge and implementation.

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Addressing Hillslope Heterogeneity for Rainfall-Runoff Modeling: KINEROS2 Case Study

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There are no homogeneous hillslopes. For modeling purposes hillslope characteristics are usually averaged. The consequences of such averaging are poorly understood. The purpose of this study is to construct a set of rules and an algorithm to distinguish conditions when such averaging can be done and when it cannot, given some tolerance level in peak runoff rate and total runoff depth differences. KINEROS2 was used as the rainfall-runoff model. The undertaken analysis consists of several steps: parameter sensitivity analysis based on Sobol' indexes, High Dimensional Model Representations (HDMR) for the response functions, and application to hillslopes of Coyote Wash watershed, San Pedro Valley.

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Impact of Errors in the Global Precipitation Measurement Mission on Flood Forecasting

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The Global Precipitation Measurement (GPM) is an international effort to improve climate, weather and hydrological predictions through more frequent and accurate predictions of precipitation. This new system, scheduled to be launched in 2010, will allow high precision measurements of precipitation and an almost complete coverage of areas where liquid precipitation occurs. The main focus of the study is the evaluation of the impact of GPM measurements on hydrologic predictions and water resources management, especially in underdeveloped regions of the world. We seek to understand how errors in satellite-derived precipitation affect simulated hydrological fluxes and what is the potential value of GPM for seasonal to interannual hydrologic prediction of runoff and water management. We will superimpose errors simulating retrieval and sampling errors to observed precipitation to generate synthetic precipitation data. The Variable Infiltration Capacity model will be driven with the synthetic fields. Events with a return period larger than 10 years will be selected to evaluate the impact of errors in high flood events. Simulated streamflows generated with synthetic precipitation will be compared to observed streamflows. Results of the study will help to estimate the impact of error structure in precipitation on the simulation of the hydrologic cycle.

Post-Wildfire Changes in Suspended Sediment Rating Curves: Sabino Canyon, Arizona

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Wildfire effects a severe pulse-change in a watershed, simultaneously altering the interdependent systems of hydrology and ecology, which rapidly and profoundly affect channel geomorphology through erosion processes. Though the initial transformation is rapid, recovery occurs over several different timescales. This work focuses on the short term and seasonal variations in suspended sediment dynamics following a wildfire in a semi-arid drainage basin in the southwestern U.S. Surface water samples were collected using an event-based sampling strategy, and sediment rating parameters were determined for individual storm events. After an initial step change to higher sediment loads, the progression of rating parameter values indicated preferential removal of fine to coarse sediment in the monsoon seasons. During the corresponding winter seasons a lower supply of sediment from the hillslopes resulted in a time invariant set of sediment rating parameters. The temporal variability in the sediment rating parameters demonstrates the importance of storm-based sampling in areas with intense monsoon activity in order to accurately characterize post-fire sediment transport. These data can be used to constrain rapid assessment fire-response models for discerning appropriate application of mitigation resources.

Groundwater Flow Dynamics in the Colorado River Delta: An Investigation to Support Riparian Habitat Restoration in Northern Mexico

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Quantification of groundwater flow dynamics and of the interactions among groundwater, surface water, and riparian vegetation, represent key components in the development of a balanced restoration plan for functional riparian ecosystems. The goal of this research is development of a groundwater model, using MODFLOW 2000, in support of riparian restoration along the Colorado River Delta (Mexico: Baja California, Sonora). Our research focus is understanding water table dynamics with particular attention to stream-aquifer interactions and groundwater behavior in the root zone. The project aims to quantify groundwater reliant transpiration requirements for a set of dominant riparian species native to the region using the Riparian ET (RIP-ET) package, an improved MODFLOW evapotranspiration (ET) module. RIP-ET simulates ET using a set of eco-physiologically based curves that more accurately represents individual plant species, reflects habitat complexity, and deals spatially with plant and water table distribution. Based on these objectives we will specify locations where riparian restoration has the maximum chances of success without artificial irrigation. Groundwater requirements determined in this research will be used by the international non-profit organizations, The Sonoran Institute and Environmental Defense, to implement large-scale planting activities within the riparian corridor and to secure instream flow rights for the Colorado River Delta from the Mexican Government.

In-Situ Chemical Oxidation of 1,1-DCE in a Low-K Zone Using Potassium Permanganate

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An in-situ chemical oxidation project was conducted using potassium permanganate ($KMnO_4$) to remediate a part of the TIAA Superfund site (located in Tucson, AZ), which is contaminated with 1,1-dichloroethene (1,1-DCE). Laboratory tests were conducted to determine the amount of $KMnO_4$ to use based on the levels of 1,1-DCE present in the subsurface. The $KMnO_4$ solution was injected into eight wells encompassing a square grid of approximately 30 m by 30 m. A 3-dimensional profile of hydraulic conductivity values was generated using well-log texture data and a site-specific K-texture relationship, combined with geostatistical interpolation. These data, combined with additional physical parameters measured for the site, were used as input to MODFLOW and MT3DMS to simulate the injection process. The modeling results will be used to help evaluate the $KMnO_4$-solution distribution and 1,1-DCE degradation.

Partitioning of Evapotranspiration in a Chihuahuan Desert Grassland

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Key to evaluating the consequences of woody plant encroachment on water and carbon cycling in semiarid ecosystems is a mechanistic understanding of how biological and non-biological processes influence water loss to the atmosphere. To better understand how precipitation is partitioned into the components of evapotranspiration (bare-soil evaporation and plant transpiration) and their relationship to plant uptake of carbon dioxide (CO_2) as well as ecosystem respiratory efflux, we measured soil evaporation, evapotranspiration (ET), and CO_2 fluxes over the course of a growing season at a desert grassland site in southeastern Arizona. We used microlysimeters (ML) and eddy covariance to measure E and ET respectively, and then we were able to calculate T (ET – E). Additionally we measured plant pre-dawn water potential and leaf level CO_2/H_2O exchange to understand how species-specific leaf-level plant controls determine ecosystem flux partitioning. The study was conducted over the course of the 2005 summer growing season at the Kendall grassland site located on the Walnut Gulch Experimental Watershed in southeastern Arizona.

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Economic Impacts of Water Allocation Adjustments in the Lower Rio Grande Valley

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The population of the Lower Rio Grande Valley (LRGV) is expected to double in the coming decades, effectively doubling the demand for municipal water from the Amistad and Falcon Reservoirs. In order to most effectively make water allocation decisions, stakeholders must better understand the economic impacts of water allocation tradeoffs. There are 29 established irrigation districts in the LRGV that provide irrigation as well as municipal water. Domestic, municipal and industrial rights have the highest priority in the allocation procedures, with irrigation water rights given a secondary claim to residuals or surpluses. Municipal water demand is projected to double from 253,000 ac-ft presently to 506,000 ac-ft in 2050. Total demand for water is expected to decline from 1,803,000 ac-ft in 2001, to 1,738,000 ac-ft in 2050 due to a decline in irrigated agriculture. Using existing production data for the LRGV, agricultural response models will be developed to forecast economic impacts of irrigation reduction scenarios. These results will then be incorporated into existing integrated models for of the Rio Conchos/LRGV in order provide decision support for stakeholders in the region.

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Water Content Measurement Errors Associated with Using Angled Access Tubes

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Angled access tubes provide access to the subsurface for monitoring while minimizing disturbance of overlying sediments. However, boreholes in the vadose zone alter the flow of water near the borehole. The altered flow patterns can cause significant changes in the water content and pressure head within the sample volume of instruments placed on or in a cased borehole. Specifically, the pressure head and water content will be overestimated if instruments are placed at the top of the borehole and underestimated if instruments are placed at the bottom of the borehole. We examine the dependence of these over- and under-estimates on the borehole diameter and dip angle, applied flux, and soil hydraulic properties under steady-state, unit gradient flow conditions. We then identify optimal locations for measurements on angled boreholes and provide approximate corrections for existing instrumented boreholes. The results of these analyses show that the errors caused by flow diversion around angled boreholes can be large ($\pm$ 0.15 cm^3/cm^3), but can be minimized by the appropriate choice of instrument location.

Hydrologic Controls on Nutrient Dynamics in the San Pedro River, Arizona, USA

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We conducted pre-monsoon (June) and monsoon (August) sampling campaigns on a gaining and a losing reach in the San Pedro River in 2005 to quantify the effects of variability in hydrologic flowpaths on carbon and nitrogen cycling. A large increase in baseflow during the monsoon campaign (98.9±40cfs vs. 2.1±0.5cfs) resulted in significantly higher ($p<0.001$) total dissolved nitrogen (TDN: 0.90±0.21mg N/L vs. 0.24±0.06mg N/L) and dissolved organic carbon (DOC: 5.01±0.90mg C/L vs. 2.09±0.52mg C/L) concentrations. No significant differences in solute concentrations along reaches were observed during the monsoon, but local variability in hydrologic flowpaths resulted in large differences in biogeochemically cycling solutes during the non-monsoon season.

During pre-monsoon, a decrease in chloride concentrations from 19.91±1.28mg/L to 15.21±1.80mg/L along the gaining reach indicated a net input of 35.1±3.6% new groundwater that was associated with a significant ($p=0.03$) decrease in DOC concentrations. An increase in chloride concentrations from local groundwater concentrations averaging 7.5mg/L to 8.98±0.40mg/L along the losing reach indicated a net evaporation of 19.75±5.4% of in-stream water and is associated with a significant increase ($p=0.04$) in organic nitrogen concentrations. Additionally, ET driven fluctuations in both stage and chloride concentrations are associated with changes in carbon and nitrogen solutes, presumably due to changes in flowpaths across the hyporheic zone.

Solute Flux in Paired Watersheds,
Valles Caldera National Preserve, NM

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We compared patterns in nutrient and major ion concentrations in surface water and soil solution of neighboring catchments in the Valles Caldera National Preserve, New Mexico. The catchments have similar vegetation and climate; however, they vary in aspect, elevation, and size: La Jara Creek (LJC) catchment (3.7 km^2, 2728-3414m), and Redondo Creek (RC) catchment (13.4 km^2, 2485-3414m). Both daily to biweekly samples at catchment outlets between late winter and early autumn and three surface water synoptic surveys throughout the summer indicated significantly higher solute concentrations ($p<0.05$) in RC. Conservative solute concentrations in LJC exhibited a hysteretic pattern suggesting seasonal changes in dominant flowpaths, while RC concentrations indicate a source dilution. LJC synoptic results showed greater variation carbon content between the three surveys (σ_{DOC}=2.76 mgC/L) than RC (σ_{DOC}=0.15 mgC/L) also supporting changing source areas. Rhizon Tension Lysimeters installed to collect soil solutions, demonstrated a significantly higher ($p<0.05$) difference in LJC mean chloride than RC; they did not significantly differ in nutrient content. These data suggest that a combination of complex flow routing and biogeochemical modification during transport result in significant differences in solute concentrations in these outwardly similar, neighboring catchments.

Demonstrating a Methodology for Incorporating Climate Information in a Lower Colorado River Basin Operations Model

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The U.S. Bureau of Reclamation (USBR) currently uses a 24-month planning model to simulate reservoir operations, energy generation, and water demands on the Colorado River Basin. This model is implemented in RiverWare, a software package specifically tailored to water resources management applications. The Lower Basin's 24-month model does not currently make use of weather forecasts, nor does it use information about future climate. To aid in better management of scarce water resources, we will demonstrate a methodology for incorporating climate information in the inflow time series for the 24-month model. One method for evaluating these different scenarios is to use a hydrology model, which can be forced with meteorological ensemble data. This output is used in turn as input to the 24-month model. The University of Washington currently uses a hydrology model, the Variable Infiltration Capacity (VIC) model, to make 12 month streamflow forecasts for the Colorado River, based on historical meteorological conditions. We are using these VIC flows as input to the inflow points in the 24-month model and comparing them with USBR forecasted flows. This methodology will enable incorporation of new scientific information into the water resources decision-making process.

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Scenario Development for the Southwestern United States

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To assess the future of water supply with respect to water resources sustainability in the southwestern United States, the sensitivity of water-related variables in the region to expected future changes needs to be examined. This is achieved using a scenario development approach in which potentially variable parameters within the region are adjusted to values representative of likely changes that may occur. Each set of mutually agreeable projected changes will be designated as a separate scenario. This phase of scenario development relies heavily on the input of basin stakeholders, SAHRA, field scientists, and basin-associated research agencies to obtain a comprehensive and complete collection of likely future scenarios. From the inventory of scenario-projecting variable parameters, those of relevance to future water-stress and of practical interest to water sustainability will be streamlined. This insures that only the most essential scenarios directly affecting the Southwest's water resources are evaluated prior to scenario construction. Therefore projections of climate change, physical conditions, economic conditions, meteorology, engineering infrastructure, demography, land-use, and water-use must be developed. The end-product from this entire process will be a compilation of preliminary scenarios along with associated detailed descriptions of future conditions and dataset sources that are required in developing the respective scenarios.

Solution of the Groundwater Inverse Problem

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The geostatistical inverse method of estimating hydraulic parameters of a heterogeneous porous medium at discrete points in space, called pilot points, is presented. The nonlinear parameter estimation problem is solved iteratively until an optimal solution to a likelihood based objective function is obtained. The forward problem is based on nonlocal moment equations, which make possible optimal deterministic predictions of fluid flow in heterogeneous media as well as assessment of associated predictive uncertainty. In this work, second order (in the standard deviation of log hydraulic conductivity) approximations of the moment equations are solved using the finite element method. Results of four illustrative examples are presented where parameter estimates and the corresponding predictions of system state are conditioned on measurements of: head only; head and log-conductivity with no prior information; head and log-conductivity with prior information; and, head and log-conductivity with regularization. An example in which predictions of system state are conditioned on measurements of log-conductivity is also included for comparison. In all the illustrative examples a superimposed mean uniform and convergent transient flow field through a bounded square domain is used. The examples show conditioning on measurements of both head and hydraulic parameters with regularization yields the best results.

Exploring Information Theory for Improving Hydrologic Model Performance

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For more than 30 years Information Theory (IT) concepts have appeared in literature and practice of hydrology in several ways. Although these concepts are implicit in many practical applications and ideas, still the language and use are not widespread among the scientific community dedicated to study hydrologic processes. At the same time, new points of view reflect the increasing availability of data and information with finer resolution. Equally, increasing computing capabilities, the development of more complex decision-making systems, and better forecasting tools impose on hydrologists new challenges related to the optimal use of data and the information that can be extracted from it. In our understanding, one of the approaches to address these challenges is to recognize that the notion of information is inherent to the problem of dealing with hydrologic data and the evaluation of its characteristics. The goals of this poster are to evaluate how IT can be used to generate a conceptual framework for assessing the performance of models against real data, and how these assessments can help us to increase our knowledge about the physical mechanisms involved.

Distributed Parameter Estimation for Flash Flood and River Prediction

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Distributed RER (Rainfall - Evaporation - Runoff) models provide better spatial resolution of the watershed and, if properly calibrated, have the potential to provide accurate flood forecasts at the outlet and in the interior locations of the watershed. However, although the shift from lumped to distributed modeling increases the spatial representation of the watershed, it also increases the complexity of the parameter estimation problem, since the increase in spatial discretizations of the model area also increases the number of unknown parameters.

Fortunately, the spatial variability of the model area, watershed, are usually well behaved and exhibit some sort of pattern, which if recognized properly allows us to place some sort of constraints that can reduce the dimensionality of the parameter estimation problem. In other words we can exploit the fact that the unknown parameters are not independent of each other and can be related to the neighboring parameter values by some properly chosen constraints.

In this research, Regularization, a technique that is widely utilized in petroleum engineering and ground water inverse modeling problems, will be explored as a way of spatially constraining the parameter estimates for the distributed model. Thus, it is envisaged that the reduced parameter space/dimensionality resulting from constraining parameters allows us to utilize the preexisting global optimization techniques such as SCE or SCEM effectively to estimate the optimum set of parameters for the distributed RER models.

Quantifying River Restoration Benefits for Society

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River restoration efforts typically receive broad public support. However, standing questions include whether restoration efforts are "worth it," whether some types of restoration are more beneficial than others, and how restoration efforts were ultimately received by the public they serve. This research identifies restoration metrics to quantify physical changes that will actually take place, and uses econometric methodology to determine how human well-being will be improved from these changes.

Ongoing restoration in the Albuquerque reach of the Middle Rio Grande Bosque is used as a vehicle to investigate public restoration values. A 2005-2006 mail survey explores visitation statistics and potential recreation improvements. The survey also partitions use and non-use values for the ecosystem as a whole. Valuation focuses on key restoration attributes identified by focus groups. A choice model is used to decompose value of these restoration attributes in both a relative and absolute (dollar) sense. Results are applicable to other southwestern riparian areas with qualifications for site-specific factors.

The long-range goal of this work is to inform a dynamic simulation model of Total Riparian Value. This Total Riparian Value model is itself a component of a larger watershed decision support tool, being developed by a interdisciplinary multi-institutional team.

Evaluation of a semi-Arid Distributed Flash-Flood Model

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Flash floods in semi-arid regions, caused by summertime convective storm systems, often result in significant risk to life and property. Arid/semi-arid regions currently span approximately one-third of the earth's surface with possibly greater coverage in the future, for example, due to current global warming. The short spatial and temporal extents of flash-flood hydrometeorology make the subsequent predictions extremely difficult. To improve our predictive capability, an established event-based semi-arid rainfall–runoff model, KINEROS2, is modified to ultimately allow for the continuous simulation of the basin response driven by high-resolution precipitation measurements in an uncertainty framework. The model contains process descriptions required to represent semi-arid and arid regions, including a dynamic infiltration algorithm and the ability to account for channel transmission losses. The complex process description and the spatially distributed system representation require a large number of parameters to be estimated. The calibration burden is reduced through a Monte-Carlo filter-based and variance-based global sensitivity analysis method incorporating parameter, input, initial state and objective function interactions. This sensitivity analysis and subsequent multi-objective calibration results for an example application to the Walnut Gulch basin in Arizona is presented.

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Constraining Parameters of a Distributed Hydrologic Model using both Apriori Information and Optimization

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Automatic calibration of distributed hydrologic models is complicated by the high dimensionality of the parameter space and uncertainties arising from various sources. Spatial organization of hydrologically important watershed characteristics can be used to constrain (and therefore reduce) the dimension of the parameter space. This study uses an apriori parameter estimation framework (based on soil information) to estimate the parameters for the distributed Sacramento Soil Moisture Model and further assumes that spatial patterns of the model parameters are well defined by this framework. Using this approach as a baseline, several model calibration strategies (incorporating uncertainty) were explored, including 1) optimization of apriori parameter multipliers, and 2) penalizing deviations from the apriori parameter values. An important implication of basing the derived hydrologic model parameters on soil information is that, uncertainties in the soil hydraulic parameters will be reflected in the hydrologic parameter estimates. This presentation will include the results from this study and discuss the consequences of the above uncertainties in hydrologic predictions.

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~ NOTES ~

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